European Water 60: 147-153, 2017.

Effect of land use change on flood extent in the inflow stream of lake Paralimni, Cyprus

C. Sophocleous and I. Nalbantis*
Centre for the Assessment of Natural Hazards and Proactive Planning & Laboratory of Reclamation Works and Water Resources Management, School of Rural and Surveying Engineering, National Technical University of Athens, Athens, Greece
* *e-mail: nalbant@central.ntua.gr*

Abstract: Land use is a crucial factor that influences flood characteristics such as peak discharge, volume, peak water elevation and inundation extent. It is therefore logical that land use change entails changes in these characteristics, thus leading to increased potential harm. In this work the drainage basin of the inflow stream of lake Paralimni, Cyprus (11.5 km^2) is investigated, which has undergone significant land use changes, primarily due to the conversion of agricultural land into urban space. At the methodological level, both hydrological and hydraulic modelling is used. Regarding hydrological modelling the SCS method is employed, combined with the synthetic Unit Hydrograph of the Institute of Hydrology of UK and the Muskingum method for river routing. Hydraulic modelling is based on the standard step method for solving the energy equation under 1D steady flow conditions. Software packages such as HEC-HMS, HEC-RAS, HEC-GeoHMS and HEC-GeoRAS are used together with a Geographical Information System. Regarding the input data, observed five-minute precipitation depths from three gauges are used for a historical storm event occurred in February 1988 which is known to have caused inundation. Also, a Digital Elevation Model at the resolution of 1 m is used which is based on Lidar data. Two periods with distinct land uses are examined (1983-2003 and 2006-2016), which allows the assessment of the impact of changes in curve numbers and Manning's roughness coefficients. Significant changes in peak flow rate, flood volume and inundation extent were found when passing from the old to the current land uses.

Key words: Land use change; flood mapping; Lake Paralimni, Cyprus; HEC-HMS; HEC-RAS

1. INTRODUCTION

As indicated in the title of the congress EWRA 2017 (Panta Rhei – Everything Flows), a critical issue in hydrological sciences is associated with the notion of "change". Additionally, the International Association of Hydrological Sciences (IAHS) has recently launched the "Panta Rhei" Initiative for the decade 2013-2022 (Montanari et al., 2013). As stated in that paper "Panta Rhei focuses on science for society" having set as its science question No 1 (SQ1) the following: "What are the key gaps in our understanding of hydrological change?". Within this broad question, the issue is raised regarding the hydrological effects of disasters in human societies (e.g., conflicts) and related changes in economy. Real-world examples of socioeconomic changes that impact hydrological processes are valuable for SQ1.

In this work the focus is on the effect on floods of the land use change that resulted from a rapid economic change. Land use changes may be due to various causes such as forest fires (Nalbantis and Lymperopoulos, 2012) or urbanisation (Efstratiadis et al., 2015). They may be hypothetical (Niehoff et al., 2002; Batelis and Nalbantis, 2014) or real such as the studied one.

The selected study area is the basin of the inflow stream of lake Paralimni in Southeastern Cyprus. Before the events of 1974 the basin was mainly an agricultural area. Rapid changes in its economy and land uses in subsequent years transformed the agricultural land into a sparsely urbanised area with infrastructure that mainly serves tourism.

2. METHODOLOGY

2.1 General

The assessment of the flood extent and other flood characteristics is based on information on precipitation transformed into flood information using hydrological and hydraulic models. The output from a hydrological model is inserted as input to a hydraulic model, which, in turn, yields flood hydrographs for discharge and water elevation at selected river cross-sections. Peak water elevations are used to assess the inundation extent. The software packages of the Hydrologic Engineering Centre (HEC) of the U.S. Army Corps of Engineers are used for model implementation.

2.2 Hydrological modelling

The study basin is divided into sub-basins based on the hydrographic network and land uses for two periods. Historical hyetographs from a number of raingauges allow for the assessment of the hyetographs for each sub-basin, subsequently transformed into rainfall excess hyetographs using the SCS method (US Soil Conservation Service, 1986). The cumulative excess rainfall depth PE is

$$\mathrm{PE} = \begin{cases} \dfrac{(P - I_\mathrm{a})^2}{P + S - I_\mathrm{a}} & P > I_\mathrm{a} \\ 0 & P \le I_\mathrm{a} \end{cases} \tag{1}$$

where P is the cumulative rainfall depth from the beginning of the studied storm, S is the potential maximum retention, and I_a denotes the initial abstractions. The quantity S is related to the dimensionless curve number, CN, through

$$S = 254\left(\frac{100}{\mathrm{CN}} - 1\right) \tag{2}$$

where S is given in mm. Based on tabulated values of CN for combinations of soil and land use categories (Wanielista and Yousef, 1993) CN in each sub-basin is computed as a weighted spatial average.

