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Catchment Processes in Regional Hydrology: Field Experiments and Modelling in Carpathians Basins

Abstracts of the Conference

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Péter Kalicz, Kamila Hlavčová,
Silvia Kohnová, Viera Rattayová, Zoltán Gribovszki

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STOCHASTIC PRECIPITATION MODELLING

KORBINIAN BREINL

Institute of Hydraulic Engineering and Water Resources Management, Vienna University of Technology

In recent years, hydrology has progressed rapidly in stochastic precipitation modelling. So-called weather generators are stochastic algorithms for extrapolating observed weather variables (precipitation, temperature, etc.) with statistical characteristics similar to those of observations. Rainfall is the most important variable, and its complex intermittent nature in space and over time has resulted in a diversity of space-time weather generation philosophies. Applications of stochastic precipitation models are numerous. For example, by means of a rainfall-runoff model, stochastic rainfall probabilities can be transformed into flood probabilities to overcome important limitations of statistical flood frequency analysis such as missing information on flood volumes. Coupled precipitation rainfall-runoff model frameworks can thus help to better understand the "hydrological dice", i.e., how the rainfall and physical processes on a catchment scale operate in space and over time. This talk gives an overview of the state of the art and the opportunities and challenges of stochastic precipitation modelling, thereby providing concrete examples from ongoing research at TU Vienna in the Upper Danube basin within the project "Space-Time scAling of the Rainfall to FLOOD transformation" (STARFLOOD).

THE USE OF STOCHASTIC MODELS FOR PREDICTING WATER QUALITY PARAMETERS. CASE STUDY IN THE TRANSBOUNDARY (BALKAN) CATCHMENT OF THE THESAURUS RESERVOIR, RIVER NESTOS

ARIS PSILOVIKOS

Deptartment of Ichthyology & Aquatic Environment, School of Agricultural Sciences, University of Thessaly, Odos Fytokou, N. Ionia Magnisias, 38446, GR (psiloviko@uth.gr)

This study presents the development and validation of three different stochastic models on the basis of: a) their efficiency to forecast and b) their ability to utilize auxiliary environmental information. The three models are a) ARIMA, b) Transfer Function (*TF*) and c) Artificial Neural Networks (*ANN*). Our study area is the Thesaurus Reservoir in the River Nestos, Eastern Macedonia, Greece. The River Nestos is a transboundary river in the Balkans, which is shared between Bulgaria and Greece. The Thesaurus Reservoir is the deepest water body in the Hellenic territory. The rough geomorphology and steep relief of its catchment area contribute to the reservoir's depth, which is approximately 140 m at its highest operational level with a maximum altitude of 380 m above sea level. This reservoir was constructed by the Public Power Company of Greece (P.P.C. – DEI) in order to cover the increased needs for hydroelectric power in the north-eastern regions of Greece, especially Eastern Macedonia and Thrace. It was fully constructed in the year 1997; for 3 years, no water outtake took place in order to fill up the reservoir. Fully respecting the environment and following the norms of the Ministerial Agreement No. 18492/19-09-1996, the P.P.C. conducted a four-year monitoring program (19/1/2004 – 28/12/2007) with daily measurements of (DO) and (Tw) data at four different depths (1m, 20m, 40m and 70m) that covered the water column of the reservoir and the vertical fluctuations in both parameters. This useful data gave our research team the opportunity a) to understand the natural operation of the reservoir in its first stages of life and also b) to obtain the best simulation models for the time series. Four statistical parameters (*MSE, RMSE, MAPE, NSC*) were used to evaluate the accuracy and compare the forecasting ability of each approach. Useful results and answers were obtained to the questions of: 1) Which is the best and simplest model to use? 2) How can the reservoir be operated in an optimal way in order to avoid stagnation phenomena? 3) Which monitoring station of the four used could be omitted and be simulated from the data of another station, thus saving monetary resources?

ATTRIBUTION OF FLOOD CHANGES IN UPPER AUSTRIA: A DATA-BASED APPROACH

MIRIAM BERTOLA, ALBERTO VIGLIONE, GÜNTER BLÖSCHL

Vienna University of Technology, Institute of Hydraulic Engineering and Water Resources Management, Vienna, Austria (bertola@waterresources.at)

In this study we applied a data-based approach for the attribution of flood changes to 97 stations in Upper Austria. The aim was to identify the main processes driving the positive trends in flood peak discharge series that have been detected in the region during the last four decades of flood records. We considered decadal variations of the atmospheric (i.e., annual and extreme precipitation), catchment (i.e., land-use changes), and river-system processes (i.e., reservoirs) as potential drivers of flood changes.

In each site, we fitted a set of competing Gumbel distributions to the annual maximum discharge series, with the parameters conditioned on local drivers. The parameters of the extreme value distribution were estimated with a Bayesian Monte Carlo Markov Chain (MCMC) approach, and the competing models were locally compared with the Watanabe-Akaike information criterion (WAIC). Through comparisons and selection of the models, we formally performed the attribution of flood changes at the catchment level.

The sensitivity of the attribution to different time scales of the atmospheric driver and the dependency on the catchment area of the effects of the drivers on floods were researched.

Our findings show that, in general, atmospheric processes drive the long-term evolution of floods in Upper Austria and that changes in extreme precipitation series correlate better to changes in floods. On the other hand, land-use changes and reservoirs have marginal roles in the study region.

TOWARDS AN IMPROVED ESTIMATION OF THE TIME OF CONCENTRATION IN MEDIUM-SIZED HUNGARIAN CATCHMENTS

ESZTER DÓRA NAGY, JÓZSEF SZILÁGYI, PÉTER TORMA

Budapest University of Technology Economics, Department of Hydraulic and Water Resources Engineering (nagy.eszter@epito.bme.hu)

Timing parameters, such as the time of concentration (T_c), provide significant information in many fields, e.g., flood risk management and rainfall-runoff modelling. In Hungary, the generally applied method to describe a catchment's response is to use the empirical equation derived by Wisnovszky in 1958. The aim of this study is to derive a more accurate estimation of T_c and obtain a deeper understanding of the relationship between the morphometric parameters, rainfall event characteristics, and corresponding response time. The four most important morphometric parameters out of 23 were identified by a principal component analysis. A new polynomial equation was calibrated based on the parameters identified. Further improvement of the T_c estimation was achieved by applying a new catchment grouping method. A hyperbola was fit to the maximum rainfall intensity versus the T_c data for every watershed. The constant multiplier of the hyperbola displayed a linear correlation with the catchment area for each group, but the reason for this behaviour has not yet been identified. The calculations were carried out employing 736 events at 38 watersheds, with catchment sizes varying from 16 to 978 km^2. As a result, the root mean square error was reduced from 8.6 to 2.3 hours.

SCALING CONSTRUCTED WETLANDS THAT TREAT COMBINED SEWER OVERFLOWS – A CASE STUDY WITH THE ORAGE DESIGN-SUPPORT MODELLING TOOL

TAMÁS GÁBOR PÁLFY[1,2], **PASCAL MOLLE**[3]

[1] University of Sopron, Institute of Geomatics and Civil Engineering, H-9400 Sopron, Bajcsy-Zs. utca 4, Hungary
[2] Tamas Gabor Palfy EIRL, 19 rue de la Doua, 69160 Tassin-la-demi-Lune, France (tamas@ghaemesh.com)
[3] IRSTEA Lyon, Freshwater Systems, Ecology and Pollution Unit, 5 rue de la Doua, CS70077 69626 Villeurbanne Cedex, France

Constructed wetlands for combined sewer overflows (CSO CW) are ecotechnologies that effectively remove TSS, COD, NH_4-N and TP. They also remove micropollutants and reduce floods caused by storms over urban catchments at construction costs of about one fifth that of concrete tanks. We report a case study of wetland optimization using the Orage design-support model. The simulations were based on detailed volumetric data, and a limited number of grab samples served as input for the water quality. The optimized wetland could ensure emission thresholds for TSS, NH_4-N and COD, with median emissions of 9.3, 1.1 and 57 g/m^3, respectively. The filter area was scaled to 109 m^2 to treat overflows of up to 1000 m^3, which corresponded to a return period of six months. We showed how decision making and engineering could be supported by simulations and analysing the inputs and results manually in a TOWS matrix, especially if the input series is incomplete.

