Czech University of Life Sciences Prague

Faculty of Forestry and Wood Sciences

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Diploma Thesis

The Impact of Forest Cover on Rainfall-Runoff Relation - Study in the Jevany Creek Basin

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Faculty of Forestry and Wood Sciences

DIPLOMA THESIS ASSIGNMENT

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Forestry Engineering
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The impact of forest cover on Rainfall – Runoff relation – study in the Jevany creek basin

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Objectives of thesis

The relation between rainfall events and runoff is an exceptionally complex problem. Hydrological answer of the catchments on rainfall events has been studied and it is known that it depends on a variety of factors. To start with processing of this master thesis it will be necessary to select the basin, where data exists and most of the data is collected on-line.
Reliable measurements and monitoring of stream flow during the rainfall events will be the most important factor for the successful calibration of the rainfall-runoff model as well as hydrodynamic model for stream flow (1D) of the chosen basin of the Jevany creek, right tributary of the River Sazava. The main objective of this research will be to rate the role of vegetation in the process of runoff formation. Special attention will be put on the forest coverage in the catchments. It will be necessary to describe its type e.g. monoculture or mixed forest, age of forest, species structure of forest, percent of coverage regarding the area of the catchment etc. The idea is to describe the actual situation in the catchment through measurements of the vegetation influence on the parameters of runoff and its intensity and variety in space and time. Vegetation affects the runoff directly in all processes such as interception and evapotranspiration, runoff and indirectly by infiltration, soil moisture storage and ground water flow. By getting the parameters of these actions it will be possible to make and calibrate a valid model of the experimental basin of the Jevany creek. Then, in order to conclude if this coverage is suitable for a catchment in terms of runoff, different scenarios will be made by altering the parameters, one by one, in the existing model. Main focus will be made on the impact of changes of the forest cover, which is in many countries question of today, because some of the regular forest trees species would be changed and replaced by more resistant types under situation of climate change. Even some extreme hazard events will be investigated e.g. the situation of forest calamity or wildfire in the catchment, or some slight modification in the structure of the forest as it is changing in the tree species composition (species other than those which were determined in the catchment). The results will show if it is necessary to make some changes in the approach in changes of tree species in catchments in order to improve understanding and quantify the impact of these changes of the tree species on runoff and hydrological balance in more general. This means that the results of the theses could lead to some more general guidance both in prevention of flood events, or impact on water balance in basin. At least the theses might suggest further steps in the expected directions of necessary research topics.

Methodology

1. literature review

2. Description of the basin of Jevansky creek

3. Assessment of the current monitoring systems in the Jevanský creek basin

4. Improvement of the existing modelling tools and assessing the ability of existing model for RR process description

5. Impact of changes in the forest cover on runoff, evapotranspiration processes using HD and RR models

6. Alternatives for future adaptation measures and their impacts on RR

7. Assessment of proposed changes and their impacts based on results of modelling vehicles

8. Recommendation

The proposed extent of the thesis

60

Keywords

Rainfall – Runoff, Basin hydrology, Forest cover, water balance, basic flow, HD 1D modelling

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Declaration

I declare that I have worked on my diploma thesis titled "**The Impact of Forest Cover on Rainfall-Runoff Relation-Study in the Jevany Creek Basin**" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the diploma thesis, I declare that the thesis does not break any copyrights.

In Prague on ________________________ ______________________________

Acknowledgement

I would like to thank my professor and supervisor, Ing. Evžen Zeman, CSc., for all the support and consultations. I would, also, like to thank Ing. Jan Špatka, Ph.D. from DHI Group (Danish Hydraulic Institute), who helped me understand MIKE 11 software and advised me on how to use it for my thesis.

I would like to also say thank you to my family, friends, and boyfriend who supported and encouraged me throughout all my studies.

The Impact of Forest Cover on Rainfall-Runoff Relation-Study in the Jevany Creek Basin