Subsequently, a triangular Synthetic Unit Hydrograph (SUH) (NERC, 1975) for each sub-basin is constructed using the SCS formula for the basin lag time, t_L, i.e.

$$t_\mathrm{L} = \frac{L^{0.8}(2540 - 22.86\mathrm{CN})^{0.7}}{1410\mathrm{CN}^{0.7} I_\mathrm{m}^{0.5}} \tag{3}$$

where t_L is in h, L is the maximum travel length (m), and I_m is the average ground slope (%).

The SUH allows for constructing the direct runoff hydrograph for each sub-basin, which is then routed downstream using the Muskingum method. Parameter K of the method is taken as the length of the studied river segment divided by flow velocity, whilst parameter x is set to 0.2, which is typical for the region.

The HEC-GeoHMS (Fleming and Doan, 2009) and HEC-HMS (Scharffenberg and Fleming, 2010) packages are used for calculations.

2.3 Hydraulic modelling

Hydraulic modelling in river reaches of the study basin is based on the following assumptions: (1) One-dimensional flow is considered; (2) steady flow conditions are adopted; (3) the energy equation is used, which is written and solved between successive river sections.

The energy equation is written as

$$z_2 + y_2 + a_2 \frac{V_2^2}{2g} = z_1 + y_1 + a_1 \frac{V_1^2}{2g} + h_{\mathrm{e}} \quad (4)$$

where z_i, y_i, V_i, a_i are the bottom elevation (m), water depth (m), average water velocity (m/s), and kinetic energy correction factor respectively for cross-section i, where $i = 1$ for the upstream cross-section and $i = 2$ for the downstream one. Quantities h_{e} and g are respectively the total energy losses and the acceleration due to gravity. Details on calculations based on equation 4 are given by Brunner (2010).

The Manning's roughness coefficient, n, is calculated based on land use information and tabulated values found in Chow (1959). The HEC-GeoRAS and HEC-RAS (Brunner, 2010) packages are used for calculations.

3. STUDY BASIN AND DATA

3.1 The study basin

Paralimni is a village located at the southeastern part of the Island of Cyprus, close to the Lake of Paralimni. Up to 1974, its main economic activities were agriculture and fishing, whereas after 1974, the village was rapidly transformed into one of the most popular destinations for tourism in Eastern Mediterranean. Population rose from 5270 in 1976 to 14863 in 2011. Employment in the sectors of commerce and services showed a 100% increase within a decade, while for tourism the increase was 200%. Evidently, land uses in the study area followed its economic transformation.

The study basin is the basin of the inflow stream of lake Paralimni whose area of 11.54 km^2 covers the entire area of the Paralimni municipality (Fig. 1). The length of the main watercourse is 5.884 km, while the maximum valley length is 9.237 km. The basin is considered as a flood-prone area according to the EU Flood Directive (European Council, 2007; Tsakiris et al., 2009).

3.2 Data used

Precipitation depths for the event that occurred in 15 February 1988 were collected for three recording raingauges (Aghia Napa, Paralimni, and Sotira) at the five-minute time step. The choice of this event was based on the knowledge that this has caused significant flooding. The Thiessen polygon method was used to estimate spatial averages of precipitation for each one of the sub-basins of the study basin (Sophocleous, 2016). Based on intensity-duration-frequency curves for point rainfall (Pasiardis, 2012) and by referring to the five-minute duration, the return period was found to be 87, 51, and 36 respectively for Aghia Napa, Paralimni and Sotira.

Land use information was provided in the form of two maps: a conventional map for the period 1983 – 2003 (Fig. 2) and the map for the period 2006-2016 from the project known as Corine 2000 (Fig. 3). The land uses are coded as follows: 242: Crops and dispersed houses; 112: Discontinuous urban surface; 121: Commercial and industrial areas; 211: Non-irrigated arable land; 212:

Permanently irrigated areas; 122: Roads and Railway networks; 323: Sclerofyllous vegetation; 142: Sport and recreation facilities; 231: Pasture.

The Digital Elevation Model (Fig. 1) was provided by the Water Development Department of the Republic of Cyprus and is based on Lidar measurements. The soil map of the Geological Survey Department of Cyprus was used for soil classification.

