Urban stormwater runoff and pressure on the sewerage system in Pécs, Southwest-Hungary

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Keywords: urban hydrology, impervious surfaces, topography, stormwater runoff, sewerage system, DEM, Hungary

Abstract

Pécs is a city with rugged topography on the foothills of the Mecsek Mountains, Southwest-Hungary. As a consequence of uncontrolled city development in an environmentally sensitive area, the sewerage system is unable to cope with the additional pressure and overflow following torrential rainfalls and rapid stormwater runoff. The main objective of our study is to investigate the problems involved by extra rainwater released illegally into the sewerage network in the city. Special attention is paid to the analysis of the topographic factor contributing to enhanced runoff using Digital Elevation Model. A neighbourhood with particularly diverse topography, the Magyarürög Valley on the Mecsek foothills, where blocked stormwater drainage is a most serious problem, is selected for a representative case study. Residential buildings in different topographic positions, as potential sources of extra water inflow into the network, are referred into four classes of probable input into the system. The findings of the survey can be used in the design of a future stormwater runoff monitoring system. Controlling illegal release into the sewerage system is an important task since it could cause millions of Euros of losses to the community-owned waterworks. Our study presents a typical example how private preferences confront with public interest in an urban landscape.

Introduction

Natural runoff conditions are significantly modified by urban development and this constitutes a central issue in urban ecology. Two major types of interferences into urban runoff conditions are identified: the anthropogenically modified hydrological cycle and human-created artificial supply and waste-water disposal system (Douglas and James 2014). The environmental (hydrological) implications of planned and unplanned urban development are usually rather different (Sliuzas et al. 2010). During the stages of planned development (site planning, land subdivision, and provision of infrastructure), land is often cleared of vegetation. The creation of extensive bare surfaces and sealed terrain of housing and infrastructural developments (road building) change runoff conditions. Hard paved surfaces in urban areas prevent the natural dissipation of rainwater and substantially increase both volume and rate of runoff (Arnold & Gibbons 1996). Although infiltration into paved surfaces is generally less than into permeable surfaces, some researchers point out that it may still be significant through macro-cracks or joints in the pavement (Mansell & Rollet 2007). Its amount (usually much less than 10%), however, cannot be compared to runoff (up to 50%). The unfavourable impacts of development may be amended by native landscaping in the final stage of development (Diekelmann and Schuster 2002; Karvonen 2011).

In contrast, unplanned development often begins with land occupation and the hasty erection of temporary buildings (Sliuzas et al. 2010). If their owners do not have to be afraid of demolition, the neighbourhood stabilizes and residences will be gradually improved in quality. Access roads and utilities will also be supplied. Although most typical of Latin American cities, a similar chain of events also characterizes urban development in some neighbourhoods of Pécs.

In the developed world the combined stormwater and sewage system is replaced by sewer separation. This has several benefits:

- precludes the overflow of combined sewer;
- prevents flooding by increasing capacity;
- allows stormwater to be used as a resource.

Separation is now complete for the urban area of Pécs. This means that only illegal release into the separated stormwater collection network causes pressure during severe rainfall events, when there is a recurrent overflow hazard. The high runoff ratio from the paved surfaces of urban areas with high relief is most often not seen by inhabitants as a major environmental issue, merely as a technological problem to be served by water suppliers (Ronczyk & Lóczy 2006). With gradually reducing water tariffs, the Hungarian population is hardly aware of the costs involved by wastewater treatment.

Similarly to other cities, recently significant efforts have been exerted for sustainable stormwater management in Pécs, including bioretention swales and permeable pavement facilities. However, given the dissected topography and high relief of the city, partly built on the southern slopes of the Mecsek Mountains and the in the valleys of the Baranya Hills, excess urban runoff and localized inundations (urban flash floods – see e.g. Xia *et al.* 2011) remained common phenomena, especially during the late spring and early summer period when torrential rainfalls occur (Czigány et al. 2010), possibly also associated with climate change (Blanka and Mezősi 2012). Today the total area of impervious surfaces in Pécs amounts to 37% (Ronczyk & Wilhelm 2006) – not particularly high in international comparison, but still significant.

While in hydrological literature the direct impact of runoff from impervious urban surfaces on streamflow is debated (see e.g. McCuen 1998 vs. Evett 1994), there is ample evidence that urbanization, with the accompanying loss of vegetation, replacement of soil with impervious surfaces, and routing stormwater runoff directly to stream channels, substantially transforms runoff conditions and streamflow crossing urban areas.

Objectives

Sewerage system design is a well-defined engineering task, where the emerging technical challenges can be solved applying the existing standards. During the calibration phase of the system it is easy to calculate sewage runoff from drinking water consumption. But in practice other factors – beyond the scope of engineering design – could substantially modify the amount of sewage to be accommodated. The paper deals with that portion of runoff which is illegally released into the sewerage network, where this potentially causes overflow and flooding. The main objective of our study is reveal these hidden factors, focusing on topographical influence upon surface runoff routes. It is pointed out that individual decisions of people in an environmentally sensitive area with insufficient infrastructure can cause environmental hazards difficult to mitigate.

Since Hungary's accession to the European Union large-scale investments have been implemented in Pécs, the seat of Baranya County (2014 population: 146,581), including the completion of the drinking water supply and sewerage network (figure 1). The opportunity to join to both networks is open to all residents of the city.

