Automated updating of land cover maps used in hydrological modelling

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Abstract. Urbanization and rapid growth in population are common development in many catchments and flood plains, often leading to increased flood risks. In hydrological models of regions with urban spread out, the parameters representing changes in land cover need to be frequently updated for obtaining better estimations of the discharge (runoff). This article presents an automated method for incorporating updated model parameters (SCS curve numbers) as per new land cover maps, and using them in a hydrological model. The presented work is developed for one part of Kifisios catchment in Greece, which is a pilot area of the Horizon 2020 SCENT research project (https://scent-project.eu/), focused on producing updated land use / land cover maps using crowdsourcing data provided by citizens, combined with data from remote sensing and drone images.

The method uses a newly available land cover map, which, together with other data, is automatically geo-processed in ArcGIS to provide updated SCS curve numbers. This is achieved using Python programing language and the ArcPy libraries of ArcGIS. The updating of the pre-developed HEC-HMS hydrological model with new SCS curve numbers is implemented in MATLAB, through a specialized API for changing inputs to the HEC-HMS model. The whole process is executed via a GUI developed in MATLAB, which also allows to run the HEC-HMS automatically, and present updated results - discharge hydrographs.

Keywords: ArcGIS, HEC-HMS, automatic geo-processing, flood modelling.

1 Introduction

Quantifying the consequences of land cover changes on the runoff dynamics in a catchment has always been an area of interest for hydrologists and water researchers. The cities are growing worldwide and a large amount of urbanization has already been witnessed [1]. Currently, 54% of the population of the world lives in cities and this percentage is projected to increase to 66% by 2050 [2]. Urbanization poses a serious threat to flooding and water quality [3]. Catchment urbanization seals the natural surfaces, which leads to increase in imperviousness, resulting in reduced rainfall infiltration into sub-soils and smaller surface storage capacity [4]. Combined effects on discharge runoff are: overall increase of volume [5, 6], base flows reduction [7], and decrease of response times of catchments [8]. Consequently, more flashy response of the catchment to the rainfall events occurs, which may result in faster floods with higher peak discharges [9]. Urbanization and land cover changes thus provide a challenging task to urban planners, as the development in formerly rural / natural catchments changes the hydrologic response of the area. Careful planning is required that can accommodate these altering responses in such catchments [10].

Urban planners and managers seek help from modelling results for assessing the increased flood risks and to formulate preventive and response strategies [11]. Models use different input data to simulate the runoff generated as a response to a rainfall event, including spatially varying land cover parameters, which also represent urban extent and imperviousness of the catchment. Hydrological models developed for regions of urban spread out need to frequently update the input parameters representing changes in land cover for better estimations of the discharges (runoffs).

SCENT, an ongoing research project funded under the Horizon 2020 program, has the goal of engaging citizens in environmental monitoring of land cover /use changes and to quantify the impact of such changes on flood risks and spatio-temporal inundation patterns, assessed with appropriate hydrodynamic and hydrological models. The crowdsourced data by citizens is combined with information from remote sensing and drone images within a platform that will provide regularly updated land cover maps. However, further processing is required to use such data in the hydrological models upon each update. The required data processing is generally done manually, using multiple software packages, which are often laborious and time consuming activities.

In this study a convenient method has been developed that can support the modelers in pre-processing of the land cover maps and integrating them as relevant parameters in a hydrological model, therefore keeping the developed models updated. For this purpose MATLAB was used as main software package to interact with ArcGIS and HEC-HMS through batch files and Python scripts. The methodology is implemented on a specific case study in the Kifissos catchment, in Greece, as discussed in section 2.

2 Study Area

The study area is located in Greece and is a sub-basin of Kifissos catchment (Fig.1). The natural streams in surrounding mountainous area flow down forming Kifissos River, which passes thought the city of Athens and discharges into the Saronic Gulf. The area of whole Kifissos catchment is 374.6 km^2 while the study area covers 136.5 km^2 in the upstream part of the catchment. The area has mostly retained its natural form, but rapid changes in land cover are observable. The lower portion of the catchment is already fully urbabanised. The climate is Mediterranean. August is hottest month while January is coldest, with mean temperatures of 27.7ºC and 10.4ºC respectively [12]. Average mean annual rainfall is 332.2 mm but maximum daily rainfall has enough potential to generate flash floods in the area [13]. Topography varies from moderate to steep [14].