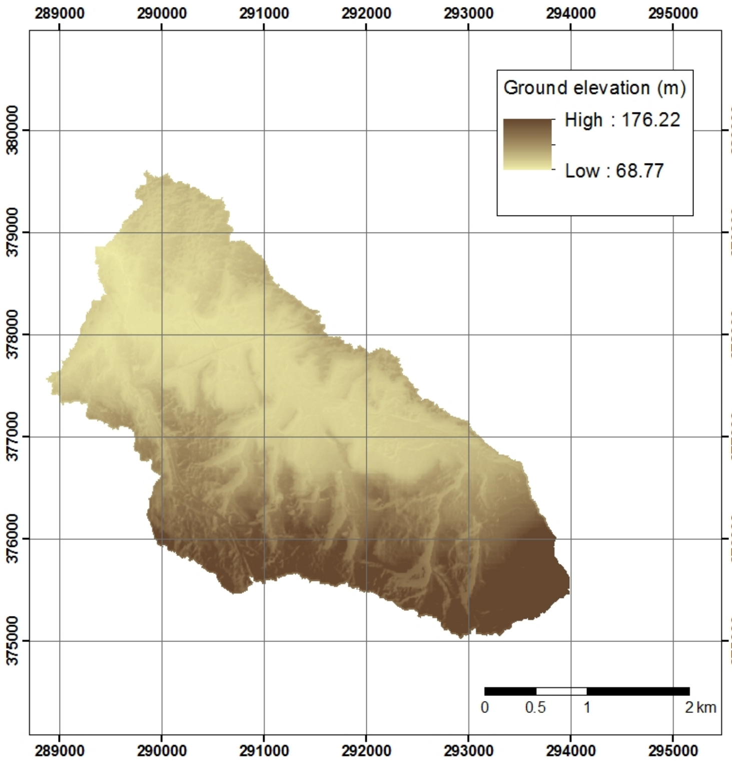

Figure 1. The basin of the inflow stream of lake Paralimni.

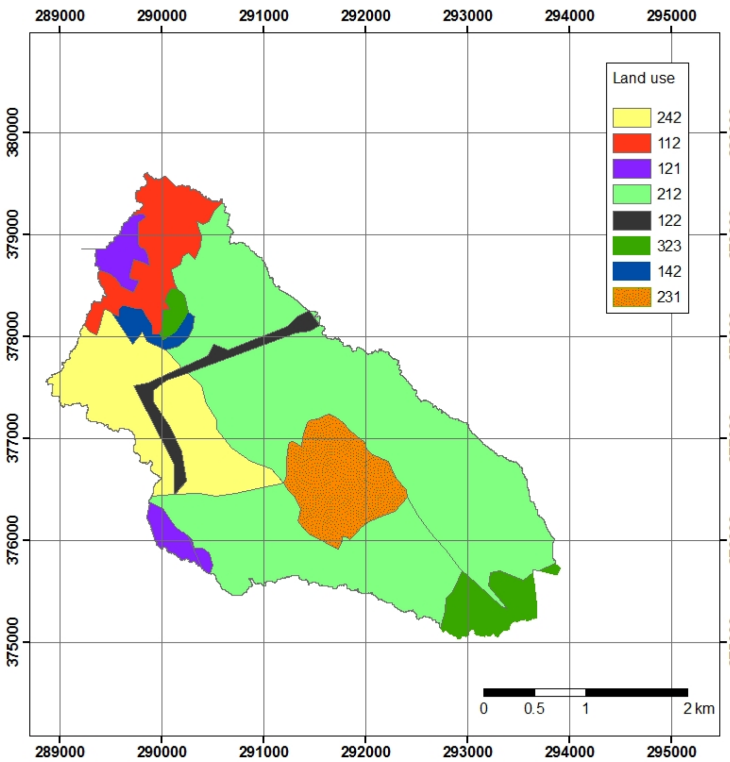

Figure 2. Land uses in the study basin for the period 1983-2003.