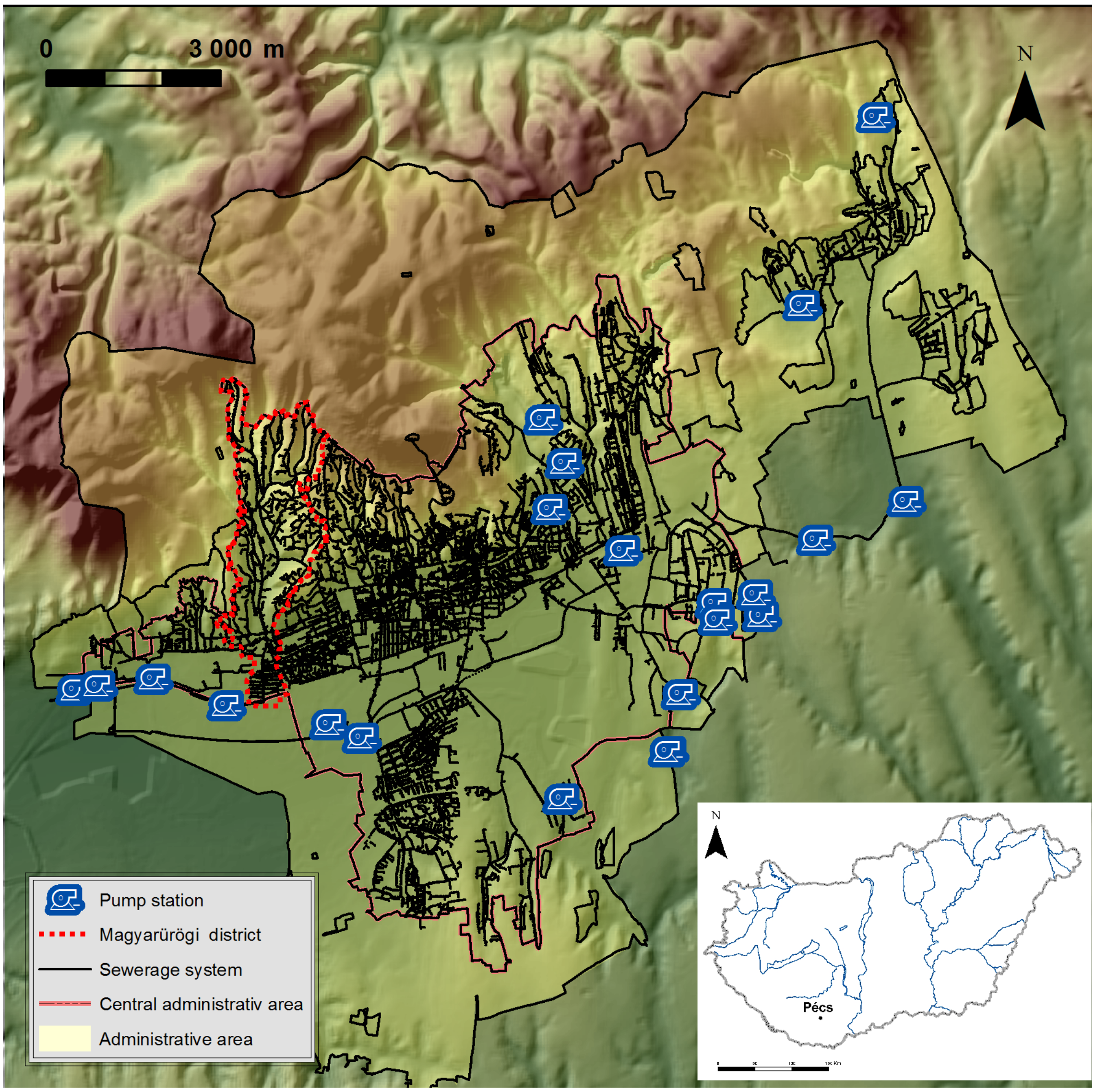

Figure 1 – The sewerage network of Pécs with locations of the 16 pumping stations.

The here presented research involved detailed analyses of physico-geographical factors, including runoff routes, hydrometeorological and hydrogeological conditions, land cover and urban structure which influence urban water management. The investigation focused on potential illegal inflow from plots against the background of the physico-geographical environment.

The primary goals were

a) to analyse rainfall and runoff conditions as a function of topography;

b) to determine whether excess stormwater runoff significantly contributes to increased volumes of sewage;

c) to localize and typify major source areas of runoff water and

d) to present the sewer overflow problem on a case study.

To achieve these goals integrated catchment modelling using GIS is employed to identify periods and locations critical for overflow due to torrential rainfalls. The findings provide the basis for designing a monitoring network. Through reliable prediction stormwater overflow could be prevented and severe economic losses avoided in the future.

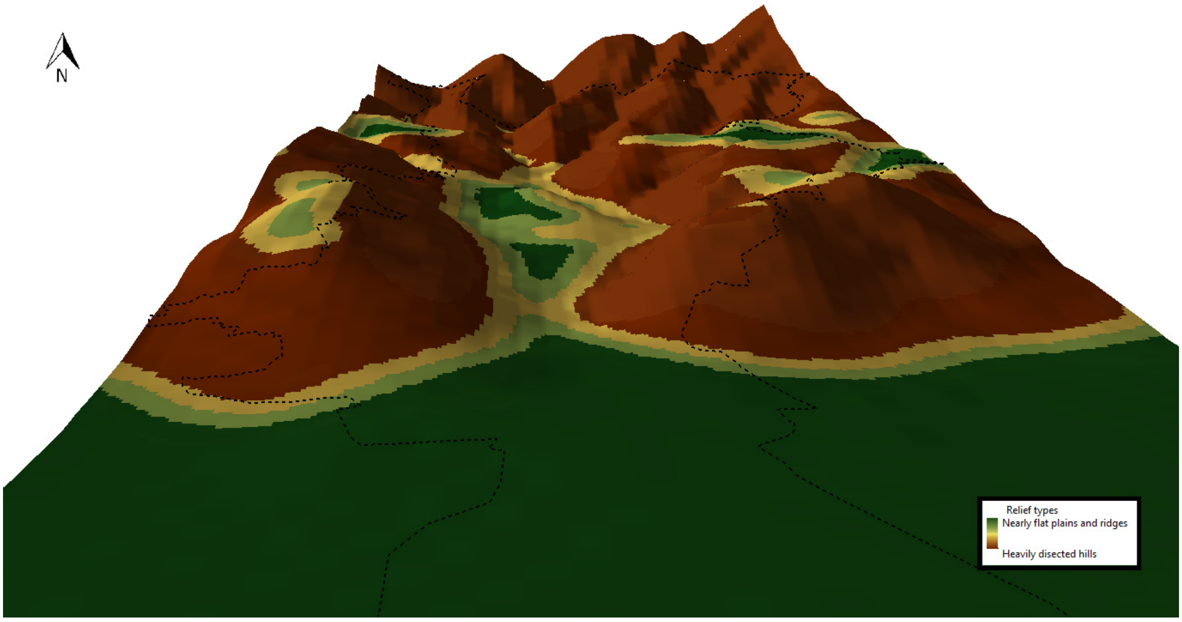

Figure 2 – Types of topography of the administrative area of Pécs (after Hammond 1964).

