Final report

Research no SNN 125727 (Possible ecological control of flood hazard in the hill regions of Hungary and Slovenia)

Significance of research and precedents

In the 19th and 20th centuries the main goal of flood control was to promote the passing of flood waves as rapidly downstream as possible. In recent decades, it is increasingly recognised that flood control can only be efficient if runoff is retained in the higher sections of catchments before concentration induces runoff beyond a threshold where inundations cannot be prevented (Hümann, M. et al. 2011). The requirements of modern integrated and sustainable watershed management call for the re-evaluation of existing approaches to reduce runoff and flood hazard in hill regions, incorporating some traditional techniques (like spill channels and retention ponds) as well as novel technologies (bioinfiltration, rain gardens). Therefore, in recent decades soft engineering and low-impact development solutions have been preferred in watershed management plans, both in urban areas (Pyke, C. et al. 2011) and in agricultural land (Emerson, C.H. et al. 2005). Ecological flood control systems intend to meet the demands for sustainable development under the conditions of climate change (Gao, Ch. et al. 2013, Berry, P. et al. 2017). In addition to flood control, such systems are of other benefits too, including the restoration of the connectivity of water systems, enriching the landscapes with watercourses and lakes, ensuring the diversified use of water bodies through the integration of various economic or environmental targets.

To design ecological flood control, basic research into the landscape ecological factors of runoff and flood generation is needed. Among such factors, landscape pattern and land use are both influential in the retention of runoff and prevention of erosion damage. The infiltration and water storage capacity of soils also contributes to runoff reduction. The superposition of flood waves along streams can be efficiently prevented by establishing cascades of small reservoirs on their tributaries (as it has been described from various regions of Asia – Gotoh, H. et al. 2011; Putra, S.S., Ridwan, B.W. 2016). However, in the hill regions of Hungarian Transdanubia, for example, the flood-control function of such reservoirs have been substantially reduced when most of them were converted to fish-ponds for economic purposes. This involved the transformation of their water regime and their floodwater-storage capacity proved to be insufficient to prevent flooding.

Seldom so concentrated in space and more difficult to localize, droughts are apparently less dangerous than floods (World Bank 2019). Although they develop more gradually, they last for much longer periods than floods (often for years). An important component of adjustment to new climatic conditions could be an integrated water management, equally directed to the prevention of floods and droughts (Grobicki, A. et al. 2015). Water retention is a crucial task here (European Commission 2014). The damage brought about by extreme weather events always depends on the local context. As a good example, it could be cited that in Hungary 2010 was by far the most humid year since the beginning of meteorological observations, while 2011 was somewhat drier than anything observed before. In most of the regions of the country, however, thanks to the storage of surplus moisture from the previous year in soils, the 2011 drought did not cause remarkable losses of crop yield.

Although the basic principles of runoff reduction and soil conservation have been established in both countries (Erődi, B. et al. 1965; Zorn, M., Komac, B. 2011), inappropriate land use and water management still leads to flooding problems. International experience shows that in some cases not even stream impoundment is necessary (Water Resource Development …no date).

In the Institute of Geography, University of Pécs, previous research financed by OTKA was directed at the solution of land use conflicts (Lóczy, D. 2007) in Transdanubian pilot areas (partly hilly, partly lowland regions). The hydromorphological and landscape ecological conditions of flood control were investigated in detail along the Kapos River (Lóczy, D. 2013) and along the Hungarian section of the Drava River (Lóczy, D. et al. 2016). The geomorphological research group of the Institute has experience in the study of hillslope processes (landslides and soil erosion – Fábián, Sz.Á. et al. 2006), which was also utilized in the present project. The geomorphological and sedimentological studies pointed out important interactions between factors influencing runoff and erosion. Research into landscape pattern and groundwater recharge (in previous research with focus on floodplains – Lóczy, D. and Gyenizse, P. 2011) were additional significant background studies. Finally, the monitoring of soil and land use conditions of flash flood generation in foothill areas (Lóczy, D. et al. 2002) also provided valuable information for the present project.

The contribution of the Slovenian partner (Anton Melik Geographical Institute, Slovenian Academy of Sciences) was significant because both countries have similar landscape characteristics with similar bedrock, climate, and topography, thus transfer of knowledge, research, and good practices in runoff, flood and erosion control are needed. The Slovenian partner has carried out parallel research, following identical protocols, and thus their results allow international comparison (see joint publications).