Acknowledgement: the corresponding author wants to thank IRSTEA and the University of Sopron for supporting research translation into practice and further research, respectively.

Keywords: combined sewer overflow, CSO, constructed wetland, modelling, ecotechnology, Orage

GNSS REMOTE SENSING OF SNOW COVER PROPERTIES IN HIGH-ALPINE TERRAIN

FRANZISKA KOCH[1,2], PATRICK HENKEL[3], FLORIAN APPEL[4], LINO SCHMID[5], HEIKE BACH[4], MATTHIAS BERNHARDT[1], KARSTEN SCHULZ[1], JÜRG SCHWEIZER[5], WOLFRAM MAUSER[2]

[1] Institute of Water Management, Hydrology and Hydrologic Engineering, University of Natural Resources and Life Sciences, Vienna, Austria.
[2] Department of Geography, Ludwig-Maximilians-Universität München, Munich, Germany.
[3] ANavS - Advanced Navigation Solutions GmbH, Munich, Germany.
[4] Vista Remote Sensing in Geosciences GmbH, Munich, Germany.
[5] WSL Institute for Snow and Avalanche Research SLF, Davos Dorf, Switzerland.

Information on the snow water equivalent (SWE) and snowmelt is essential for diverse water resources management tasks, especially in alpine regions. These encompass e.g., the fields of hydropower generation, flood prevention, and ski resort management. In-situ measured snow properties are essential for the validation of remote sensing data as well as for model inputs. However, until now, continuous measurements are either scarce, expensive, time consuming or lack temporal or spatial resolution.

We have developed a novel approach using only one measurement device to derive the SWE, snow depth and liquid water content (LWC) in snow, based on the freely available signal strength and carrier phase signals of the Global Navigation Satellite System (GNSS). For this purpose, two static low-cost Global Positioning System (GPS) sensors were installed at a high-alpine test site in Switzerland (Weissfluhjoch) since 2012. One GPS antenna is placed on the ground below the snowpack and the other antenna on a pole permanently placed above the snowpack. Before the first snowfall in autumn, the baseline between the two antennas was determined with millimetre accuracy using a Real Time Kinematic (RTK) positioning approach. As soon as snow accumulates on top of the antenna on the ground, the GNSS signals are delayed and attenuated compared to the signals, which travel in the air. We validated the GNSS-derived bulk snow cover properties with data from a snow pillow, a snow scale, ultrasonic sensors, and meltwater outflow at a snow lysimeter as well as bi-weekly manual snow profile measurements during the seasonal evolution of the high-alpine snowpack for three entire winter seasons (2015-2016, 2016-2017 and 2017-2018). The results agree very well with the validation data. Entire networks of such GNSS sensors could improve the spatial and temporal information on dry and wet snow. Besides hydrological approaches, we aim to apply this measurement technique for technical snow management in alpine skiing resorts, e.g., at Zugspitze, Germany.

A METHODOLOGICAL PROCEDURE FOR THE APPLICATION OF A PHYSICALLY-BASED EROSION MODEL WITH AN ASSESSMENT OF SOIL WATER EROSION IN TWO SLOVAK CATCHMENTS

ZUZANA NÉMETOVÁ, SILVIA KOHNOVÁ

Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia

The development of methods and assessments for the evaluation of soil water erosion has been increasing in recent decades. Although this topic has been investigated by a large number of authors, it is still significantly under-researched and unclear.

The main aim of the study is to present an application of the physically-based EROSION-3D model together with an analysis of the complex structural equations in two Slovak catchments. The main concept of the physically-based model is the representation and quantitative estimation of soil erosion (soil detachment, transport and deposition) using physically-based equations. Physically-based models take into account an understanding of the physics of the hydrological processes and represent a powerful and innovative technique for the assessment of complicated runoff-erosion processes. Due to the complexity of these processes, the EROSION-3D model contains two submodels, i.e., an infiltration model and an erosion model.

The study describes a model system in a complex way by a set of equations and variables that establish relationships between the variables and explain how they affect each other. The methodical application procedure created provides not only explanations of the relationships between the individual equations but also mainly offers a fundamental tool for the application of the EROSION-3D model and the interpretation of its outputs for the end users. At the end of the study, the approach was applied in catchments with variable land uses using extreme rainfall events. The results confirm not only the complexity of the model but also show the variable influence of each input and output parameter.

Key words: soil erosion, physically-based model, soil detachment, erosion model, modelling of soil water erosion, extreme rainfall event

IMPACT OF CHANGES IN SPATIAL RESOLUTION ON THE PERFORMANCE OF AN OPERATIONAL DISTRIBUTED HYDROLOGICAL MODEL

CAROLINA MASSMANN, DANIEL KLOTZ, JOHANNES WESEMANN, MATHEW HERRNEGGER, KARSTEN SCHULZ

Institute of Water Management, Hydrology and Hydraulic Engineering (IWHW), University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna, Austria.

An analysis of the evolution of ensemble weather forecasts during the last 25 years shows that there have been improvements in the climate models and data utilized. The most prominent difference, however, is the large growth in the amount of data provided. This is reflected in an increased number of ensemble members at higher (spatial and temporal) resolutions, which are updated more frequently and provide information for longer lead times. This increase in the data that needs to be processed and analysed constitutes a challenge for forecast users. This is illustrated by the situation of the VERBUND AG, the largest hydropower company in Austria. Their operational hydrological model runs at a $1 \cdot 1$ km^2 spatial resolution, which does not allow for the operational use of the complete forecast ensemble, as driving the hydrological model with 51 ensemble members takes longer than the one-hour forecasting interval.

Several approaches are available for reducing the computational burden, i.e., reducing the number of ensemble members considered, decreasing the frequency at which the hydrological forecasts are updated, or running the hydrological model at coarser resolutions. This contribution will show the results of a study that focuses on this last alternative.

The main objectives of the study are (i) to investigate the sensitivity of the performance of an operational hydrological model to changes in the spatial resolution and (ii) to identify the factors affecting the magnitude of the spread in the model results between different spatial resolutions.

The results of the analysis show that the model with highest spatial resolution is not necessarily better and that the impact of changing the spatial resolution is more important in smaller catchments. It was further seen that the impact of changes in the spatial resolution depends on the evaluation metric considered.

The results suggest that running the model at different spatial resolutions might be an option for operational hydrology. It would be possible, for instance, to run the most probable forecast at higher spatial resolutions and the remaining forecasts in the ensemble at lower resolutions.

EXPERIMENTAL RESEARCH OF INVASIVE PLANTS (*Fallopia japonica*)

MARTINA MAJOROŠOVÁ

Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia (martina.majorosova@stuba.sk)

Invasive plants are dangerous elements for riverbank vegetation. They create massive monocultural stands that spread very aggressively and attack the original riverbank vegetation.

This work is focused on the invasive species *Fallopia japonica*, which causes a loss of biodiversity and disharmony in riverbank vegetation. This work deals with the presence of the invasive species *Fallopia japonica* (Japanese knotweed) in riverbank vegetation and is focused on comparisons of different options in the mapping of invaded stands. The behaviour of the species was monitored by using a 3D scanner, drone, and GPS locator.

The work also presents complex revitalisation steps for the invaded riverbanks. The revitalisation project consists of the following parts: project documentation, eradication of Fallopia japonica stands, revitalisation, controlling and monitoring of *Fallopia japonica* stands, and a final revitalisation.

THE DIURNAL TEMPERATURE CYCLE OF A FORESTED HILL – IS THE INFLUENCE OF THE RELATIVE HUMIDITY THE PREDOMINANT FACTOR?

KRISZTIÁN STOFA, RITA SZ. VIRÁG, BORBÁLA GÁLOS

University of Sopron, Faculty of Forestry, H-9400 Sopron, 4th Bajcsy-Zs. Street, Hungary (galos.borbala@uni-sopron.hu)

Orography can be an important climate forcing from local to regional scales. The aim of our case study was to quantify the microclimate conditions on forested hills. As a first step, the effects of the aspect of orography on the diurnal temperature cycle were analyzed on a hill close to the city of Sopron (Hungary). Mobile temperature devices were installed, i.e., three on the northern slope and three on the southern slope (one on the top and two on the bottom, respectively) of the hill.