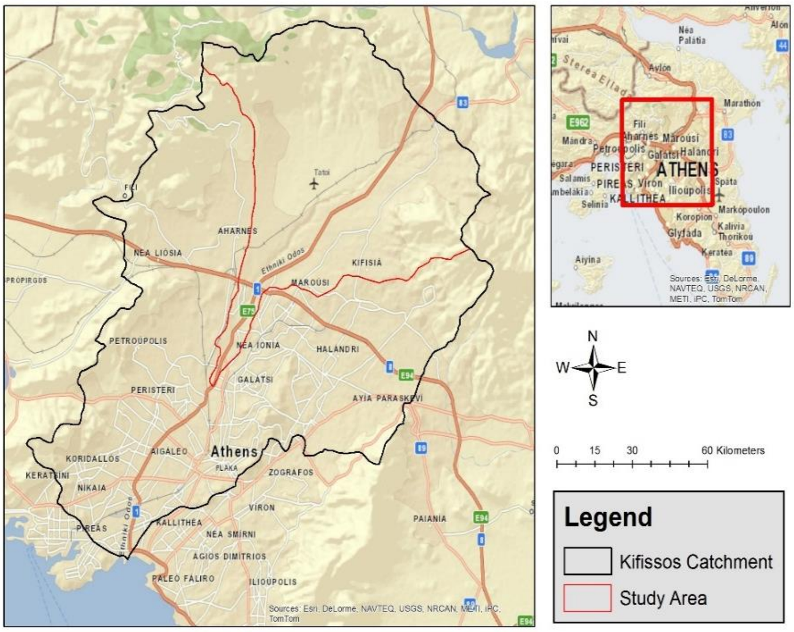

Fig. 1. Location of study area

The catchment is highly urbanized as 40 percent of the national population of Greece lives in the metropolitan city Athens and 31 surrounding municipalities. The area used to be drained by natural streams in the past but due to extensive urbanization, the natural streams were ignored in the urban management and most of them were concealed under streets and / or built upon, consequentially making the area flood prone [15, 16].

3 Methodology

The automated method developed to update the land cover information in the hydrological model includes calculation of new parameters based on the updated land cover map. An event-based hydrological model was developed for the study area using the HEC-HMS modeling system. The pre-processing of the available Digital Elevation Model (DEM) was done in ArcGIS using HEC-GEO-HMS toolbox and the catchment was delineated into 21 sub-basins based on their physical characteristic and flow regime (see Fig.2 left). Data of two rainfall events (19-20 November 2000 and 14-15 January

2001) with corresponding discharge at the outlet were available. The model parameters were calibrated for the first one rainfall event and validated for the second event.