Study area

The administrative territory of Pécs (16,261 ha) is shared by three microregions of the mesoregion Mecsek Mountains and Tolna-Baranya Hills, which is part of the macroregion Transdanubian Hills in Hungary. Geologically, the area covers the anticline of the Western Mecsek Mountains. Its eastern limb of horsts of Middle Triassic carbonates (the Misina-Tubes range) provides the background for the built-up area, while in the east it drops steeply to the Pécsbánya syncline with economically important Jurassic black coal seams. The southwestern hillslopes of the mountains are built up of carbonaceous debris dismembered by tectonic and erosional processes into a series of anticlinal hills. Further to the south the city centre is located in the Pécs Basin, a recent subsidence area with flat floor. Rising above the basin, the marginal zone of the Pleistocene Baranya Hills follows. The average elevation of Pécs is 180 m above sea level; the highest point of the built-up area is 416 m, while the lowest is 115 m. This means an absolute relief of 301 m (figure 2).

This rugged topography of Pécs results in a heterogeneous spatial distribution of rainfall. Orographic effects on precipitation have already been determined by Simor (1938), who found a rainfall gradient of 26.3 m per 100 for the data from five rain gauges in Pécs and one at Szentlőrinc, 16 km to the west. The long-term mean annual precipitations at the various meteorological stations range from 663 to 839 mm (areal mean: 726 mm) (Bötkös 2006). During the period of 2009 to 2011, studied in this paper, peaks, indicating the impact of global climate change, were frequently observed (Ronczyk et al. 2014). Annual rainfall totals were below the long-term average values for the years of 2009 and 2011, while they significantly exceeded the mean value in 2010 (table 1).

The orographic effect is also detectable in 2010 and 2011. The annual amounts of precipitations and the approximate volume of stormwater runoff could be estimated for any units of study (sewerage subdistricts) in Pécs as a function of elevation. The hypsographic method is widely used in spatial rainfall interpolation (Goovaerts 2000).

Most of the city area (140 km^2) is drained by the Pécsi-víz Stream (length: 51.4 km) (figure 2). An inventory covers 152 springs in the city area, but their number (including non-catchment springs) can be even higher. Occasional measurements testify that the water yields of springs range from 0.001 to 0.15 $m^3 s^{-1}$. The annual yield of the most abundant natural karst spring (Tettye) reached 4.2 million m^3 in 1896 and 2.3 million m^3 in 2010 (ENVICOM 2003).

In Pécs wastewater is collected by seven main collector systems (Ronczyk et al 2012). The total length of gravitational conducting pipes is 506.8 km. The longest network is that of Magyarürög (52 km). In our research we paid special attention to the variations in the physical environments and build-up conditions of the individual sewerage subdistricts. As an example, the topographic parameters of a typical watercourse, the Ürög Stream, derived from the DEM (table 2) was selected for a detailed analysis the findings of which are presented as a case study.

Table 1 – Mean annual precipitations at rain gauges in Pécs, 2009-2014.

Meteorological station	*Elevation (m)*	*Annual rainfall (mm)*					
		2009	*2010*	*2011*	*2012*	*2013*	*2014*
Ifjúság útja	174	632.4	1133	546.6	577.7	724.1	1026.5
Jegenyés utca	115	588.6	1078.4	505.1	614.9	736.6	1063.2
Erdész utca	382	791	1338.3	526.0	688	793	1033

Table 2 – Topographic parameters of the watercourse of Magyarürög.

Name of catchment	*Magyarürög watercourse*
Recipient	Pécsi-víz Stream at rkm 41.772
Catchment area	14.1 km^2
Average elevation above sea level	306 m
Highest point	610 m
Lowest point	114 m
Absolute relief	496 m
Maximum relative relief	71 m/100 m
Average relief	21 m/100 m
Maximum slope	33°
Average slope	10.4°
Slope exposure	SW (on 4.7 ha: N)

Methods

In our research we used GIS analyses on Digital Elevation Model and its derivates as well as infrastructural and cadastral vector datasets. The topographic elements (natural streambeds, open ditches, closed canals, paved channels) were analysed for runoff routing. The sites of buildings lying within a fixed distance (25 m) from stormwater collecting utilities were selected. Stormwater conduction was regarded solved for such structures located on valley floors. For the rest of the residences elevation above sea level was identified and compared with the elevation of the sewerage network. To the buildings we rendered the closest point of the sewarage network and from the elevation of the building subtracted the elevation of that point. The sites where the building is situated more than 1 m lower than the sewerage network and, thus, releasing rainwater into the network is expensive, are not referred to those with potential hazard. Higher hazard is assumed for sites where the building lies next to the sewer and gravitational inflow is feasible. Another factor of hazard is steep slopes around the site since this involves extra costs of establishing cisterns on the plot.

Precipitation was measured at five locations with automated tipping bucket rain gauges since 2009, partly operated by the Faculty of Sciences, University of Pécs, and partly by the Hungarian Meteorological Service.

We also determined the types of extra water inflow into the sewers: direct (intentional) inflow and unintentional (accidental and natural) inflow. Both classes fall into subclasses: surface and subsurface inflow. Direct surface water inflow is typical of the highly urbanized districts of Pécs with high relief, while indirect inflow is observed in the lowland part of the city, where, during heavy rainfalls, water enters into the sewers through the manhole lids. The radius of direct surface inflow from springs and wells was estimated to be 50 m. Additional indirect inflow may be due to high groundwater table. Each category was mapped individually during the current project.

The employed digital elevation model (DEM), originally with a spatial resolution of 50 m, was obtained from the Institute of Geodesy, Cartography and Remote Sensing (FÖMI) and its resolution was enhanced to 10 m by using the elevation of the manhole lids. The elevation database of the manhole lids was obtained from the Tettye Forrásház Ltd, a water utilities company in Pécs. Spatial analyses were carried out in ArcGIS 10.2 software environment. The topographic parameters derived from the Digital Elevation Model are the extreme elevation values (the highest and lowest points), their difference (relief), mean elevation and vertical terrain dissection. The vertical terrain dissection index illustrates the topographic diversity of the city. This index is calculated as the percentage of maximum relative relief to absolute relief within circles of 300 m diameter. From the topographic parameters relief types were identified and mapped.

Then the topographic data were coupled with demographic and sewage management data: character of the neighbourhood, population number and density, length of sewerage network, number of clearing shafts.

According to their elevation above sea level, the residential buildings were referred into four classes:

1, Buildings at -2 m position below the level of the sewerage pipes present minimum risk of rainwater pumped into the network.
2, Buildings between -2 m and +1 m position relative to the pipes can be connected to the network.
3, Similarly, buildings at +15 m may also be connected (with 50% probability).
4, The group of buildings between +1 m and +15 m have the highest probability to release rainwater into the sewerage network.

Results and discussion

The topographic parameters were calculated for 50 neighbourhoods. Those with the highest relief are shown in table 3.