The preliminary results in April (leafless vegetation) indicated that in the daytime, the southern slope was up to 5 °C warmer than the northern slope. In May (maximum leaf area) this difference reached 9 °C. In contrast to our expectations, the nighttime temperatures were higher on the northern slope all of the days. This effect can be partly explained by the slightly different diurnal cycle of the relative humidity. Since there is almost no difference in the altitude, the signal was the same on the top and the bottom of the slopes. To find out the exact reasons for this phenomenon, further research is essential concerning the weather patterns and the local wind conditions.

The methodology and results of this case study can provide a starting point for an assessment of the microclimate conditions and potential ecological benefits of agroforestry systems.

Acknowledgements: The research was supported by the Argoforestry (EFOP-3.6.2-16-2017-00018) project.

Keywords: microclimate, aspect, temperature, relative humidity, agroforestry systems

ESTABLISHMENT AND INVESTIGATION OF HYDROLOGICAL ASPECTS OF A "SILVO-ARABLE" AGROFORESTRY SYSTEM AT THE UNIVERSITY OF SOPRON

JUDIT SZENTESI, GÁBOR KOVÁCS, BÁLINT HEIL

University of Sopron, Faculty of Forestry, Institute of Environmental and Earth Sciences, H-9400 Sopron, Bajcsy-Zs. street 4, Hungary (heil.balint@uni-sopron.hu)

Our agroforestry research project (EFOP-3.6.2-16-2017-00018) is being carried out under the title "Let's produce together with nature – agroforestry as an opportunity for an outbreak". The first step was the establishment of a so-called "silvo-arable" system in Northern-Hungary (48°02'01.8"N, 19°12'12.6"E), where agricultural crops are grown simultaneously on 5 ha with a long-term tree crop. We are planning three types of crops (mustard, spelt wheat, sweet sorghum) to plant combined with hybrid poplar tree rows. All three plants are drought-tolerant, because their roots are well-developed and extend to deep layers they can thus adapt to arid periods on the sandy textured soil of our research site.

We are principally investigating the nutrient and hydrological cycle of this agroforestry system. The development of an applicable hydrological model and in-situ tests have been started in our collaboration with the Institute of Geomatics and Civil Engineering.

AUTOMATION EFFORTS OF INTERCEPTION MEASUREMENTS IN THE HIDEGVÍZ VALLEY, HUNGARY

PÉTER KALICZ, PÉTER CSÁKI, KATALIN A. ZAGYVAI-KISS, ZOLTÁN GRIBOVSZKI

University of Sopron, Faculty of Forestry, Institute of Geomatics and Civil Engineering, H-9400 Sopron, Bajcsy-Zs. street 4, Hungary (kalicz.peter@uni-sopron.hu)

Canopy interception plays an important role in the water cycle. This work summarizes the automation efforts of interception measurements at the Hidegvíz Valley Experimental Catchment (Sopron, Hungary). These include several years of a long time-series of throughfall and stemflow data collected in the research catchment with labor-intensive manual recording at different sites. The high spatial and temporal variability of the process suggests an increase in the sampling point numbers and time resolution of the measurements. The only possible way to fulfill this requirement is to introduce modern digital equipment.

An alder-dominated plot in a riparian zone of an agroforestry area by the Rák Brook is already equipped with a digital datalogger. Both the stemflow and throughfall are collected in large containers. The water level in those containers is registered by vented pressure transducers. The measurements give information about the temporal variability, but can not represent spatial differences. In this work we have introduced our most recent efforts in interception measurements as well as possible enhancements too.

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THE GROUNDWATER SUPPLY OF A RIPARIAN ZONE – A CASE STUDY IN THE KASZÓ FOREST (HUNGARY)

ELŐD SZŐKE[1], PÉTER CSÁKI[1], CSABA CSEKE[1], HEILIG DÁVID[2], BÁLINT HEIL[2], PÉTER KALICZ[1], GÁBOR KOVÁCS[2], KATALIN ZAGYVAINE KISS[1], LÁSZLÓ NAGY[3], KITTI SZALAI[4], LÁSZLÓ HORVÁTH[4], ZOLTÁN GRIBOVSZKI[1]

[1] University of Sopron, Faculty of Forestry, Institute of Geomatics and Civil Engineering, H-9400 Sopron, Bajcsy-Zs. Street 4, Hungary (elod0324@gmail.com)
[2] University of Sopron, Faculty of Forestry, Institute of Environmental and Earth Sciences, H-9400 Sopron, Bajcsy-Zs. Street 4, Hungary
[3] National Agricultural Research and Innovation Centre, Forest Research Institute, H-9600 Sárvár, Várkerület 30/a
[4] KASZÓ Forestry Stock Company, H-7564 Kaszó, Kaszópuszta 1., Hungary

As agroforestry systems, riparian zone forests have very important roles. As a buffer zone they protect a stream system against stress factors (both quantitatively and qualitatively). On the other hand, these ecosystems are very diverse, and the biological production of these forests is high; therefore, they are valuable from an economic viewpoint as well.

In a changing climate the drought periods can be longer and become more serious, so the state of these ecosystems with high water demands is getting worse. Water scarcity for a prolonged period will degrade ecosystems (reduction in the number of species, a decrease in productivity) or eventually result in the disappearance of these riparian forests. With reasonably designed water supply systems, unfavourable processes can be stopped, and valuable ecosystems can be preserved.

In this study we analysed the effect of the water supply for the groundwater in the case of 18 experimental plots. For the representative locations selected more detailed field monitoring was done (meteorological, soil, groundwater and phenological measurements), and a new hydrological modelling framework was developed using the Hydrus model. With this modelling system we were able to follow the effects of the water supply on the groundwater recharges for even longer time periods in a complex manner.

Acknowledgements: The research was supported by the Argoforestry (EFOP-3.6.2-16-2017-00018) project and by the LIFE12 NAT/HU/000593 titled “Restoration and conservation of alluvial forests with Alnus glutinosa and Fraxinus excelsior in the Kaszo area” within the framework of The European Union’s LIFE + programme.

SPATIALLY DISTRIBUTED EVAPOTRANSPIRATION MAPS FOR FOREST MANAGEMENT APPLICATIONS

PÉTER CSÁKI[1], KORNÉL CZIMBER[1], GÉZA KIRÁLY[1], BORBÁLA GÁLOS[2], PÉTER KALICZ[1], KATALIN ZAGYVAI-KISS[1], ZOLTÁN GRIBOVSZKI[1]

[1] Institute of Geomatics and Civil Engineering, University of Sopron, Sopron, Hungary (csaki.peter@uni-sopron.hu)
[2] Institute of Environmental and Earth Sciences, University of Sopron, Sopron, Hungary

Obtaining spatially distributed evapotranspiration (ET) estimates is crucial in water balance calculations for forests. The increasingly used remote sensing-based techniques, such as CREMAP (which uses MODIS surface temperature data), provide information about the spatial and temporal variability of ET at field and regional scales.

In forest management, the CREMAP ET with a 1000 m resolution can be used for a comparison of the water balance of forests with different land cover types (agricultural areas, artificial surfaces, etc.). Based on the CREMAP data, a climate-runoff model was previously developed. It was used to evaluate the effects of climate change on the water balance in the case of selected forest regions in Hungary. However, the 1000 m spatial resolution is too coarse to be used in precision forest management.

Therefore, the CREMAP ET was downscaled to a resolution of 250 m (considering the average size of forest compartments) with the MODIS NDVI data as a co-variable. The downscaled product was analyzed for Hungary and for the Sopron Hills, according to forest stand types.

This research was supported by the EFOP-3.6.2-16-2017-00018 in the University of Sopron project and by the ÚNKP-17-3-III New National Excellence Program of the Ministry of Human Capacities.