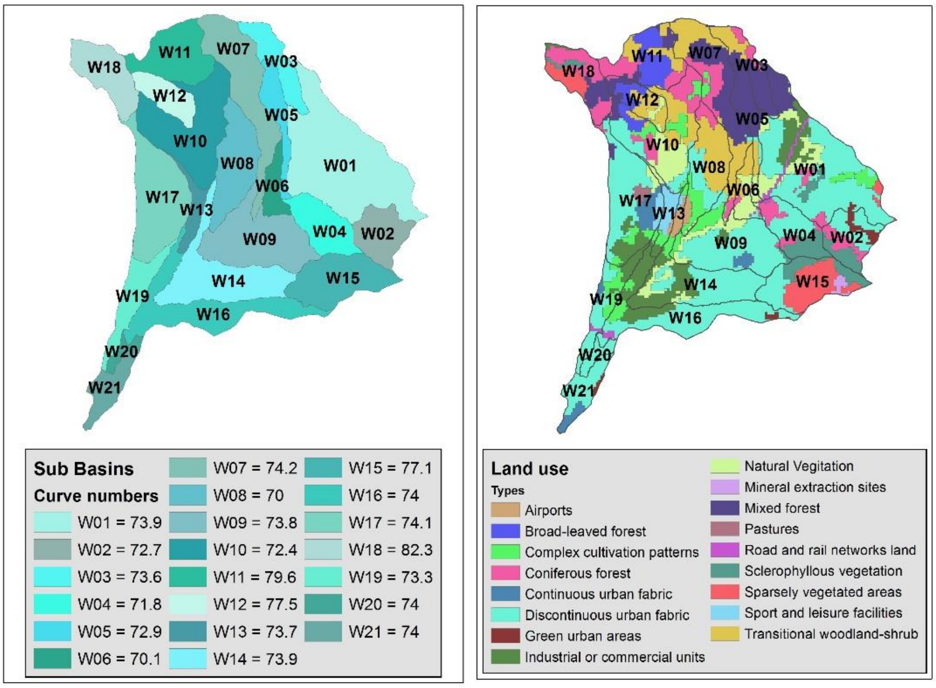

Fig. 2. Delineated sub-basins (left) and Land use map (right, [17])

SCS curve number method was used for the calculation of runoff in each sub-basin. The method uses empirical formulae for determining runoff from a given catchment, which include different parameters (curve numbers) for different land covers. These were calculated by pre-processing in ArcGIS of three maps: land cover map, hydrological soil group map and imperviousness map. The required steps are shown in Fig.3.

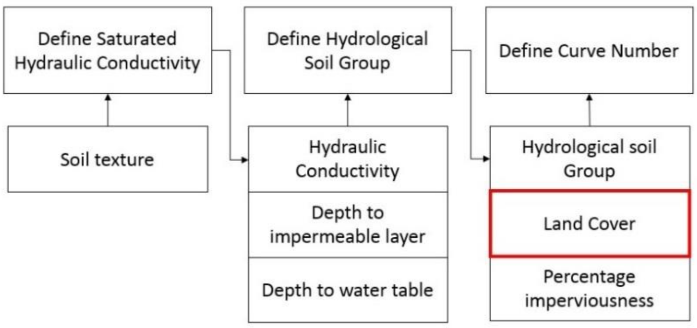

Fig. 3. Flowchart for determination of curve numbers

The red box in Fig. 3 is showing the main input (land cover map) in the whole process while other data remain same, as long as the area under consideration remains same. Each time land cover changes, curve numbers will change and so does the runoff generation capacity of catchment. So curve numbers need to be updated in the model and the laborious task of pre-processing needs to be repeated. The solution proposed hereis to automate this process using MATLAB, Python and ArcPy libraries of ArcGIS, as shown in the flowchart in Fig.4.