Research objectives

The primary tasks of research in preparation for the planning of ecological flood control and drought prevention measures were the following:

1, a detailed survey of all natural and manmade landscape elements, landforms and structures (ponds, ditches etc.) which influence the rate and concentration of runoff, its pathways (flood routing), rates of sedimentation;

2, an inventory and evaluation of the benefits of dams and reservoirs along with their actual use; proposing a scheme of integrated water management to achieve that their future use should not prevent their functioning as rentention spaces for flood waves;

3, evaluation of possible non-engineering solutions (e.g. land use change, restoration or function modification of beneficial landscape elements etc.) to the flood problem; the integration of water retention into the ecosystem services (see e.g., Fisher, B. and Turner, K. 2008);

4, assessment of the opportunities for the storage of moisture in soils, through revealing infiltration rates, water retention capacities under different land use types.

Methods

The methods applied included

1, Laboratory measurements of water storage capacities of different soil types found in the study areas;

2, UAV surveys of runoff and erosion conditions in hillsopes for the study of the impacts of rainfall events;

3, Digital Elevation Modelling based on LiDAR survey (completed for the study areas in Hungary);

4, assessment of archive historical data on landscape elements relevant for runoff generation and retention;

5, monitoring of water balance (precipitation, stream discharge, soil moisture) and hydrological modelling in small catchments;

6. estimation of the value of water retention as an ecosystem service;

7, typology of partial catchments in hilly regions by topography, soils and land use influencing runoff retention and flood hazard.

Three areas were selected for detailed studies:

1. Boda area (foothills of the Mecsek Mountains)

Located in the western neighbourhood of Pécs, in the southern foreland of the Mecsek Mountains, gently sloping towards the Pécs half-basin, its elevation ranges from 172 to 182 m. Typical land use is large-scale arable farming with conventional tillage, growing sugar-beet, cereals and oil plants as the main crops. The prevailing genetic soil type is Ramann's brown forest soil (its WRB equivalent is Haplic Luvisol). The soil moisture monitoring sites are placed on a slope of 4.24% inclination. It means that this surface can be regarded almost horizontal, but the steepest slopes with southern or southwestern exposure have angles up to 10%. The distance between the upper and the lower measurement sites is 190 m. Erosion features in the study area include a derasional valley and an erosional stream with a group of trees which influences soil moisture budget in the immediate environs of the valley.

2. Palkonya area (northern foreland of the Villány Hills)

Enclosed between the settlements Palkonya, Ivánbattyán, Kisjakabfalva, Villány and Villánykövesd, the parent material is loess overlying a Mesozoic limestone basement. The soils are described as Chromic Cambisols. Elevation above sea level is somewhat lower, 113–128 m, while the plot where the monitoring equipment is placed is steeper than at Boda, average slope angle is 8.98%. Land utilization is partly orchard and partly grazing land. The measurement sites were designated at 156 m distance from each other.

3. Almamellék area (Zselic Hills)

Situated in a basin of the Zselic Hills at 127–142 m elevation, its relief is subdued (mean slope angle is 4.24%) but still slightly more dissected. Ramann's brown forest soils (Calcaric Phaeozems) are locally severely eroded. (The Hungarian Agricultural Plot Registration Database [MePAR] indicates medium to severe water erosion hazard for ca 40% of the study area.) The valleys are are used as meadows and hillslopes mostly as grazing land. The measurement sites are located at 167 m distance from each other.

Results

1. Capillary rise in various soil types of the Transdanubian Hills

Our small- scale model experiment lasting 30 days involved the study of capillary rise in homogeneous and multilayered soil columns representing the texture types most common in South-Transdanubia. The results show a 150-cm limit of capillary water rise for the investigated textural types. This finding points to an important limitation to plant disponible water amounts. The experiments with soil columns indicated that soils of heterogeneous texture are not able to raise moisture to the same height as soils of homogeneous texture. This is explained by the distribution of the clay fraction in the solumn. Capillary rise can supply the root zone of crops with moisture to a maximum of 150 cm in 30 days. This is of great significance during periods of drought.