Keywords: evapotranspiration, water balance, forest management, MODIS

FOREST ROADS AND THEIR IMPACT ON FLOW TIME AND RUNOFF COMPONENTS

JOHANNES WESEMANN, MATHEW HERRNEGGER, JOSEF FÜRST, KARSTEN SCHULZ

Institute of Water Management, Hydrology and Hydraulic Engineering (IWHW), University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna, Austria.

Networks of forest roads influence the flow paths and flow time in small headwater catchments, mainly by altering natural (sub-surface) drainage networks and by creating artificial linear structures with high flow velocities. This leads to reduced residence times of the water within the catchment, which can further induce increased peak flows during flood events. Nevertheless, this influence remains difficult to quantify, and study results differ quite widely.

This contribution determines the impacts of forest roads for "Rosalia" ($2.2 km^2$) the small-scale experimental catchment in Austria. Here, comprehensive maps showing the temporal development of the forest road network since 1902 are available; they include the location of skid trails, gullies and culverts. Additionally, information on the forestry, climate, soils and hydrology of this watershed exists from previous studies.

Based on the flow length, which was derived from a high-resolution digital elevation model ($1\ m^2$ grid) and different surface runoff velocities, the flow time and the time-area graph are calculated for the current state and stream network. To analyse the impact of the forest roads, an undisturbed historic catchment topography has been constructed. Here, all the roads are levelled out, and the calculations are conducted in a similar manner to compare the historic and current scenarios.

The results highlight that forest roads have a relevant influence on the discharge for this small size catchment. For example, the peak discharge is higher and occurs earlier for the current status with existing forest roads. This is not primarily caused by different flow paths but by significantly higher flow velocities on the unpaved but highly sealed forest roads and compacted skid trails. Generally, it can be concluded that the integration of these linear structures in the model setup is crucial to better represent the overland flow in a catchment.

CHANGES IN THE HYDROLOGICAL BALANCE COMPONENTS IN SELECTED SUBCATCHMENTS OF SLOVAKIA AND UKRAINE

MARCEL GÁRAJ[1], PAVLA PEKÁROVÁ[1], TETIANA ZABOLOTNIA[2], LIUDMYLA GORBACHOVA[2]

[1] Institute of Hydrology, Slovak Academy of Sciences, Dúbravská cesta 9, 841 04 Bratislava (garaj@uh.savba.sk),
[2] Ukrainian Hydrometeorological Institute, Prospekt Nauki 37, 03028 Kyiv, Ukraine, (gorbachova@uhmi.org.ua)

Assessments of the impact of climate change on the runoff from the territory of Slovakia is frequently discussed (Kostka & Holko, 1996; Majerčáková et al., 2004; Szolgay et al., 2007). All climate change scenarios predict an increase in the mean annual air temperature for the territories of Slovakia and Ukraine until the year 2100. It is necessary to carefully analyse the development of particular elements of the water balance when discussing the impact of climate change on water resources. This contribution deals with an assessment of the changes in the hydrological balance in the Topľa River basin in Slovakia up to the Hanušovce nad Topľou water gauge in the period 1961/62 – 2014/15. The length of the stream is 115 km, and the area of its catchment extends 1506 km^2. The shape of the catchment is strictly longitudinal in a northerly – southerly direction with a mean altitude of 440 m a.s.l. up to the Hanušovce water gauge. The Uzh catchment up to the Uzhgorod water gauge in the Danube Basin was used for the period 1961/1962 – 200/2010. Its catchment area is 1950 km^2, and the mean elevation reaches 523 m a.s.l. up to the Uzhgorod water gauge. We obtained data from the Slovak and Ukrainian Hydro-Meteorological Institutes. Both of the areas studied contain two climate stations. We used meteorological data (precipitation [mm], air temperature [°C] and relative humidity [%]) from the Bardejov and Čaklov stations for the Topľa Basin, and the Uzhgorod, Velyky Berezhnyi stations for the Uzh River Basin. All the meteorological variables were set up for the mean elevation of the particular basins. The BILAN water balance grey box was applied to assess the share of individual runoff components in a monthly step in the Topľa and Uzh River basins. The calibrated model simulates the runoff volume according to the potential climate change scenarios for the territories of Slovakia and Ukraine. The predicted mean monthly runoff volume from both basins is the output of the model.

ANALYSING DYNAMICS IN ASCAT SOIL MOISTURE AND VEGETATION IN LOWER AUSTRIA

ISABELLA PFEIL[1,2], MARIETTE VREUGDENHIL[2], SEBASTIAN HAHN[2], WOLFGANG WAGNER[1,2], PETER STRAUSS[3], GÜNTER BLÖSCHL[1]

[1] Centre for Water Resource Systems, TU Wien, Vienna, Austria
(isabella.pfeil@geo.tuwien.ac.at, mariette.vreugdenhil@geo.tuwien.ac.at, sebastian.hahn@geo.tuwien.ac.at, wolfgang.wagner@geo.tuwien.ac.at, peter.strauss@baw.at, bloeschl@hydro.tuwien.ac.at)
[2] Department of Geodesy and Geoinformation, Faculty of Mathematics and Geoinformation, TU Wien, Vienna, Austria
[3] Institute for Land and Water Management Research, Petzenkirchen, Austria

The Metop-A ASCAT soil moisture (SM) product yields very good results in a number of validation studies. However, biases between the ASCAT and in situ SM observed during the spring and summer suggest a need for an improvement of the retrieval algorithm. The parameters related to the characterization of the vegetation have been defined globally in the algorithm. In this study, we have analysed whether adapting those parameters to regional conditions leads to improved SM and vegetation optical depth (VOD) products and investigated possible factors that explain any remaining differences between the satellite and in situ products. The study was carried out for an agricultural region in Lower Austria, which features an experimental catchment equipped with a SM network (HOAL SoilNet).

By comparing the ASCAT products to SM and VOD from the microwave radiometers AMSR2 and SMAP, we found that applying a stronger vegetation correction improves both datasets considerably. Moreover, we have shown that the seasonal dynamics of croplands and forests are reflected in the ASCAT VOD time series.

Keywords: Microwave remote sensing, advanced scatterometer (ASCAT), soil moisture, vegetation

SOIL MOISTURE SEASONAL DYNAMICS IN THE CONTEXT OF CLIMATE CHANGE RELATED TO THE SOIL RESILIENT MODULUS

ZOLTÁN GRIBOVSZKI, KORNÉL CZIMBER, PÉTER KALICZ, BALÁZS KISFALUDI, PÉTER PRIMUSZ, JÓZSEF PÉTERFALVI

University of Sopron, Faculty of Forestry, Institute of Geomatics and Civil Engineering, H-9400 Sopron, Bajcsy-Zs. street 4, Hungary (gribovszki.zoltan@uni-sopron.hu)

Climate change can modify the seasonal dynamics of soil moisture, which has an effect on the bearing capacity of roads and on road construction works. For analyzing changes in soil moisture seasonality in Hungary, a Thorntwaite-type water balance model was adapted to a geo-informatic system. From the modelling results we especially focused on the soil moisture in the spring.

On average the relative soil moisture (which represents the saturation of capillary pores) in springtime was reduced by 22%, but the heterogeneity in space increased when comparing the past (1951-81) and present (1981-2010) data. For future projections we used bias corrected data of the REMO regional climate model, which has the most valuable data for Central Europe. According to the modelling results, the future (2016-2045) soil moisture in the spring will probably further decrease by 15%, and the spatial differences will continue to increase. On the basis of these data, an average increase in the resilient modulus closely related to soil moisture is expected for the spring months in the future.

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Keywords: climate change, soil moisture, resilient modulus, Thornthwaite-type model

SPATIAL PATTERNS OF EVAPORATION IN A SMALL CATCHMENT

PATRICK HOGAN[1], JURAJ PARAJKA[1,2], MARKUS OISMÜLLER[1], PETER STRAUSS[3], GÜNTER BLÖSCHL[1,2]

[1] Centre for Water Resource Systems, TU Vienna, Karlsplatz 13, 1040 Vienna, Austria. (hogan@waterresources.at)
[2] Institute of Hydraulic Engineering and Water Resources Management, TU Vienna, Karlsplatz 13/222, 1040 Vienna, Austria.
[3] Institute for Land and Water Management Research, Federal Agency for Water Management, Pollnbergstrasse 1, 3252 Petzenkirchen, Austria.