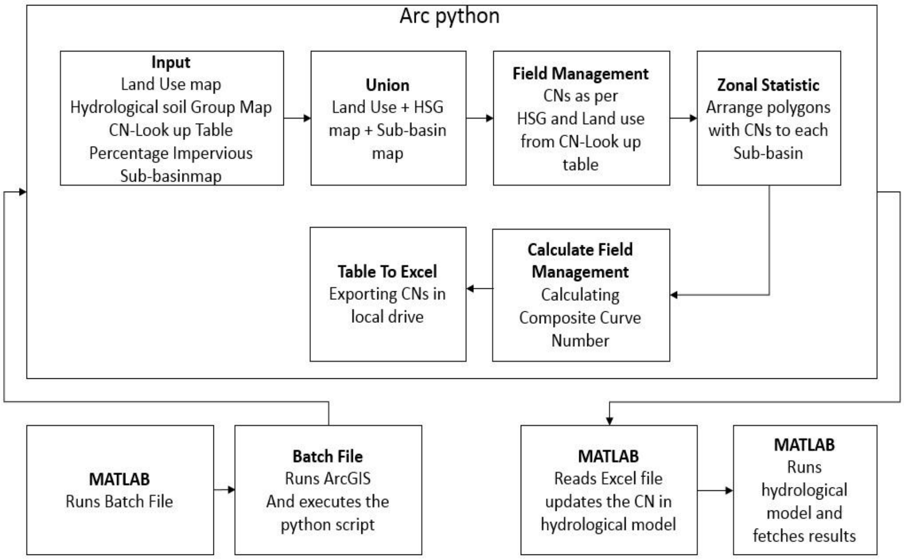

Fig. 4. Flowchart to update land cover map in the hydrological model

The Curve Number (CN) lookup table was generated, which contains the list of curve numbers corresponding to general land cover taxonomy and hydrological soil group classification. CN look up table, Hydrological soil group map, percentage imperviousness map and sub-basins shape file were exported to the default data base of ArcGIS as these remain same. A GUI was developed in MATLAB for controlling and executing all steps in the application. ArcGIS tasks were executed using Python scripts running in background. For each command there is a Python library (ArcPy). A batch file was called through MATLAB which executed a Python script that contained all necessary calls to AcrPy library to carry out pre-processing and calculate composite curve numbers for each sub-basin. The resultant new curve numbers were stored on the local drive upon process completion. MATLAB code then replaces the new curve numbers with the old curve numbers in the hydrological model and re-runs the model. HEC-HMS stores its output data in its standard database known as HEC-DSS. HEC-DSS has its own Python libraries to perform some specific tasks. Again batch files and Python scripts were used to fetch the data out of HEC-DSS and to be displayed in the GUI.

4 Results

The MATLAB GUI is shown in Fig.5. It provides functionalities to upload new land cover map, integrate the newly extracted curve numbers into HEC-HMS hydrological model, control the HEC-HMS model run and fetch the data out of HEC-DSS for plotting.

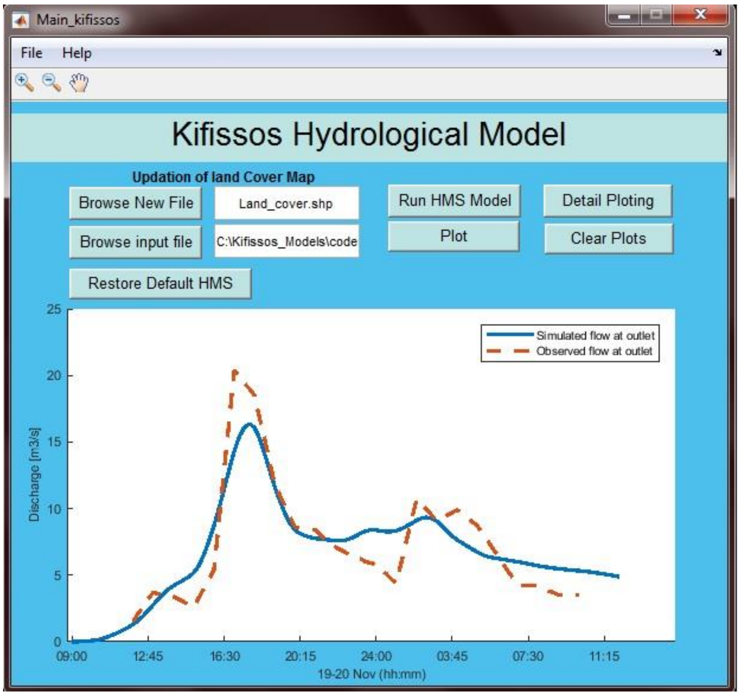

Fig. 5. MATLAB GUI for the hydrological model

The graph in Fig.5 is discharge hydrograph of catchment at the outlet for the rainfall event of November, 2000 and using the original land cover map as shown in Fig.2 (right). Blue line in graph is representing the simulated discharge hydrograph by the model while red one is representing actual observed discharge hydrograph at the outlet. Efficiency of the hydrological model was measured in terms of Nash-Sutcliffe coefficient and RMSE which were equal to 0.85 and 1.6 m^3/s respectively.