Table 3 – Topographic parameters of selected neighbourhoods in Pécs (arranged according to elevation above sea level).

Neighbourhood	*Lowest point (m)*	*Highest point (m)*	*Absolute relief (m)*	*Mean elevation (m)*	*Vertical terrain dissection (m)*
Deindol	201.2	407.8	206.6	300.4	38.9
Szkókó	203.9	384.8	180.9	295.2	41.4
Szentmiklós	124.8	287.9	163.1	178.4	33.6
Makár	121.4	271.5	150.0	173.8	45.4
Magyarürög	139.9	285.7	145.8	196.2	29.8
Szentkút	234.8	370.9	136.1	304.4	33.5
Patacs	124.4	236.5	112.1	168.2	24.1
Kismélyvölgy	226.4	337.5	111.1	274.5	24.6
Zsebedomb	118.0	221.0	103.1	152.9	20.3
Donátus	179.0	280.2	101.2	245.4	21.0
Csoronika	148.0	248.5	100.5	193.9	28.7
Rácváros	127.7	171.3	43.6	140.9	8.9
Fogadó	109.2	132.7	23.5	119.4	4.4
Uránváros	117.3	132.3	15.0	122.1	3.2
Bolgárkert	118.9	133.9	15.0	124.7	3.3
Kovácstelep	121.4	133.2	11.8	126.1	2.8
Szigeti tanya	116.0	124.3	8.3	119.0	1.4

The typology of topography well demonstrates the diversity of the terrain (figure 2). A clear dominance of flat (34%) or gently rolling surfaces (28%) is seen, particularly if the areas not yet reclaimed after coal mining (50 hectares) and the plateaus rising above the foothills (16.5 hectares) are included.

The orographic effect on precipitation distribution is also detectable in 2010 and 2011. Rainfall gradient as a function of elevation reached 95 mm per 100 m for 2010 (*r* = 0.98623). In 2010, precipitation characteristics showed extreme values, i.e. annual totals, and especially monthly totals for May, June and September significantly exceeded the long term (30-year) mean values. In May and June 2010 two Mediterranean cyclones produced more than 200 and 150 mm of precipitation in three- and two-day periods, resp. The May 2010 monthly precipitation totals exceeded 200 mm for many parts of SW Hungary. The orographic effect for this month is again clearly shown for the extremely dry year of 2011 with monthly totals of a mere 0.1 mm for all four rain gauges in Pécs.

Comparing the data for 2014 at rain gauges to the time series of the 20th century, the following comments are made. Precipitations in 2014 were somewhat below the 100-year average in January (-11.9%) and in June (-21.8%) and substantially below that in March (-64.5%) and November (-50%) (figure 3). In six months the precipitation surplus is high (79.2% on the average), in May more than twofold and in September almost threefold (182.2%). No monthly records, however, were set. The wettest month was May, followed by September, and March was the driest.

More detailed analyses focused on the impact of a Mediterranean cyclone (14-17 May) and a local convectional rainfall (3 August). From 14 to 17 May 2014 more than 100 mm fell with 0.4 mm/10 min average and 1.5 mm/10 min maximum intensity. In the eastern part of the city rainfall was continuous for 34 hours and 40 minutes. The precipitations ranged from 83 mm to 130.4 mm in the various neighbourhoods (figure 4). The August rainfall only caused minor flood waves in the western part of the city. Another Mediterranean cy-

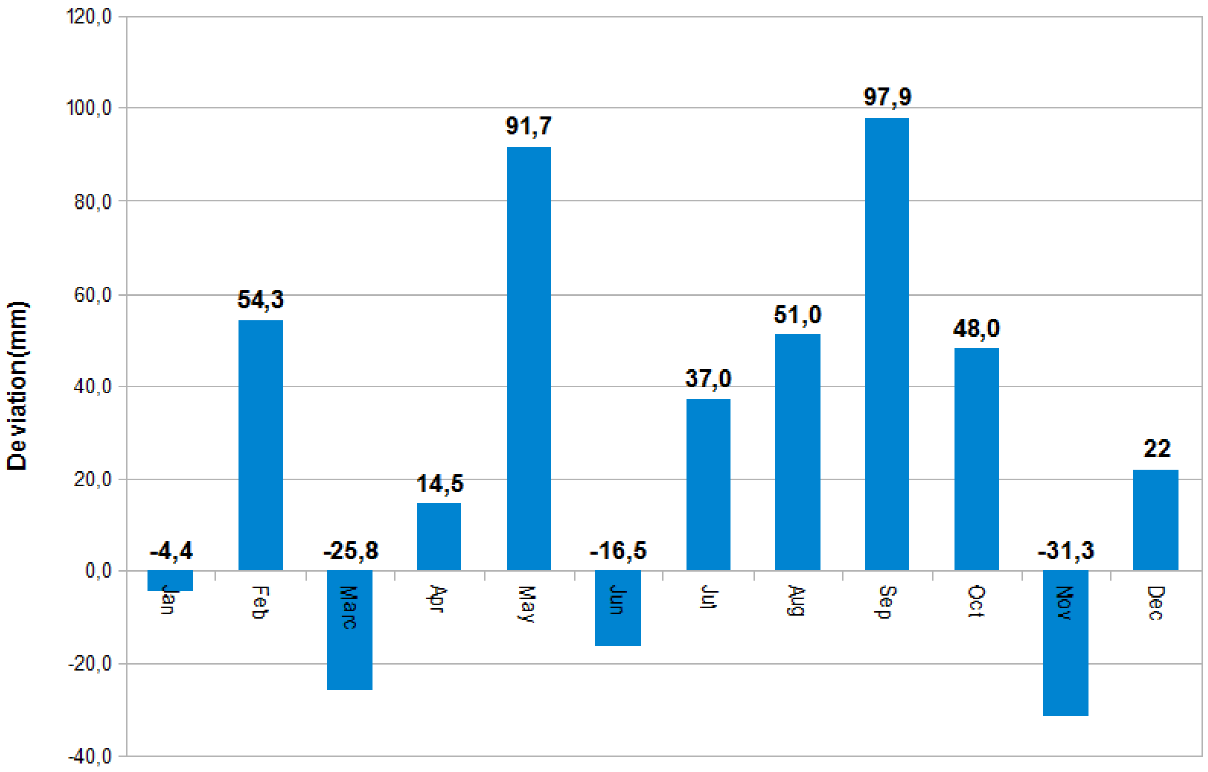

Figure 3 – Deviation of the 2014 precipitation figures from the 100-year average.