Abstract

Present changes in land cover caused by climate change affect the rainfall-runoff relation. Jevanský catchment is one of the areas which have been noticed to be affected by climate change. The decrease of the Norway spruce forests stands is happening all around the Czech Republic and is also present in this catchment. Apart from economical and biodiversity questions, a question regarding rainfall-runoff relation can be raised. MIKE 11 is software that allows utilization of the Unit Hydrograph Model (UHM), a rainfall-runoff model, which was calibrated for the Jevanský catchment based on historic rainfall episodes and then used for simulation of various scenarios. As a part of this thesis, 5 scenarios were designed. The first one being the current land cover of the catchment, and the other 4 representing different forest cover shares. The land use of the catchment for each scenario was represented by different CN values. All of them undergone simulations by using design precipitation data for return periods of 10, 50, and 100 years. The scenario where all current forest cover was removed showed the greatest maximum runoff values and accumulated runoff values. The runoff amount was greater for 36.29 %, 33.64 %, and 32.31 %, for 10, 50, and 100 years return periods, respectively, compared to the current land use situation in the Jevanský basin. The absence of the forest cover for this scenario also caused the fastest hydrograph peak occurrence. Broadleaved forests showed lower retention abilities than coniferous by producing greater peak values and runoff amounts. Runoff accumulation was greater (9.84-11.36 %) in the scenario where broadleaved forests were the only forest type in the catchment.

Keywords: Runoff, Jevanský creek, rainfall, land cover, coniferous forests, broadleaved forests, MIKE 11, UHM, SCS, CN

Dopad lesního pokryvu na srážko-odtokový vztah – studie v údolí Jevanského potoka

Abstrakt

Současné změny v krajinném pokryvu způsobené změnou klimatu ovlivňují srážko-odtokový vztah. Jevanské povodí je jedním z míst, na kterém byly pozorovány dopady klimatické změny. Úbytek porostu smrku ztepilého se projevuje na celé ploše České republiky a je viditelný i v tomto povodí. Kromě ekonomických otázek a otázek biodiverzity, vyvstává zde i otázka srážko-odtokového vztahu. MIKE 11 je software umožňující využití modelu jednotkového hydrogramu (UHM), tedy srážko-odtokového modelu, který byl kalibrován pro Jevanské povodí na základě historických srážek a využíván pro simulaci různých scénářů. V rámci této práce bylo vytvořeno pět scénářů. První počítá se současným krajinným pokryvem, zbývající čtyři počítají s různým zastoupením lesů. Využití půdy v povodí bylo pro každý scénář reprezentováno různými hodnotami CN. Všechny simulace využívaly připravená srážková data pro doby opakování 10, 50 a 100 let. Scénář, ve kterém byl odstraněn všechen současný pokryv, vykazoval nejvyšší hodnoty maximálního odtoku a kumulovaného odtoku. Odtok byl vyší o 36.26 % pro dobu opakování 10 let, 33.04 % pro 50 let a 32.31 % pro 100 let v porovnání se současnou situací v Jevanském údolí. Absence lesního pokryvu pro tento scénář také způsobilo nejrychlejší výkyv v hydrogramu. Listnaté lesy vykazovaly nižší zadržovací schopnost než jehličnaté, vytvářely vyšší vrcholové hodnoty a větší množství odtoku. Kumulovaný odtok byl vyšší (9.84-11.36 %) ve scénáři, kde listnaté lesy byly jediným typem lesa v povodí.

Klíčová slova: Odtok, Jevanský potok, srážky, krajinný pokryv, jehličnaté lesy, listnaté lesy, MIKE 11, UHM, SCS, CN

Table of content

List of pictures

List of tables

List of abbreviations

AD – Advection-Dispersion

AMC – Initial antecedent moisture conditions

CLC – CORINE Land Cover

CSV – Comma Separated Values

DA – Data Assimilation

DEM – Developed Elevation Model

DHI – Danish Hydraulic Institute

FF – Flood Forecasting

HD – Hydrodynamic

masl – Meters Above Sea Level

NRCS – Natural Resources Conservation Service

NST – Non-Cohesive Sediment Transport

RR – Rainfall-Runoff

SCS-CN method – Soil Conservation Service-Curve Number method

SO – Structure Operation

UHM – Unit Hydrograph Module

USGS – United States Geological Survey

VRV – Vodohospodársky rozvoj a výstavba a.s.

VÚMOP – Výzkumný ústav meliorací a ochrany půdy

WBL – Water Balance Error

1 Introduction

Water circulation is a never-ending process and it goes over and over through a couple of well-known phases. Runoff production is a part of the hydrological cycle and runoff itself represents the amount of precipitation that flows into the watercourse from the surrounding areas that make one basin. During a rainfall event, one part of the water volume falls directly to the ground; the other part can be intercepted or immediately evaporated. Intercepted water is the one caught by vegetation, which, however, can later partly drip from leaves and branches of vegetation or can flow down the branches, trunks, and stems and reach the ground with delay. Once the water from precipitation reaches the soil, ideally it will start to infiltrate. However, if the surface is made out of bare rock, or covered by concrete, or soil is already saturated by water, before the rainfall event started water will be disabled to go through the deeper soil layers and the runoff will be formed immediately (Beven, 2012).