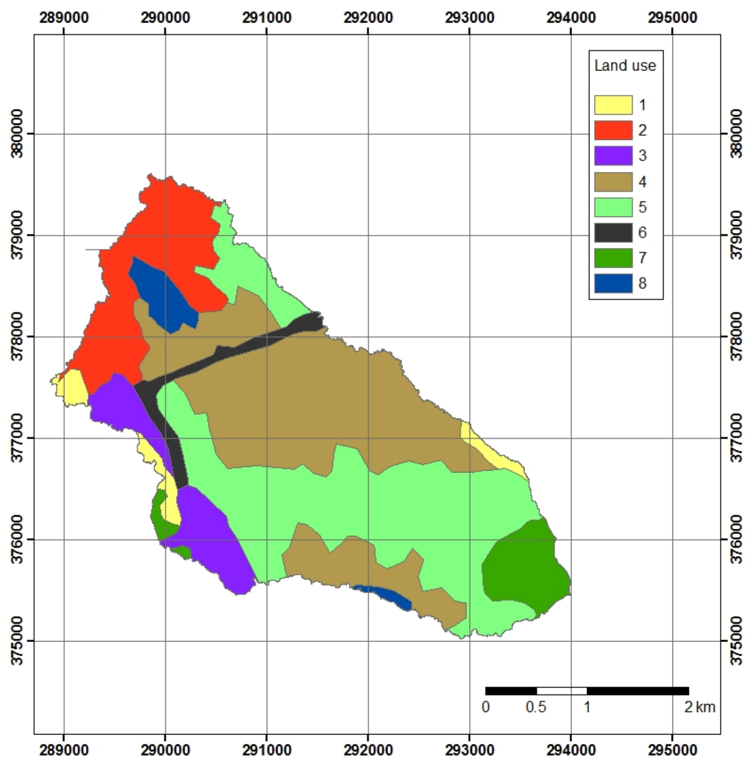

Figure 3. Land uses in the study basin for the period 2006-2016.

4. RESULTS

4.1 Land uses for the period 1983-2003

The study basin was subdivided into eleven sub-basins with the purpose to distinguish between homogeneous sub-areas with different land uses, while also capturing land use changes. The subdivision was kept constant from one land use case to another, which enables comparisons. Six river reaches were used for flood routing by adopting typical values for contraction and expansion coefficients and differentiating between main channel bed and right and left banks when selecting Manning's *n*.

The peak flow rate at the basin outlet was estimated at 38.9 m^3/s, while the flow volume was 621.5×10^3 m^3. The peak flow rate for each sub-basin is depicted in Fig. 4(a) (blue bars), while the variation of the flow volume from one sub-basin to another is shown in Fig. 4(b). The maximum inundation extent was 32.97 ha.

4.2 Land uses for the period 2006-2016

For the recent period 2006-2016 the land use change led to increased values of CN while also affecting roughness coefficients.

The peak flow rate at the basin outlet was estimated at 62.0 m^3/s, while the flow volume was 899.3×10^3 m^3. Again, the peak flow rate and flow volume for each sub-basin are depicted in Figs 4(a) and 4(b) respectively (red bars). The maximum inundation extent was 39.30 ha.

4.3 Comparison of results

Starting from the entire basin as the spatial level for comparison of the effect of land use change, results showed an increase of peak flow rate by 59.4 %. The flow volume was increased by 44.7 %. The examination of peak flow rates at the sub-basin level revealed that the median flow rate passed from 4.4 m^3/s to 5.5 m^3/s, which corresponds to a relative increase by 71.4 %. The maximum increase was found to be 233.3 %. As far as the flow volume per sub-basin is concerned, a median increase of 44.8 % was found, while the maximum increase was 162.5 %. The maximum inundation extent was found to have increased by 19.2 %.

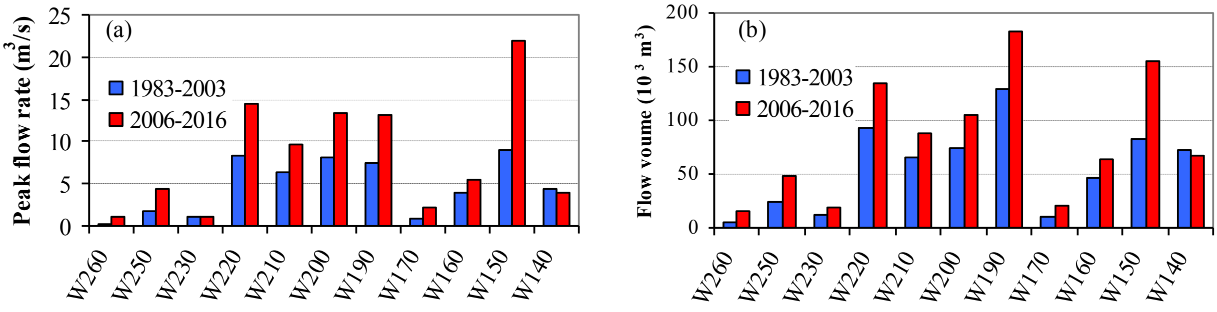

Figure 4. (a) Peak flow rate and (b) flow volume for each sub-basin and each one of the land use cases (1983-2003 and 2006-2016).