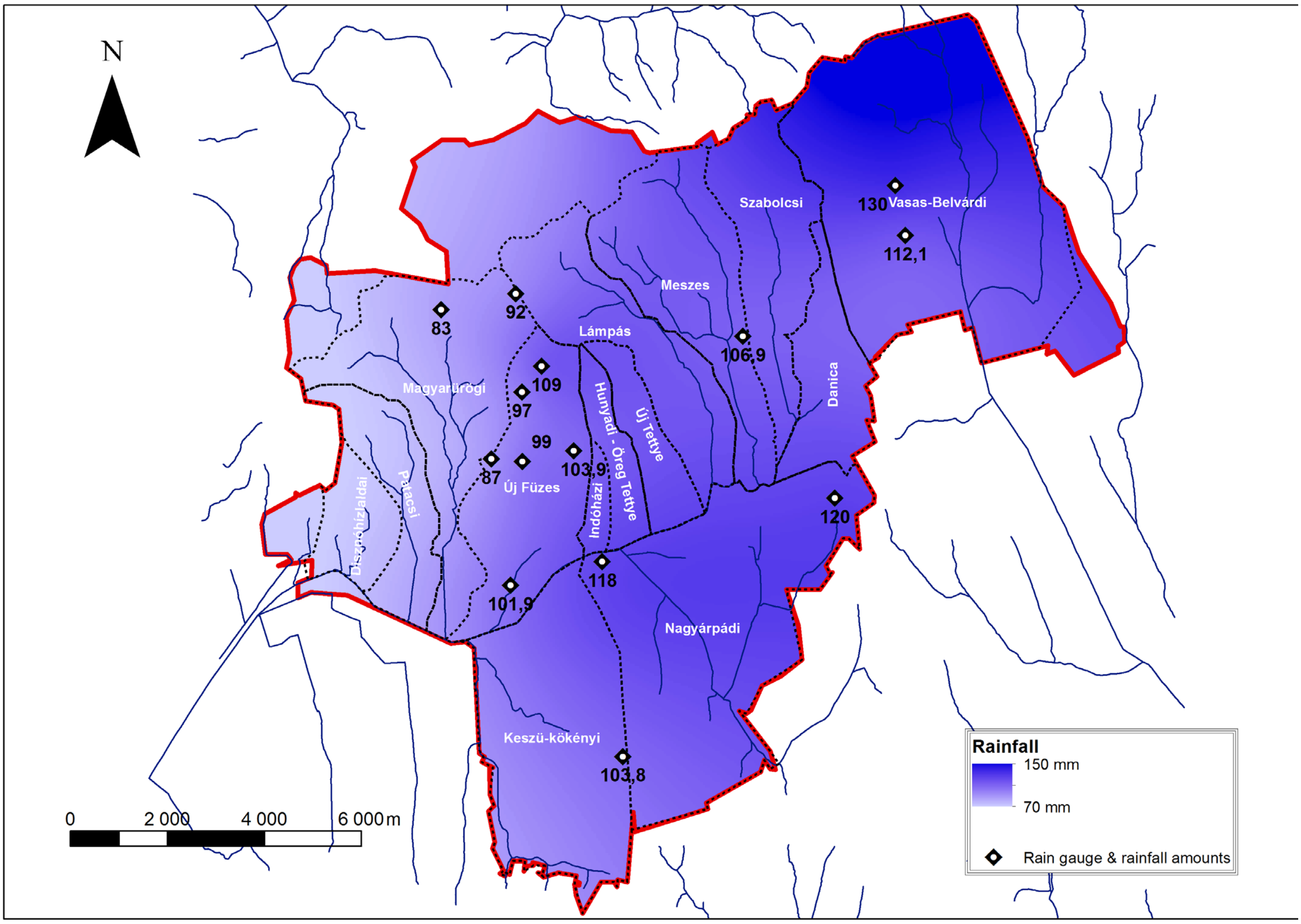

Figure 4 – Distribution of rainfall with neighbourhoods on 14-17 May 2014.

clone generated rains in more homogeneous distribution in the administrative area. The most intense rainfall occurred on 3 August, when intensity reached 9.5 mm/5 min at the Jegenyés Street. The collection interval of urban runoff was around 1 hour for the various catchments, which indicates a typical flash flood event (figure 5).

The results indicate that the monitoring system offers valuable assistance in identifying hot spots of flash flood hazard. Preventive measures could be concentrated on these focal areas.

As far as soil moisture regime is concerned, peaks coinciding with the rainy periods of May and August are conspicuous in the record. On 26 August 2014 a groundwater table sensor was also installed in the basin floor area of the city, where the sandy alluvia (partly anthropogenic fill) rapidly responds to changes in groundwater recharge. The minimum depth to groundwater table was observed on 24 October 2014 (-55 cm from the ground surface).

In order to truly depict spatial variations in the spatial distribution of pressure on the sewerage network, population and water infrastructural data for the individual neighbourhoods were also analysed (table 4). The wide range of population density indicates that the severity of hazard is highly variable even within the land use category of detached housing.