Knowledge of the spatial variations in evaporation is important for agricultural water use and conservation at a local level and for improving estimates of regional water balances on larger scales. The measurement of evaporation remains a challenge, due to the turbulent nature of water vapour fluxes, particularly over heterogeneous surfaces. Estimating the spatial distributions of evaporation with different model approaches is also a complex process with large amounts of information needed to account for the factors that influence the rate of evaporation, e.g., net solar radiation, precipitation, vegetation and soil texture.

Using a network of eddy covariance stations, measurements of evaporation were taken at the Hydrological Open Air Laboratory (HOAL) catchment in Petzenkirchen, Austria, over 6 years. In conjunction with the meteorological and environmental data from observations and a permanent weather station, the spatial distribution of evaporation over the different land surfaces was studied and used to investigate the catchment's water balance by focusing on temporal differences in the closure of the water balance.

SEPARATION OF SCALES IN EFFECTS OF TRANSPIRATION ON LOW FLOWS IN A SMALL AGRICULTURAL CATCHMENT

BORBÁLA SZÉLES[1,2], **PATRICK HOGAN**[2], **JURAJ PARAJKA**[1,2], **GÜNTER BLÖSCHL**[1,2]

[1] Institute of Hydraulic Engineering and Water Resources Management, Faculty of Civil Engineering, Vienna University of Technology, Vienna, Austria (szeles@hydro.tuwien.ac.at, parajka@hydro.tuwien.ac.at, bloeschl@hydro.tuwien.ac.at)
[2] Centre for Water Resource Systems, Vienna University of Technology, Vienna, Austria

The main objective of this study was to understand whether spatial differences in runoff generation mechanisms observed at twelve outlet points of a 66 ha Austrian experimental catchment in the Hydrological Open Air Laboratory (HOAL) affect the magnitudes of diurnal streamflow fluctuations during low flow periods and which part of the catchment induces the diurnal fluctuations of the streamflow. The spatio-temporal variability of the streamflow fluctuations were explained by the differences in the vegetation cover, the runoff generation mechanisms, and the groundwater-surface water connectivity. Almost a quarter of the volume associated with diurnal streamflow fluctuations at the catchment outlet were explained by transpiration from vegetation along the tributaries; more than three quarters were due to transpiration by the riparian forest along the main stream. The lag times between the radiative forcing and evapotranspiration estimated by a solar radiation-driven model increased from 3 to 11 hours from the spring to the autumn. The recession time scales increased from 21 days in the spring to 54 days in the autumn. The observations and model simulations suggest that a separation of scales in the effects of transpiration on low flows exists both in time and space, i.e., the diurnal streamflow fluctuations are induced by transpiration from the riparian vegetation, while most of the catchment evapotranspiration, such as evapotranspiration from the crop fields further away from the stream, do not influence the diurnal signals in the streamflow.

Keywords: evapotranspiration, diurnal streamflow fluctuations, runoff generation mechanisms

CHARACTERISTICS OF EVENTS UNDER DIFFERENT DISCHARGE MECHANISMS IN HOAL

XIAOFEI CHEN, BORBÁLA SZÉLES, JURAJ PARAJKA, GÜNTER BLÖSCHL

Institute of Hydraulic Engineering and Water Resources Management, Vienna University of Technology

Rainfall responses under different discharge mechanisms have been thought to have various patterns of runoff coefficients (Rc) and recession time constants (tc). This research was conducted in the 65.82 ha Hydrological Open Air Laboratory (HOAL), where the flows in four kinds of discharge regimes (Wetland, Tile, Outlet, and Natural drainages) were measured continuously at 9 different locations in the period 2013 to 2015. We analyzed the discharge recessions and identified 57 events at the catchment outlet (MW) based on the method published by Merz in 2006. For purposes of comparison, events for the same periods were also identified at 7 tributaries. The Rc and tc were estimated by a single linear reservoir model. The results showed that Rc in the tile drainage discharge is higher than in other tributaries with higher peak flows in mm/h units, because underground tile pipes improve drainage conditions better. The wetland Rc is the lowest due to the high infiltration, and the natural discharge Rc on a hillslope is in the median position. Furthermore, the recession in tile drainages is apparently faster compared to the others based on the simulated tc for each event. Finally, the seasonal analysis of Rc and tc shows a lower value in the summer and a higher value in the winter, which could be explained by the low level of soil moisture in the summer.

Keywords: Rc (runoff coefficient); tc (Recession time constant); discharge mechanisms; HOAL (Hydrological Open Air Laboratory)

YEAR 2017 IN THE SLOVAK PART OF THE MORAVA RIVER BASIN WITH A FOCUS ON DROUGHT

JAKUB MÉSZÁROS[1,2]

[1] Institute of Hydrology, Slovak Academy of Sciences, Dúbravská cesta 8, 841 04 Bratislava
[2] Slovenský Hydrometeorologický Ústav, Jeséniova 17, 833 15 Bratislava
(jakub.meszaros@savba.sk)

The Slovak Hydrometeorological Institute monitored and evaluated quantitative surface water indicators for the year 2017 in a network of 416 water stations, which are divided into 11 main river basins. In this paper we will focus on the Slovak part of the Morava basin, which consists of 30 water stations. The water level, water temperature and air temperature are continuously monitored at all the stations. Twenty-seven stations measure discharges by such methods as a hydrometric propeller, an ultrasonic ADCP instrument, metering in a measuring vessel, and professional estimations. The discharges over the year are quantified using rating curves. In 2017, when compared to the reference period 1960–2000, the data showed that discharges at all the stations in the Slovak part of the Morava basin were below average, and at 77% of the stations, the average annual discharge was even less than half of the long-term average annual discharge. For our country, hydrological drought, along with floods, is a natural threat, and this contribution can help solve drought issues.

Keywords: Morava basin, discharge, hydrological drought

CHANGES IN TIME SERIES OF RUNOFF IN SLOVAKIA IN RECENT DECADES

MÁRIA ĎURIGOVÁ[1], **DOMINIKA BALLOVÁ**[2]

[1] Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia
[2] Slovak University of Technology, Faculty of Civil Engineering, Department of Mathematics and Descriptive Geometry, Bratislava, Slovakia

The Ipoltica and Boca river basins have been affected by wind calamities in recent decades that caused significant deforestation. The aim of the article is to identify changes in the discharge regime due to land use changes. The detection of changes involves a detailed analysis of hydrological data. The article focuses on an analysis of the average monthly discharges for the Čierny Váh stage-discharge gauging station on the Ipoltica River and the Malužiná stage-discharge gauging station on the Boca River. Both of them are located in central Slovakia. The Ipoltica River was measured from 1961 to 2016 and the Boca River was measured from 1970 to 2016. The approaches used in the article are hydrological exploration methods which were created by hydrologists in an attempt to describe the behaviour of time series in hydrology. Two methods have been used to identify the change point with residues and an analysis of the relationship of the mean annual flow deviations from the long-term annual flow and the deviations of the average monthly flows from the long-term average monthly flow. The change point was also detected by using a nonparametric statistical method, i.e. Pettitt's test, which was primarily developed for the change point detection of hydrological time series.