2. Surveys of runoff and erosion

Because of the late purchase of UAV equipment, this survey was accomplished through field work and recording of observations. Rainfall intensities obtained from tiping-bucket raingauges (ECRN-100) were recorded with EM-60 data logger at every 15 minutes. At the top and bottom of each measurement plot TDR soil moisture sensors (Meter Group Inc., Teros 12) and tensiometers (Teros 21) were placed at 10 and 30 cm soil depths.The most severe rainfall event was observed at the Almamellék site. The soil and water conservation measures which had been implemented by landowners prior to the project have not proved to be efficient. An important rainfall event was observed in March 2018. The amount of rainfall (128 mm) recorded at the station of the neighbouring Szentlászló threefold exceeded the long-term monthly average. Rapid concentration of runoff washed down huge amounts of loess along dirt roads used by agricultural vehicles into concrete-lined water-conducting ditches even plugging culverts. Also in the Boda study area heavy rainfalls between 03 and 16 July 2018 induced large-scale rill erosion on large-scale arable land in lack of traditional landscape elements.

3. Digital Elevation Modelling and interpreting its derivates

A Digital Elevation Model (DEM) was applied to regionally depict soil moisture conditions because water flow tends to follow topographic gradients and accumulate in response to gravitational potential energy. Therefore, for reconstructing the spatial distribution of moisture storage and the sites where surface runoff is concentrated, we used the Topographic Wetness Index (TWI) (Beven, K.J. and Kirkby, M. J. 1979; Beven, K. and Wood, E.F. 1983). This is a GIS technique which relies on a high-resolution DEM and calculates TWI only from the size of the catchment area and slope inclination as input parameters. Digital Surface Model, DSM represents the elevations of the reflective surfaces [trees, buildings and other features] which rise above the ground surface – Zhou, Q.M. 2017.) Natural water retention potantial was assumed to be the difference between the TWI calculated from the DEM and the DSM. It was assumed that the elements of microtopography with water retention potential have some (even is minimal) spatial extension and, therefore, are represented in the DSM as higher-lying surfaces. Subtracting the elevations of pixels in the DSM-derived TWI from the DEM-derived TWI, the difference can be any value (negative, positive or zero). The thus calculated TWI (Land Use TWI or LU-TWI) shows potential runoff paths which are due to the joint effect of topography and vegetation (land use) in the study areas. In addition to microtopography, the LU-TWI also indicates the influence of landscape elements, in the case of the orchard, tree rows, on runoff reduction and moisture storage. At the Palkonya orchard site runoff is diverted into the alleys between tree rows, land use differentiates water retention through interception and modifying the infiltration/runoff ratio. The LU-TWI index allowed a clear distinction between surfaces with the predominance of runoff and those with water retention. The latter mostly coincide with the rows of fruit trees. In a considerable portion of the Palkonya area, however, the patches of high water retention were not parallel with the tree rows. This fact underlines the modifying effect of natural microfeatures in relief. On the other hand, the LU-TWI model still reflects higher water retention capacity along the tree rows as opposed to the interrows. Differences in moisture contents are striking between the spring and summer sections of the growing season. Average values are higher in the spring (0.305 m^3m^{-3}) and shows less fluctuation (±0.025 m^3m^{-3}), while averages are lower in the summer but has much higher standard deviations. As an exception, at 10 cm depth of the slope-bottom measurement site of the Boda ploughland, where standard deviation was rather high (0.15 m^3m^{-3}) (Nagy, G. et al. 2020).

4. Historical data

Land use changes over one hundred years have been revealed in the study areas. The long-term use as grassland (at the Almamellék site) is more favourable for soil mositure conservation than conversion to arable land (at Boda). The interpretation of findings and their publication is underway.

5. Monitoring moisture conditions

A detailed soil survey and mapping in the study areas was necessary to reveal the hydraulic properties of soils. Soil sampling took place by AMS-type manual augers, to maximum 200–290 cm depth, where the C horizon (loess parent material) was reached. The laboratory analyses of samples covered the identification of particle size distribution and clay contents using static light scattering with Malvern MasterSizer 3000 laser particle analyzer (Malvern Inc., Malvern, United Kingdom). Volumetric soil moisture contents for the individual soil horizons were determined by Spectrum TDR-300 (Spectrum Inc., Aurora, IL, USA). Measurements were performed in 3–5 repetitions within 50-cm radius circles drawn around the measurement sites, the locations of which were established by GPS. Measured values were averaged and their standard deviations calculated.