5. CONCLUSIONS

In this paper a typical approach was followed, which was aimed to assess the effect of land use change on flood characteristics in an ungauged basin in Cyprus. The basin of the inflow stream to lake Paralimni was investigated, which is one of the flood-prone areas identified during the process of application of the EU Flood Directive in the Republic of Cyprus.

From the investigations we can draw the following conclusions:

1. The rapid changes in land uses in the studied area have, to a large extent, transformed it into an urbanised area, whereas the formerly extended cultivated areas have shrunk considerably after the events of 1974. Tourism being currently the dominant economic activity has replaced agriculture to a large extent.
2. The aforesaid land use changes have led to changes in soil permeability which, in this work, was reflected in significant changes in the curve number of the SCS method.
3. When considering the entire basin, the peak flow rate at the basin outlet was found to have been increased by 59.4 % with respect to the former situation, while the flow volume was increased by 44.7 %. The maximum inundation extent was found to have been increased by 19.2 %.
4. When focusing on the sub-basin level, the peak flow rate showed a maximum increase above 200 %. The maximum increase of flow volume was above 150 %, while the maximum change in inundation topwidth was 133.2 m.
5. The study basin is exposed to a flood hazard which is significantly higher than in previous periods. Given that the expected losses in tourism infrastructure are higher than those in cultivated areas, the risk of economic losses is now much higher than before and, thus, mitigation and protection measures are absolutely necessary.

ACKNOWLEDGEMENTS

The authors wish to thank the personnel of the Department of Town Planning and Housing, and the Geological Survey Department of the Republic of Cyprus, as well as the Cyprus Meteorological Service for providing the data. Also, K. Aristeidou of the Water Development Department of the Republic of Cyprus is warmly thanked for his support.

REFERENCES

Batelis, S.-C., Nalbantis, I., 2014. Potential effects of forest fires on streamflow in the Enipeas river basin, Thessaly, Greece. Environmental Processes; 1(1): 73-85.

Brunner, G. W., 2010. HEC-RAS, River Analysis System Hydraulic Reference Manual (version 4.1). US Army Corps of Engineers; Hydrologic Engineering Center.

Chow, V. T., 1959. Open Channel Hydraulics. McGraw-Hill, New York.

Efstratiadis, A., Nalbantis, I., Koutsoyiannis, D., 2015. Hydrological modelling of temporally-varying catchments: facets of change and the value of information. Hydrological Sciences Journal; 60(7-8): 1438-1461.

European Council, 2007. EU Directive of the European Parliament and of the European Council on the assessment and management of flood risks. 2007/60/EU.

Fleming, M. J., Doan, J. H., 2009. HEC-GeoHMS Geospatial Hydrologic Modeling Extension. US Army Corps of Engineers, Hydrologic Engineering Center.

Montanari, A., Young, G., Savenije, H. H. G., Hughes, D., Wagener, T., Ren, L. L., Koutsoyiannis, D., Cudennec, C., Toth, E., Grimaldi, S., Blöschl, G., 2013. "Panta Rhei - everything flows": change in hydrology and society - the IAHS scientific decade 2013–2022. Hydrological Sciences Journal; 58(6): 1256-1275.

Nalbantis, I., Lymperopoulos, S., 2012. Assessment of flood frequency after forest fires in small ungauged basins based on uncertain measurements. Hydrological Sciences Journal; 57(1): 52-72.

NERC, 1975. Flood Studies Report, Volumes I-V. Natural Environment Research Council, London, UK.

Niehoff, D., Fritsch, U., Bronstert, A., 2002. Land-use impacts on storm-runoff generation: scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany. Journal of Hydrology; 267(1): 80-93.

Pasiardis, S., 2012. Meteorological Note No 18. Cyprus Meteorological Service, Nicosia, Cyprus.

Scharffenberg, W. A., Fleming, M. J., 2010. Hydrologic Modeling System HEC-HMS User's Manual. US Army Corps of Enginners, Hydrologic Engineering Center.

Sophocleous, C., 2016. Impact of land use change on the assessment of inundation extent: The case of the drainage basin of the Inflow River of Lake Paralimni, Cyprus. Diploma Thesis, School of Rural and Surveying Engineering, National Technical University of Athens, 112 p. (in Greek).

Tsakiris, G., Nalbantis, I., Pistrika, A., 2009. Critical technical issues on the EU Flood Directive. European Water; 25/26: 39-51.

US Soil Conservation Service, 1986. Urban hydrology for small watersheds. US Soil Conservation Service Technical Release; 55, p.13.

Wanielista, M. P., Yousef, Y. A., 1993. Stormwater management. John Wiley and Sons.