DETECTION OF CHANGES IN FLOODS IN EUROPEAN TRANSECT

ROMANA MARKOVÁ[1], SILVIA KOHNOVÁ[1], JURAJ PARAJKA[2,3]

[1] Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia (romana.markova@stuba.sk)
[2] Centre for Water Resource Systems, Vienna University of Technology, Karlsplatz 13, 1040 Vienna, Austria
[3] Institute of Hydraulic Engineering and Water Resources Management, Vienna University of Technology, Karlsplatz 13/222, 1040 Vienna, Austria

River floods belong among the most common and devastating natural disasters. Statistical methods such as trend analyses and circular statistics can shed more light on this problem. The main objective of this study was the detection of changes in floods in the European transect along the Alpine-Carpathian range. The length of the transect line is 1342 km and runs through the highest peaks. The analysis was performed for 309 gauging stations located in Slovakia (36), Austria (159), Switzerland (31), Germany (72), and Slovenia (11), which are not affected by known human modifications (e.g., dams or reservoirs); the length of the hydrological time series was 50 years from 1961 to 2010. The dataset consists of the dates of the annual maximum discharge and values of annual maximum discharges (based on the daily mean or instantaneous peak). A trend analysis was performed using the nonparametric Mann-Kendall test and Sen's slope estimator. The Mann-Kendall trend test showed significant trends (increasing or decreasing) for 43 gauging stations (36 stations with an annual maximum discharge based on the daily mean and 7 stations with an annual maximum discharge based on an instantaneous peak) at a 5% significance level and for 11 gauging stations (annual maximum discharge based on the daily mean) at a 1% significance level. Flood seasonality was determined using circular statistics (estimation of the mean dates of flood occurrences and the flood concentration index) for the whole period of 1961-2010 and also for recent decades (1961-1970, 1971-1980, 1981-1990, 1991-2000 and 2001-2010). The relationship between the physiographic and climate characteristics of the catchments and flood concentration index (r) shows that the mean elevation of a catchment (m a.s.l.) and long-term mean temperature of 1961-2010 have the most significant effect on the flood concentration index (r). The flood concentration index (r) grows with an increase in the mean catchment elevation (m a.s.l.). Flood concentration index (r) declines with an increasing long-term mean temperature (1961-2010).

Keywords: floods, circular statistics, transect

ASSESSMENT OF THE SURFACE WATER STREAM IN THE CONDITIONS OF SLOVAKIA, AND THE POSSIBILITIES MIXING DISTANCE IN THE WATER FLOW

TATIANA KIMLIČKOVÁ

Institute of Hydrology, Slovak Academy of Science (kimlickova@uh.savba.sk)

Water streams located in Slovakia and all over the world provide evidence of anthropogenic activity every day. In order to deal with these issues, there is an increasing demand for the use of water resources in the required quantity and quality. The aim is to ensure their sustainable use for future generations as well. The European Parliament and the Council have adopted Directive 2000/60/ES, which established a community framework for water policy; it was abbreviated as the Water Framework Directive (WFD), which became binding on Slovakia as well. By accepting the WFD, Slovakia agreed to protect and assess the quality of water resources. The content of this contribution is devoted to an assessment of water streams according to the rules set out in this Directive. If pollution has already entered a water body, it is necessary to know how the pollutant is being transported in the water stream. Therefore, another issue involves evaluating the ability of the water stream to mix incoming pollution, thereby reducing the concentration of the substance carried. One of the characteristics that describe this property is the longitudinal dispersion coefficient. The second part deals with determining its value. The values of this coefficient are often the key inputs of simulation models that are important tools for assessing measures to maintain or improve water quality in water streams.

MULTI-SITE CALIBRATION AND VALIDATION OF SWAT WITH SATELLITE-BASED EVAPOTRANSPIRATION IN A DATA-SPARSE CATCHMENT IN SOUTHWESTERN NIGERIA

ABOLANLE E. ODUSANYA[1], BANO MEHDI[1,2], CHRISTOPH SCHÜRZ[1], ADEBAYO O. OKE[3], OLUFIROPO S. AWOKOLA[4], JULIUS A. AWOMESO[5], JOSEPH O. ADEJUWON[5], KARSTEN SCHULZ[1]

[1] Institute of Water Management, Hydrology and Hydraulic Engineering, University of Natural Resources and Life Sciences, Vienna (BOKU), 1190 Vienna, Austria (bano.mehdi@boku.ac.at)
[2] Department of Crop Sciences, University of Natural Resources and Life Sciences, Vienna (BOKU), 3430 Tulln, Austria
[3] Institute of Agricultural Research and Training, Land and Water Resources Management Programme, Obafemi Awolowo University P.M.B 5029, Moor Plantation, Ibadan, Nigeria
[4] Department of Civil Engineering, College of Engineering, University of Agriculture, P.M.B. 2240, Abeokuta, Nigeria
[5] Department of Water Resources Management and Agrometeorology, College of Environmental Resources Management, University of Agriculture, P.M.B.2240, Abeokuta, Nigeria

The main objective of this study was to calibrate and validate the Soil and Water Assessment Tool (SWAT), an eco-hydrological model with satellite-based actual evapotranspiration (AET) data, the Global Land Evaporation Amsterdam Model (GLEAM_v3.0a), and the Moderate Resolution Imaging Spectroradiometer Global Evaporation (MOD16) for the Ogun River Basin (20 292 km^2) which is located in southwestern Nigeria. The novelty of the study is the use of freely available satellite-derived AET data for the calibration/validation of each of the SWAT-delineated subbasins, thereby obtaining a better performing model on the local scale as well as on the whole watershed level. The Sequential Uncertainty Fitting technique (SUFI-2) in the SWAT-Calibration and Uncertainty Program was used for a sensitivity analysis, model calibration, and validation, and an uncertainty analysis. Three different structures of the SWAT model were used in which each model structure was a set-up of SWAT with a different potential evapotranspiration (PET) equation. The two global AET products (GLEAM_v3.0a and MOD16) were subsequently used to calibrate the SWAT-simulated AET outputs from each model structure, thereby resulting in six calibration/validation procedures on a monthly time scale. The performance of the three SWAT model structures was evaluated for each of 53 subbasins through the six calibrations/validations, which enabled the model structure with the highest performing AET product to be chosen. The verification of the simulated AET and stream flow were carried out by: (i) comparing

the simulated AET of the calibrated model to GLEAM_v3.0b AET; this is a product that has different forcing data to the version of GLEAM used for the calibration, and (ii) comparing the simulated stream fPlow to the observed stream flow of three similar neighbouring catchments.

Overall, the SWAT model structure, which was composed of the Hargreaves PET equation and calibrated using the GLEAM_v3.0a data, performed well for the simulation of AET and provided a good level of confidence for using the SWAT model as a decision support tool. The 95% level of uncertainty of the SWAT-simulated variable bracketed most of the satellite-based AET data in each subbasin. Using neighbouring catchments provided helpful indicators to independently validate the SWAT-simulated streamflow. This study demonstrated the potential use of remotely sensed evapotranspiration data for the calibration and validation of a hydrological model in a sparsely gauged large river basin with a reasonable degree of accuracy.

THE IMPACT OF CLIMATE CHANGE ON THE RUNOFF PROCESSES IN THE MYJAVA RIVER BASIN IN SLOVAKIA

PATRIK SLEZIAK, MARTIN KUBÁŇ, JAN SZOLGAY, KAMILA HLAVČOVÁ

Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia (patrik.sleziak@stuba.sk, martin.kuban@stuba.sk, jan.szolgay@stuba.sk, kamila.hlavcova@stuba.sk)

Quantifying the impacts of climate change on runoff processes has been extensively investigated over the last few decades. However, this topic is still challenging (because of complex runoff mechanisms, etc.) for hydrologists.

This study focuses on estimating the impact of climate change on runoff processes in the Myjava River basin in Slovakia. Two climate scenarios (i.e., the Dutch KNMI and German MPI), which were regionally downscaled for the territory of Slovakia, were used. A lumped conceptual rainfall-runoff model (the TUW model) was used for the runoff simulations. This model follows the structure of the popular HBV model and is routinely used for assessments of the impact of climate change on a hydrological regime. The TUW model was calibrated for the period of 1981 – 2010. Fifty calibration runs were performed with the goal of estimating the uncertainties in the model parameters. According to two metrics (i.e., the Nash-Sutcliffe efficiency and the volume error), the best set of model parameters was chosen. This set of model parameters was used for the simulation of runoff for two 40-year periods (i.e., 2021-2060 and 2061-2100), which should adequately reflect the level of climate change in the future.

The results show that changes in the long-term flows are expected. During the winter periods, an increase in the long-term runoff could be assumed. This increase is probably related to a rise in temperature and anticipated snowmelt. Conversely, during the summer periods, a decrease in the long-term runoff could be expected. These changes are expected to be more pronounced in the period of 2061-2100 than in the period of 2021-2060.