Marked differences in the direction of water motion have been detected seasonally and between arable land, grasslands and orchards. Rainfall amounts around or slightly above 1 mm per event seem to be the threshold of runoff generation on ploughland and along interrows of the orchard. Drought risk is highest on ploughland. Favourable soil water budgets have been observed in the fields with different land use: less intensive types, like grazing land and orchards (particularly tree rows), were identified as places of high water retention capacity. Unfortunately, however, with the decline of animal husbandry grasslands are not properly maintained to fulfil their functions (Nagy, G. et al. 2020).

6. Ecosystem service estimation

A very rough estimation was made to approximate a value of groundwater recharge in Southern Transdanubia. It was assumed that, in the short term, the value of the ecosystem service of groundwater recharge approximately equals the total extraction cost as a compensation of the loss of reserves. The costs of some recharge engineering structures were analysed (Lóczy, D. et al. 2020). The results underline the need for water retention since it is a much cheaper solution for mitigation flood and drought hazard than, e.g., reservoir construction. However, the insufficient data on these investments and changing water prices represent major sources of uncertainty in such calculation.

7. Catchment typology

The results of measurements at pilot areas could be extended to entire watershed using UAV images. The high resolution soil moisture measurements corroborated the large spatial heterogeneity of soil physical properties (texture, macropores, and preferential flow paths) in the field as well as the influence of land use and landscape pattern on soil moisture dynamics. Classes of water retention on catchments were established on the basis of the methodology in Pásztor, L. (2021) using water retention capacities in comparison with the erosion status of soils. The catchment in Zselic Hills show outstanding values of potential runoff. The generalization of field monitoring results over catchments will be presented at the 10th Hungarian Geographical Conference in Budapest, on 24 September 2021.

References

Berry, P., Yassin, F., Belcher, K., Lindenschmidt, K.E. 2017. An economic assessment of local Farm multi-purpose surface water retention systems under future climate uncertainty. Sustainability 9: 456–478. doi:10.3390/su9030456

Beven, K., Wood, E.F. 1983. Catchment geomorphology and the dynamics of runoff contributing areas. Journal of Hydrology 65: 139–158. doi: 10.1016/0022-1694(83)90214-7

Beven, K.J., Kirkby, M. J. 1979. A physically based, variable contributing area model of basin hydrology. Hydrological Science Bulletin 24(1): 43–69. doi:10.1080/02626667909491834

Fisher, B., Turner, K. 2008. Ecosystem services: Classification for valuation. Biological Conservation 141: 1167–1169.

Emerson, C.H., Welty, C., Traver, R.G. 2005. Watershed-scale evaluation of a system of storm water detention basins. Journal of Hydrological Engineering 10: 237–242.

Erődi B., Horváth Z., Kamarás M. 1965. Talajvédő gazdálkodás hegy- és dombvidéken (Soil conserving farming in mountainous and hilly regions). Mezőgazdasági Kiadó, Budapest.

European Commission 2014. A guide to support the selection, design and implementation of Natural Water Retention Measures in Europe: Capturing the multiple benefits of nature-based solutions. European Commission, Brussels, 98 p.

http://www.ecrr.org/Portals/27/Publications/NWRMpublication.pdf

Fábián, Sz.Á., Kovács, J., Lóczy, D., Schweitzer, F., Varga, G., Babák, K., Lampért, K., Nagy, A. 2006. Geomorphologic hazards int he Carpathian Foreland, Tolna County (Hungary). Studia Geomorphologica Carpatho-Balcanica 11: 107–118.

Gao, Ch., Liu, J., Wang, Zh.W. 2013. An ecological flood control system in Phoenix Island of Huzhou, China: A case ctudy. Water 5(4), 1457-1471; doi:10.3390/w5041457

Gotoh, H., Maeno, Y., Takezawa, M., Ohnishi, M. 2011. Flood control and small-scale reservoirs. River Basin Management 6: 51–60.

Grobicki, A., MacLeod, F., Pischke, F. 2015. Integrated policies and practices for flood and drought risk management. Water Policy 17(S1): 180–194. doi: 10.2166/wp.2015.009

Haines-Young, R., Potschin, M. 2011. Common International Classification of Ecosystem Services (CICES): 2011 Update. European Environment Agency, London. 17 p.