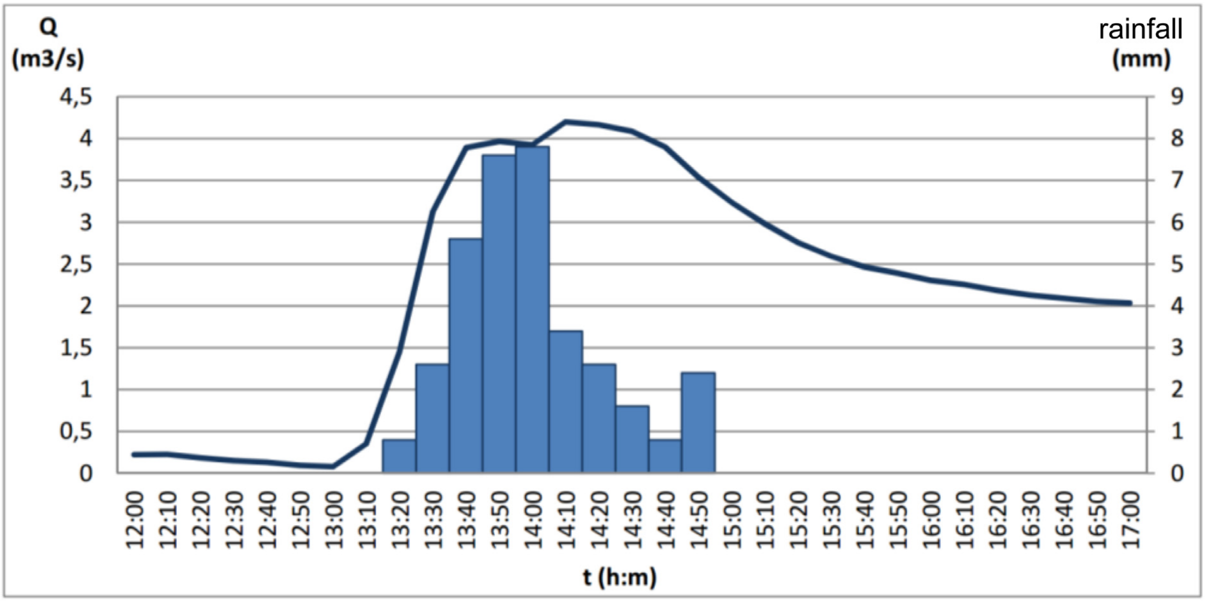

Figure 5 – Storm hydrograph of the Ürög Stream on 3 August 2014.

Table 4 – Population and water infrastructure data of selected neighbourhoods in Pécs (arranged according to population number).

Neighbourhood	*Main character*	*Resident population (2001)*	*Population density (people km^{-2})*	*Length of sewerage network (m)*	*Number of cleaning shafts*
Uránváros	housing estate	12,327	13,626	23,323	1,146
Makár	detached houses	5,337	3,459	20,775	758
Magyarürög	detached houses	3,016	1,355	19,110	644
Patacs	detached houses	2,406	852	11,544	421
Kovácstelep	detached houses	1,750	5,144	6,013	255
Szkókó	detached houses	1,657	1,984	11,034	426
Csoronika	detached houses	1,614	3,394	4,564	143
Deindol	detached houses	1,192	736	14,695	459
Rácváros	detached houses	894	2,073	5,196	185
Donátus	detached houses	879	878	11,171	338
Szentmiklós	resort	194	239	1,400	41
Zsebedomb	resort	187	185	2,446	47
Fogadó	industrial	124	407	5,812	150
Szentkút	resort	117	361	4,339	96
Bolgárkert	industrial	11	20	1,964	71
Szigeti tanya	industrial	n.a.	n.a.	432	0
Kismélyvölgy	detached	n.a.	n.a.	861	8

Case study

The network of the Magyarürög Valley catchment (5.7 km^2) illustrates the problems of sewage management in Pécs (figure 6). The gravitationally operated system collects runoff from the slopes of the Mecsek Mountains first developed as a green belt more than 50 years ago. The hardly regulated spreading of the settlement took place along narrow carriage roads leading to the vineyards and family homes were built often disregarding topographic conditions and infrastructural potentials. The situation was amended by the construction of sewers, a project that was completed in 2008. This development, however, generated a new wave of construction which will almost certainly not followed by the extension of the road and stormwater drainage network in the near future. The above factors may result in a situation where the possibility of the conduction of extra stormwater into the sewerage system cannot be excluded.

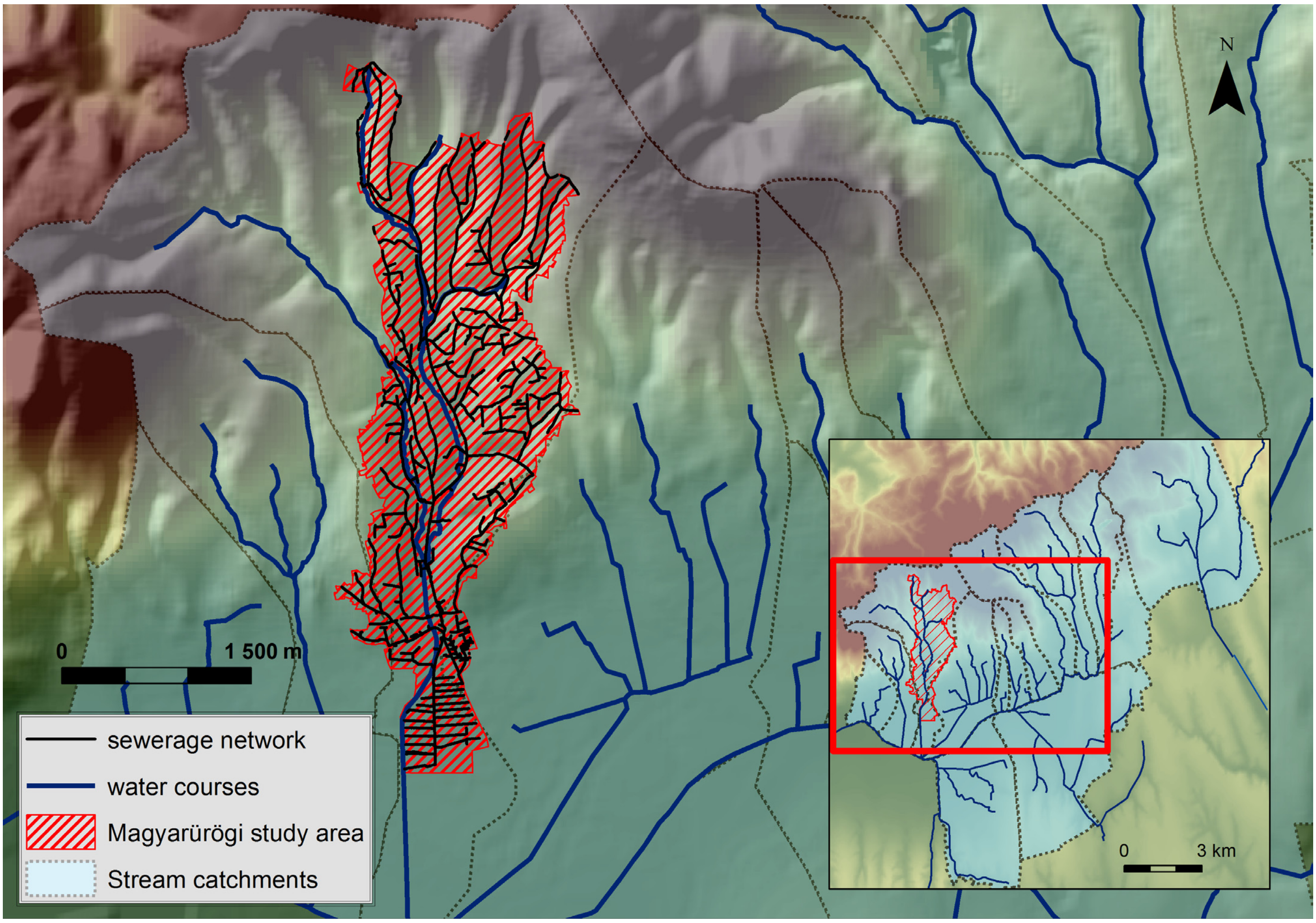

Figure 6 – Location and sewerage network of the Magyarürög subcatchment in the administrative area of Pécs. (source: Tettye Forrásház Ltd).