A comparison of the long-term mean monthly runoff for the KNMI scenario in three time periods (i.e., 1981-2010, 2021-2060, and 2061-2100) indicates that the largest runoff increase will occur in March. That is also true for the MPI scenario and the periods 1981-2010 and 2021-2060. For the MPI scenario and the period of 2061-2100, the largest runoff increase will occur in April.

Our findings point to the fact that in the future, there should be greater differences in runoff between the winter and summer. From a water management point of view, this means that capturing winter flows for subsequent use in dry summer periods will become even more important in the future.

Keywords: Climate change, TUW model, Myjava River basin

LONG-TERM FLOW PREDICTIONS USING SEMI-DISTRIBUTED FLOW MODELS

KEVIN MÁTYÁS, KATALIN BENE

Department of Transport Infrastructure, Széchenyi István University, Győr, Hungary, (matyas.kevin@sze.hu)

In northwestern Hungary there was a undertaken study to review available water supplies and evolving demands. Water resource managers need more data and reliable models to help predict both supply and demand. The prediction of different flow regimes is a key factor in making such predictions; however, there are only a limited number of gauged watersheds with a small amount of data available. The selection of a dependable model to predict long-term flows at an ungauged watershed is an important step in developing a water management system for this region.

Among the 75 watersheds where long-term meteorological and flow data measurements were available, the Cuhai-Bakonyér watershed was selected for evaluating models. This watershed had the longest data set, well-described watershed characteristics, and documented watershed management changes during the last 40 years. In addition, the watershed had two measurement flow gauges. In this study three rainfall-runoff models were compared to predict the long-term flow at the outfall of the Cuhai-Bakonyér watershed.

The selected models were HEC-HMS and RS Minerve. HEC-HMS is a hydrological modelling system originating in the United States and is widely used to model catchments. RS Minerve is a software platform which allows for hydrological and hydraulic modelling in a semi-distributed conceptual scheme. The models were evaluated and compared based on the available goodness-of-fit measures, such as the Nash and Sutcliffe Efficiency, Kling-Gupta Efficiency, and different types of biases and error terms.

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Keywords: hydrological modelling, discharge, goodness-of-fit

MODELING THE EFFECT OF LAND MANAGEMENT ON RUNOFF AND EROSION PROCESSES

VIERA RATTAYOVÁ, MARIJA M. LABAT

Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia (xrattayova@stuba.sk)

The aim of this research is to reduce direct runoff by changing land uses and using agricultural measures. The research was realized in the basin of the Haluznikov Creek, which is situated in the northern part of the cadastral municipality of Vrbovce, Slovakia. The area of the basin is 9.15 km^2. The Haluznikov Creek is a tributary of the River Teplica in the eastern part of the cadastral municipality of Vrbovce. The Teplica River flows through the center of the village of Vrbovce.

The area of the basin is mostly used as arable land, even though the terrain and soil conditions are not very suitable for this type of land use. The large areas of arable land in which the soil erosion occurs due to direct runoff along with forested areas are situated in the northern part of the basin. The flow from the Haluznikov Creek forms a large part of the peak flow in the Teplica River during extreme precipitation, which means that the high peak flow from the Haluznikov Creek is one of the reasons why the flash floods in the village of Vrbovce occur. By reducing the direct runoff from this area of the basin, the rate of soil erosion in the basin and the peak flow in Teplica River will be reduced.

At first, the historical changes in the landscape and their effect on the direct runoff formation were examined. The changes in the landscape were caused by the changing socio-economic and political conditions in Slovakia. The direct runoff was calculated for the historical and present land use using the Curve Number Method. In the second part of the research, agricultural measures on arable land were designed, the purpose of which is to reduce the direct runoff and decrease the peak flow.

Keywords: Curve Number Method, peak flow, runoff

ASSESSMENT OF USING DIFFERENT NORMALIZED DIFFERENCE SNOW INDEX (NDSI) THRESHOLDS FOR DISTINGUISHING SNOW-COVERED AREAS FROM THE MODIS SNOW COVER PRODUCTS

RUI TONG, JURAJ PARAJKA, JÜRGEN KOMMA, GÜNTER BLÖSCHL

Institute of Hydraulic Engineering and Water Resources Management, Vienna University of Technology, Karlsplatz 13/222, 1040 Vienna, Austria

Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover images have great potential in hydrological modelling because of their good temporal and spatial resolutions. A terrain was detected to be either snow covered or not by the Normalized Difference Snow Index (NDSI), which was calculated by the spectral band values. However, there were quite large errors when using the theoretic NDSI threshold 0 to separate the two conditions; therefore, 0.40 was used as the NDSI threshold in past practice. In this study, snow-covered maps from MODIS C6 products, MYD10A1 (Aqua), and MOD10A1 (Terra), at 666 Austrian eHYD snow depth stations were analysed. A new NDSI threshold for defining terrains as either snow covered or not were screened and applied in the validation of the new MODIS snow cover products. The accuracies of the MODIS snow cover maps were also discussed as to their relationships with attributes of the pixels, including the land-use type, elevation, slope and aspect.

ON THE USE OF GRID-BASED DATABASES FOR R-R MODELLING

VERONIKA SOLDÁNOVÁ[1], MILAN ČISTÝ[1], FRANTIŠEK CYPRICH[1]

[1] Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia

In different climatic and hydrological regional studies, data from grid databases that cover the data of larger areas can be used. The authors of this contribution are interested in the region of Central Europe, where they can use the publicly available CarpatClim and ECA&D climatic databases and soil moisture data from the European Space Agency for such needs. The first mentioned database provides better spatial detail of the data, but the data is available only to the year 2010. On the other hand, the ECA&D database is continually updated (up to the present), but the spatial detail in which it provides data is lower.

This paper discusses the possibility of extending the time range of the CarpatClim climate data with the help of the ECA&D database to the present. The data conversion was done using regression methods that will be described in more detail in the paper. The authors also tested the usability of the Random Forest algorithm for this purpose.

The quality of such data extrapolation was evaluated by the Pearson correlation coefficient R, which is used for the most problematic and consequently least correlated climatic data, i.e., precipitation; it has an average value of 0.91. For the best-correlated data, i.e., temperatures, the degree of accuracy determined by R is higher than 0.95.

Keywords: CarpatClim, ECA&D, extrapolation of data, regression methods

3D PRINTED RAIN GAUGE FOR CITIZEN SCIENCE

PETER VALENT, ADAM BRZIAK

Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia

Accurate measurements of atmospheric precipitation play an important role in solving a large variety of water management problems. The relatively low spatial and temporal resolution of the Slovak national monitoring network puts significant constraints on its use in small-scale studies, where a high spatial and temporal resolution is a must. Until quite recently, the high cost of the commercial devices, that have to be deployed to fill in the gaps in the space and time domains was very often the main factor restricting the focus of both scientific research and commercial applications of larger scales. The first decades of the 21^{st} century brought about massive advancements in the field of low-cost electronics, sensors, and rapid prototyping techniques. Moreover, a number of open source software solutions came into existence that provide ready-to-use tools to store, analyse and transfer data. This inspired a large community of scientists and makers to build their own prototypes of measuring instruments or dataloggers, often for a fraction of the cost of the commercial devices that comply with their specific needs.

This study presents the process of the development and calibration of a low-cost rain gauge for measuring atmospheric precipitation. The prototype was designed as a two-chamber tipping-bucket rain gauge around the Arduino open-source electronics platform. The advent of 3D printing enabled the rapid prototyping of the mechanical parts of the rain gauge, which are made of a durable ABS thermoplastic material. The study also presents the process of rain gauge calibration, with both volumetric and dynamic calibration procedures used. The rain gauge was set to a resolution of 0.5 mm with a standard deviation of ± 0.01 mm. The results of the dynamic calibration also showed that the behaviour of the rain gauge complies with that of the commercial devices.