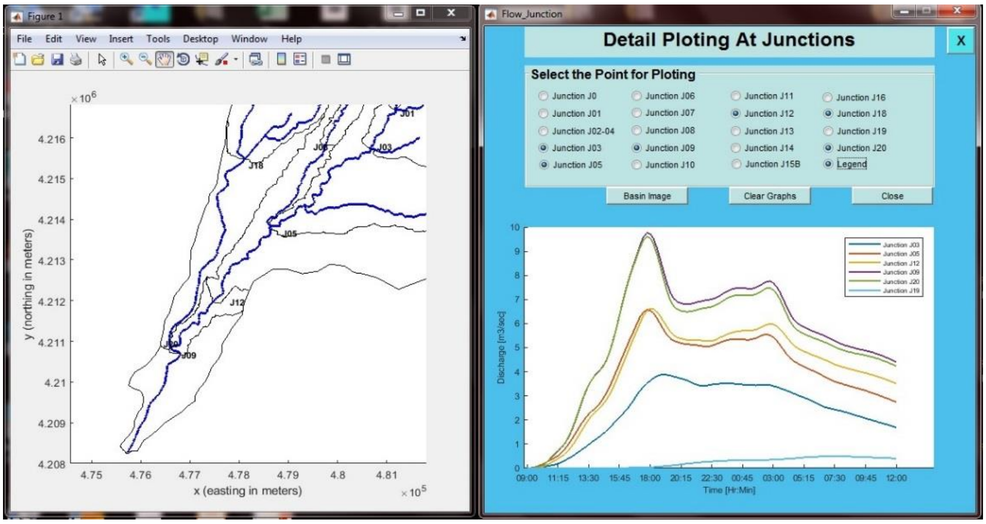

Fig. 6. MATLAB GUI showing option of detail plotting.

The GUI enables fetching data out of HEC-DSS and provides the opportunity to the user to obtain results at other points of interest in the catchment, by referring to points on the image of the detailed river network in the catchment (see Fig.6).

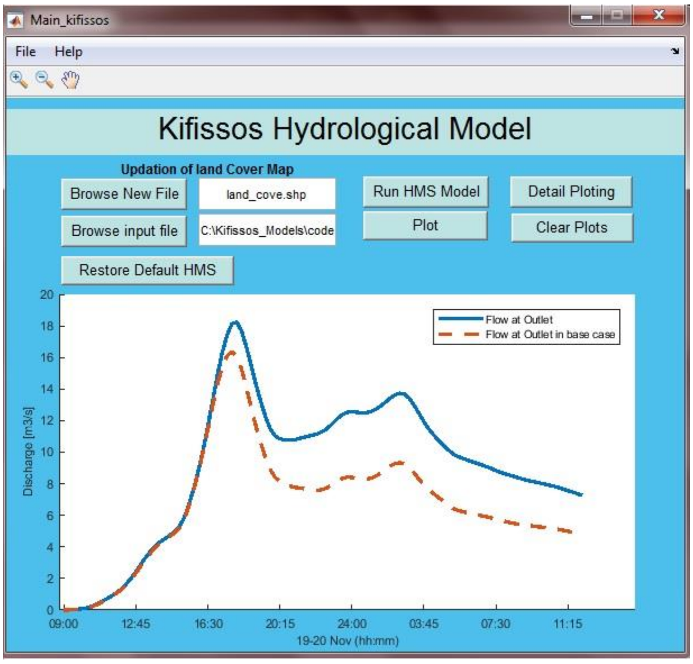

Fig. 7. Model results for assumed case scenario of future development.

A number of scenarios were prepared an executed to test the working of the application. Here we present one such scenario where it was assumed that urbanization took place in the catchment and leading to increased curve numbers by 10 percent compared to their original values shown in Fig. 2 (left). The model was run and it was found out that peak discharge would raise to about 19 m^3/sec (from 16.2 m^3/sec) while the second peak has shown even higher relative increase in discharge from 8.5 m^3/sec to 14 m^3/sec. Cumulative volume of surface water has also increased in the catchment (see Fig.7). Using the developed application this analysis can now be carried out in a matter of seconds, compared to several hours with the step by step processing. The developed application will be further tested within the SCENT project, once new land cover data will become available from the data gathering campaigns planned for late 2018 and 2019.

5 Conclusions

This study has explored and implemented procedures for automated running of HEC-HMS, ArcGIS and extracting the output of HEC-HMS from HEC-DSS. The codes developed can provide assistance to link these software packages to other tools for different purposes. Specifically, in this study the land cover map was linked with curve numbers method used in HEC-HMS, but methods of updating spatial data inputs to HEC-HMS models can also be explored with the same or modified procedures. The application can be improved further by better visualization of results, providing additional functionalities modifying more input parameters of the model, or to change input precipitation data to the model, as main (and also rather uncertain) driver of the hydrological processes. Overall, such tool can provide the modelers with an opportunity to conduct fast analysis about land cover change in the catchment, can control different software packages using one application and can keep the developed hydrological model updated.

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