In the Magyarürög system, in spite of the sparse population, water consumption amounts to 1,202 m^3 day^{-1}. The length of the gravitational network is 52,622 m. This is a foothill area of high dissection with average relative relief: 18.6 m (the highest in Pécs) and a 9.5° surface slope for pixels calculated from eight neighbouring pixels. Therefore, the operation costs of the sewerage system are relatively high. Erosional valleys cutting into masses of Lower Triassic sedimentary rocks by regression separate southward-stretching interfluvial ridges and increase relief (figure 7).

Confined groundwater derives from karst reservoirs and its movement is influenced by tectonic structures. Anticlines force waters to ascend to levels near the surface and can be exploited on the valley floors, while below the ridges they are found at several tens of metres of depth. In the valleys the density of springs is high. Although in the inventory only 10 springs are included, their true number must be much higher. Waters from springs issuing at former wine-cellars often drain into the sewerage network. Wells are 5-40 m deep and used to be important sources of drinking water before the development of piped drinking water supply.

In land use industrial and commercial estates with impervious surfaces represent a negligible proportion (1%), while forests on steep northern and northwestern slopes are extensive (15%). Orchards have been replaced by residential areas. Build-up density is around 50% in 59% of the area and

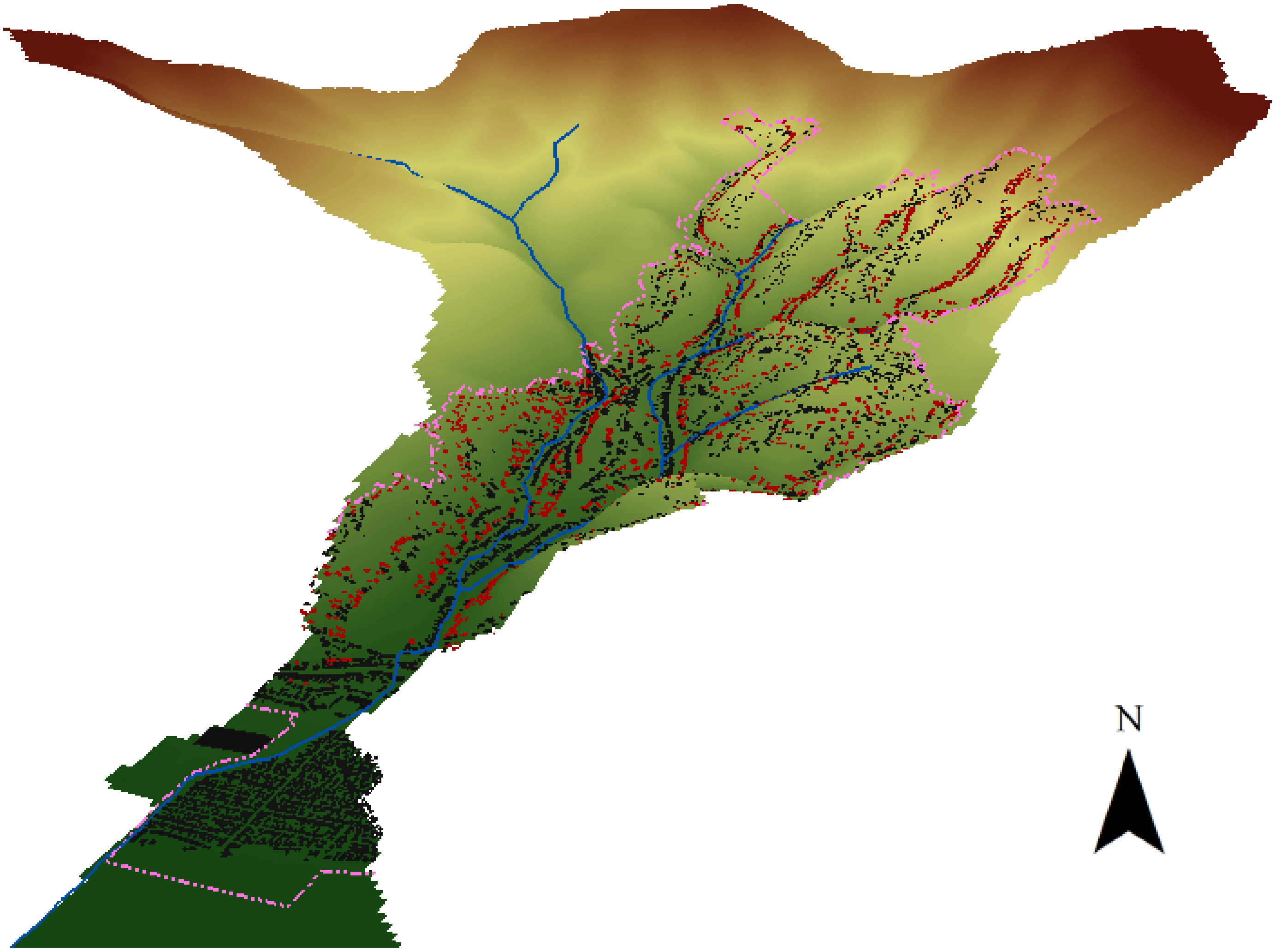

Figure 7 – DEM of the Magyarürög valley.

higher along the valley floors and broader ridges. The house-with-garden pattern allows sufficient infiltration and groundwater recharge. At the same time, the traditional land use pattern (orchards and vineyards with press-houses) is not compatible with modern requirements.

A problem for sewage collection is the fact that 56.6% of the area lies in more than 20 m distance from the next drainage facility. This means that in all higher-lying foothill terrains regulated rainwater drainage is virtually impossible. Even open ditches are unsuitable for this purpose and the sewerage is generally loaded with rainwater over 36% of the area. After a wetter autumn, groundwater is also conducted into the sewerage.

In the area of the case study 8,359 buildings of various kinds were investigated. Among them 2,551 fell into the class where release into the sewerage network is of high probability (figure 8). More than half (54%) of buildings (4,562) are assumed to connect to the network with some probability. For a relatively small number of households (1,246) is not expected to try to release stormwater into the sewerage. It is important to note that among the buildings with highest hazard (relative positions between 1 and 15 m), 1,932 only lie 5 m higher than the next sewer. All in all, for 76% stormwater inflow can be relatively easily implemented.