The low cost and precision of this type of instrumentation makes it ideal for applications in which there is a high risk of its being damaged or even lost. In addition, the open-source aspect of the project, its low-cost and relatively minor requirements for its construction make it a good candidate for use in citizen-science partnerships, which are becoming very popular mainly due to their popularization benefits.

Keywords: 3D print, tipping-bucket rain gauge, Arduino, open source electronics, rain gauge calibration

ANALYSIS OF FUTURE CHANGES IN SHORT-TERM RAINFALL IN SOUTHWESTERN SLOVAKIA

GABRIEL FÖLDES, SILVIA KOHNOVÁ, MARIJA M. LABAT

Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia (gabriel.foldes@stuba.sk, silvia.kohnova@stuba.sk, marija.labat@stuba.sk)

The study focuses on an analysis of future changes in the seasonality, trends and scaling exponents of short-term rainfall in the area of southwestern Slovakia located in the Danubian Lowlands. The analysis was performed for the Bratislava, Sereď and Gabčíkovo climatological stations. For all the climatological stations there were outputs from regional climate scenarios such as KNMI-RACMO2, KNMI-RACMO22E, SHMI-RCA4 and MOHC-HadRM-3Q0. The analysis was performed for the historical period of 1960-2000, the future period of 2070-2100, and the actual observed data in the period of 1995-2009. The seasonality of any extreme events was detected using Burn´s vector method. The Mann-Kendall test was used for testing the trends. The simple scaling method was used to analyze scaling exponents.

From the real observations for all the stations, the analysis shows that the seasonality of extreme events occurs at the end of July and at the beginning of August. Changes for the future in the seasonality of these events will prevail in the first two weeks of August for all the climatological stations. The results of the trend analysis from the actual observations show prevailing trends with increasing tendencies at the Bratislava and Gabčíkovo climatological stations; a decreasing trend prevails at the Sereď climatological station. In the future scenarios there is an insignificant change for the prevailing future rising trends.

In the next step of the analysis scaling exponents were derived for the return periods of 10 and 100 years. The design values of the rainfall intensities and IDF lines were estimated by these scaling exponents. The highest scaling coefficient for the Bratislava and Sereď climatological stations was set in the MOHC-HadRM-3Q0 scenario; for the Gabčíkovo climatological station, it was set in the KNMI-RACMO22E scenario. A comparison of the IDF lines shows that all the IDF lines constructed from the results of the future scenarios exceed IDF lines constructed from the actual observations. These results show an increase in the design values of short-term rainfall intensities in the future.

Due to the predominantly increasing results in the seasonality, the trends and also in the scaling exponents, there is an assumption of an increasing intensity in short-term rainfalls in the future. Re-evaluating the design values of the rainfall intensities will be necessary for designing water structures in the area.

Keywords: short-term rainfall, trend analysis, scaling, design values, RCM scenarios

RIVERBANK VEGETATION OF INVASIVE PLANTS

BARBORA VASEKOVÁ, ROMANA MARKOVÁ

Slovak University of Technology, Faculty of Civil Engineering, Department of Land and Water Resources Management, Bratislava, Slovakia (xvasekovab@stuba.sk)

A typical example of a habitat corridor and a vector is a water flow. There is a rapid transfer of nutrients along the flow. This work is focused on the flow area. The area around the rivers is considered unique because of the interaction between the water and the terrestrial environment. The specific feature of the flow area has a linear character. An inseparable part of the flow area is riverbank vegetation. After fluvial disturbances, invasive plant species colonize the vacated space. The species establish a population that threatens the native ecosystems.

Our research is focused on invasive plants in the Slovak Republic. Currently, according to the valid legislation, seven types of plant species are invasive in Slovakia. Two of them are Fallopia japonica and Impatiens glandulifera. The reason why the invasive species are so easily spread across a river is that rivers are managed in a country as a transport artery, which contributes to the rapid spread of seeds and stems. Impatiens glandulifera is reproduced generatively through seeds. Fallopia japonica is reproduced vegetatively through stems.

The presence of these species was researched at five streams. The research sites are Gidra, Blatina, Limbašský potok, Stoličný potok and Jurský potok. Due to the high anthropogenic load, their floodplains are largely degraded and are regularly affected by floods. The floodplains provide a lot of nutrients for vegetation. An important environmental factor is the occurrence of floods and the specific nature of each flood. Flood activity was reflected in the flow of the Gidra.

For the reference section, a hydraulic model was executed. The hydraulic models were used to analyze the process of a flood wave. Based on the field measurements, the precise locations of the invasive plants were identified. By collecting materials from the hydraulic model and field measurements, we determined that the vegetation had been flooded above their roots. The vegetation material floated from its original location. The plant material was transported for longer distances by flows. Subsequently, the transported material was rooted in further parts of the flow. The effect of the flow regime on the spreading of the invasive plants has been confirmed.

USE OF LAND COVER ANALYSIS FOR ESTIMATING THE WATER QUALITY IN SURFACE STREAMS

CYRIL SIMAN, YVETTA VELÍSKOVÁ

Institute of Hydrology, Slovak Academy of Sciences, Dubravska cesta 9, 841 04 Bratislava

The problem of water pollution is caused by changes in the composition of the land use within catchments as human activities increase (Gikas et al. 2006, Amiri and Nakane 2009; Boskidis et al. 2011). Thus, the quality of water in surface streams is mainly influenced by catchment characteristics. Among these characteristics, we can, for example, include the distribution of point and nonpoint sources of pollution. However, in such cases when we do not have any evidence about the sources of pollutants in river catchments, we can use indirect methods for estimating the water quality of surface streams. This method includes an analysis of the prevailing size of the land cover category in the river catchment. We assume that in a catchment in which forests and semi-natural areas prevail ("forest river basins"), the concentration of the pollution of surface streams will be lower than in catchments with prevailing areas of agricultural land ("farm or agricultural river basins").

We used data concerning the concentration of pollutants in seven water quality indicators from the Slovak Hydrometeorological Institute. We analysed land cover categories in 15 river catchments in Slovakia. Then we compared the average values of the concentration of pollution for each water quality indicator in three catchments with a predominance of forest and semi-natural land cover categories as well as three catchments with predominantly agricultural areas. We determined that in so-called forest catchments, the concentrations of pollutants in each of the water quality indicators were lower in comparison with the agricultural river basins. The highest differences were in the biochemical oxygen demand and suspended solids. On the other hand, the total phosphorus and phosphate water quality indicators showed very small differences. Our results indicated that an analysis of land cover is not enough to estimate the water quality of surface streams in river basins, but it can be used as a first estimate of the potential load of surface streams by pollution.

Key words: land cover, water quality indicators, river basin, Slovakia.

TRANSPORT AND FATE OF MICROORGANISMS IN AN ALLUVIAL GRAVEL AQUIFER

THOMAS J. OUDEGA, MARGARET E. STEVENSON, JULIA DERX, GERHARD LINDNER, ALFRED P. BLASCHKE

Institute of Hydraulic Engineering and Water Resources Management, Faculty of Civil Engineering, Vienna University of Technology, Vienna, Austria

Subsurface media are being used around the world as a means to mitigate microbial contamination, but vary widely in their ability to remove pathogens. To help provide accurate risk assessments of the microbial contamination of groundwater and establish safe setback distances between receiving waters and disposal fields, this study uses aquifer tracer tests and column tests to evaluate the ability of subsurface media to attenuate these pathogens.

The novelty of this work is the use of a variety of different tracer substances (bacteriophages, bacterial spores, microspheres, conservative tracers) together in the field experiments. This was done by means of injecting these substances under a forced gradient in an alluvial gravel aquifer in the Obere Lobau, Austria. The extraction of the tracers will be monitored in a pumping well at a distance of 30 m. This will be able to provide us with insights as to the characteristics of the microbial transport and how the microorganisms react to the subsurface in the study site. Subsequent numerical modelling of the experiments can tell us more about quantification of the subsurface processes such as the attachment/detachment, inactivation, and die-off of these substances.

These field experiments were carried out in 2017 and 2018. Additional tracer tests were performed in columns to examine subsurface processes on a smaller scale and in a more controlled manner. The results of these tests shall be presented as well as plans for subsequent tests with pathogenic indicators.