Hümann, M., Müller, C., Schüler, G., Schneider, R., Thiele-Bruhn, S. 2011. Identification of runoff generation processes – Impact of different forest types on soil-water interrelations. Geophysical Research Abstracts 13. EGU2011-8035-1

IUCN 1997. Fishing for a Living: The Ecology and Economics of Fishponds in Central Europe. International Union for Nature Conservation Publication, Cambridge, UK. 184 p.

Kryžanowski, A., Širca, A., Ravnikar Turk, M., Humar, N. 2013. The VODPREG Project : creation of dam database, identification of risks and preparation of guidelines for civil protection, warning and rescue actions. In: Proceedings of the 9th ICOLD European Club Symposium, Venice, Italy. 191-200.

Lóczy, D., Czigány, Sz., Pirkhoffer, E. 2012. Flash Flood Hazards. Muthukrishnavellaisamy Kumarasamy (ed.), Studies on Water Management Issues. InTech, DOI: 10.5772/28775.

Lóczy D. 2007. A lejtős felszínek geomorfológiai és földhasználati problémái (Geomorphological nad land use problems of hillslopes). – In: Hanusz Á. (szerk.): 100 éve született Peja Győző. Emlékkötet. Nyíregyházi Főiskola, Nyíregyháza. 79–92.

Lóczy, D. 2013. Hydromorphological-geoecological foundations of floodplain management: Case study from Hungary. Lambert Academic Publishing, Saarbrücken. 382 p.

Lóczy, D., Dezső, J., Czigány, Sz., Pirkhoffer, E. 2016. Hydromorphological assessment of the lower Hungarian Drava sectionand its floodplain. Landscape and Environment 10 (3-4): 109–116.

Lóczy, D., Gyenizse, P. 2011. Micromorphology influenced by tillage on a Danubian floodplain in Hungary. Zeitschrift für Geomorphologie 55. Suppl. 1. 67–76.

Lóczy, D., Tóth, G., Hermann, T., Rezsek, M., Nagy, G., Dezső, J., Salem, A., Gyenizse, P., Gobin, A., Vacca, A. 2020. Perspectives of land evaluation of floodplains under conditions of aridification based on the assessment of ecosystem services. Hungarian Geographical Bulletin 69(3): 227-243. doi: 10.15201/hungeobull.69.3.1

Nagy, G., Lóczy, D., Czigány, Sz., Ciglič, R., Ferk, M. 2020. Soil moisture retention on slopes under different agricultural land uses in hilly regions of Southern Transdanubia. Hungarian Geographical Bulletin 69(3): 263-280. doi: 10.15201/hungeobull.69.3.3

Pásztor, L. 2021. Advanced GIS and RS Applications for Soil and Land Degradation Assessment and Mapping. International Journal of Geo-Information 10(3):128. doi: 10.3390/ijgi10030128

Putra, S.S., Ridwan, B.W. 2016. Interconnected ponds operation for flood hazard distribution. AIP Conference Proceedings 1730, 070003. doi: 10.1063/1.4947415 online:

http://dx.doi.org/10.1063/1.4947415 Accessed on 03.02.2017

Pyke, C., Warren, M.P., Johnson, T., LaGro, J., Scharfenberg, J., Groth, P., Freed, R., Schroeer, W., Main, E. 2011. Assessment of low impact development for managing stormwater with changing precipitation due to climate change. Landscape and Urban Planning 103. 166–173.

Water Resource Development Issue Network Japan, No Dam Is Necessary for Flood Control. http://www7b.biglobe.ne.jp/-yakkun/suigenrennopezi2/home/suigenrentoha/teigen

World Bank 2019. Assessing Drought Hazard and Risk: Principles and Implementation Guidance. World Bank, Washington, DC. 88 p.

https://reliefweb.int/sites/reliefweb.int/files/resources/%E2%80%A2Drought_FINALWEB_LOWHRES.pdf

Zhou, Q.M. 2017. Digital Elevation Model and Digital Surface Model. In: Richardson, D. (Editor-in-Chief): The International Encyclopaedia of Geography. American Association of Geographers – John Wiley and Sons, New York. doi: 10.1002/9781118786352.wbieg0768

Zorn, M., Komac, B. 2011. The importance of measuring erosion processes on the example of Slovenia. Hrvatski Geografski Glasnik 73(2): 19–34.