If differentiation is made according to relative position compared to the stormwater conduit network, it is found that 1,160 buildings which are 1-5 m higher than the sewer network are not connected to stormwater conduits. Among them 432 are larger than 50 m^2, 399 are residential buildings and 623 are located on slopes steeper than 10°. The total area of these plots is more than 64,000 m^2. Calculating with the long-term 658 mm average precipitation, more than 42,000 m^3 of sewage has to be treated, which means, at the actual rate, 50,000 euros extra costs for the water suppliers within this single subdistrict of the sewerage network.

Additional calculations highlight that the necessary investment into stormwater drainage would amount to 30 million euros for the entire city (Ronczyk and Lóczy 2006). The return interval for this investment is estimated for 60 years based on the present yearly losses. It is concluded that this interval is beyond any planning and political periods and, therefore, this is not a priority issue for any political party.

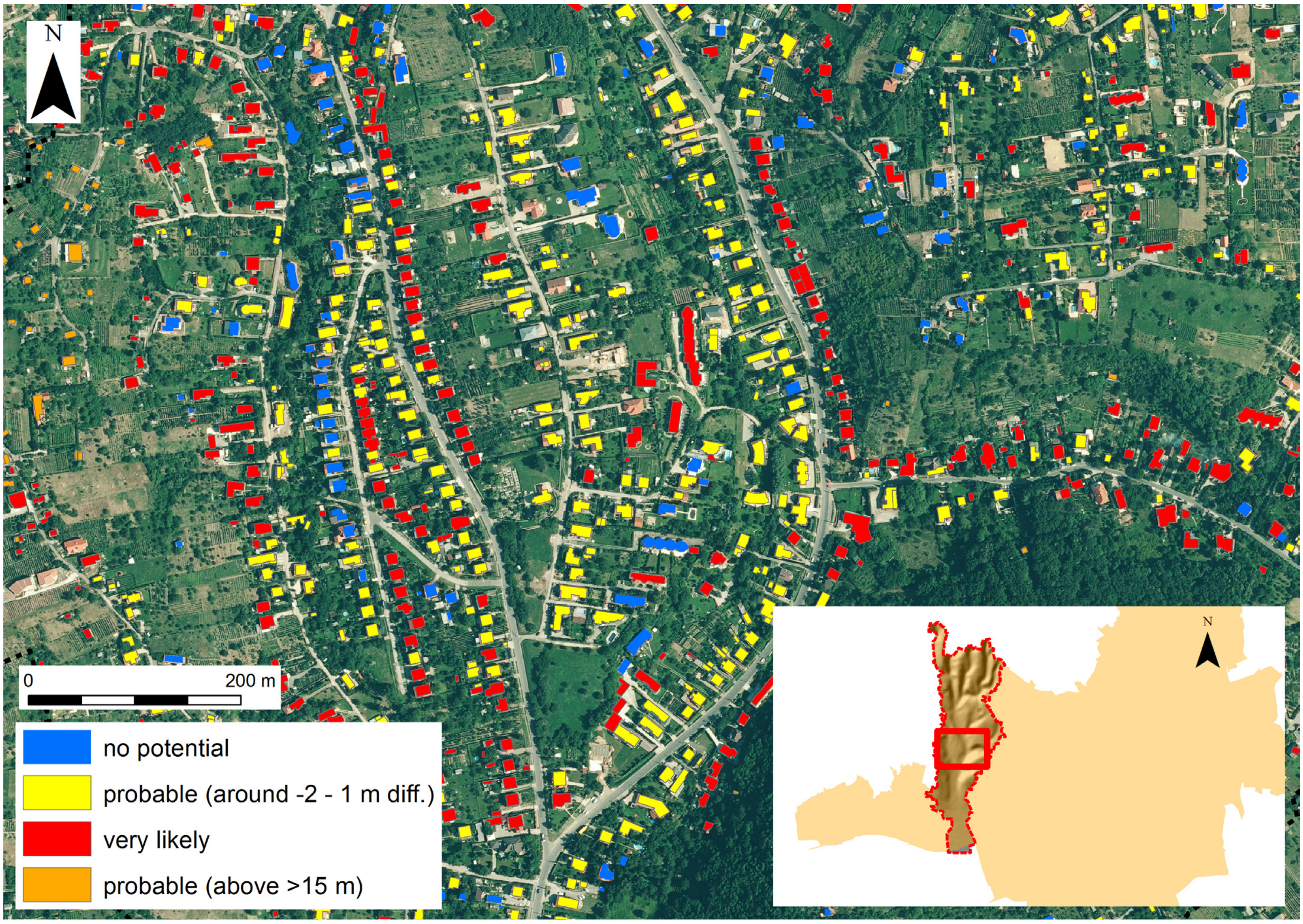

Figure 8 – Classification of buildings with potential contribution to pressure on the sewerage network in the Magyarürög Valley.

Conclusions

Unplanned urban development springing from individual interests, the changeable legal regulation environment and the particular physical environment jointly resulted in serious environmental problems in Pécs. The extra costs necessary to remedy this situation may rise to several millions of euros. The analyses presented in the paper are founded on GIS database and field checking and could be an economical solution for the screening of real estates requiring interventions, which is the first step towards the solution. It has to be supported, however, by a hydrometeorological and runoff monitoring system supplying real-time data on the loading of sewage subdistricts. Based on the results of monitoring, an automatic governance of pumping installations can be established and fining of sewage overflows can be prevented.

Regarding the intricate interactions of water management with the urban energetic and metabolic system, a collaboration of different disciplines is required. In the case of Pécs, a city with diverse topography (particularly striking in the case of the Magyarürög Valley of the Mecsek foothills), geomorphologists should also contribute to this collaboration. A complex treatment of the problem has to include the revision and strict enforcement of building regulation better observing the topographic conditions of the city, the continuous analysis of hydrological processes and raising the environmental awareness of the population.

Acknowledgements

This research was funded by the “TÁMOP 4.2.1.B-10/2/KONV-2010-0002” Operative Programme (Developing Competitiveness of Universities in the South Transdanubian Region) and the Austrian-Hungarian Action Foundation (OMAA, project No. 89öu13). The authors are indebted to the Tettye Forrásház Ltd for providing financial support and pumping station flow data to the current study. The present scientific contribution is dedicated to the 650th anniversary of the foundation of the University of Pécs, Hungary.

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