Natural processes are complex and therefore described as time-depending, nonlinear, and determined by several factors as topographic, soil, and land use characteristics in the catchment. Land cover in the catchment is proven to be one of the main factors in the process of runoff production hence it affects the amount and velocity of runoff all the way throughout the catchment area until it reaches the watercourse. The impact is reflected so that vegetation keeps a certain amount of precipitation on its surface and absorbs part of the kinetic energy of the droplets. Apart from interception, vegetation regulates the water cycle by evapotranspiration, too. It also serves as an obstacle that slows down already formed flow. Further, the root system and undecomposed litter improve soil structure in terms of quicker infiltration and retention capacity. So, the difference in the land use, presence or absence of vegetation, and even the variance in the type of vegetation (pastures, forests, arable lands etc.) can affect runoff production noticeably. Forest is so far known as one of the vegetation types which have the greatest success in reducing and slowing down runoff. However, it is further noted that there is a difference in influence on runoff among forest types themselves.

Estimation of rainfall-runoff relation has proved itself to be of great importance for different hydrological analyses. Its significance is noticeable in the area of water resources planning, flood forecasting, pollution control, etc. For all these disciplines, gathering the values of rainfall intensity and runoff amount is a starting point that allows further planning and solving of possible practical problems in the area of interest. However, constant urbanization and different consequences of climate change pose challenges that make it necessary to think in advance and rapidly calculate the possible adjustment of the runoff production in the catchment. Given the high speed at which a variety of changes are happening, new generations of software are of great help. With software such as MIKE 11, it is possible to calibrate the model relatively easily and later calculate what changes in runoff will occur if there is a shift of land use in a given basin.

One of the hazards which is becoming an ever-greater threat in Europe with its epicenter in the Czech Republic is the European bark beetle (*Ips typographus*) (Hlásny et al., 2021). The appearance of the outbreak is evidence of a climate change trend which includes a higher frequency of climate extremes. According to a variety of studies, the end of the outbreak is not visible any time soon. It is considered that this disturbance will continue and even increase in the future (Seidl et al., 2014). Therefore, because of the bark beetle parasite, a large amount of Norway spruce forests are damaged, and thus a change in the use of the areas that this tree occupied occurred. As already mentioned, the change in land use affects the production of runoff, so the appearance of bark beetles in Norway spruce forests can gain importance as a possible cause of changes in the amount of runoff especially due to the application of clear cut silviculture system on areas of destructed trees.

So the idea of using software, such as MIKE 11, to create a model of the specific catchment and then simulate different land-use scenarios to determine the variance in the runoff, appears as a good solution that can serve as a base and indicate the potential direction for actions in situation of a worst-case scenario e.g. infection of a whole coniferous forest by bark beetles in a basin.

2 Objectives and Methodology

2.1 Objectives

The thesis' objective is to investigate how replacing of forest cover with some other land use type affects runoff production in the catchment. The main focus being on determining the share of coniferous forests in creating runoff and increasing water levels in the watercourse compared to deciduous. For this purpose, a catchment of Jevany creek was chosen as an experimental area where this kind of observation can be performed.
Aims are:

1. Calibration and validation of rainfall-runoff model of Jevanský catchment.
2. Determination of runoff differences in a situation when an area with the same geographical and climatic conditions were switched from coniferous to broadleaved forest or vice versa, as well as what consequences the complete disappearance of the forest cover can have on runoff in the same conditions.

2.2 Questions

1. How would runoff production differ in the Jevanský catchment if complete removal of forest cover happened?
2. How would runoff production differ if the catchment was predominantly afforested by broadleaved forests or coniferous forests?
3. How would runoff production differ in the catchment if a clear cut caused by infestation of European bark beetle occurred?

2.3 Methodology

Methodology in this thesis includes collecting information about the basin, gathering data on the amount of precipitation and the water level in the watercourse from several available hydrological stations, determination of the discharge, creation of rainfall-runoff model calibrating the model, and simulation of various scenarios in the calibrated model.
Part of the data was taken from available internet databases (e.g. Copernicus Land Monitoring Service; USGS Earth Explorer; Výzkumný ústav meliorací a ochrany půdy etc.) while others were adopted from previous studies done throughout the area of interest.

Further, gathered data need to be processed and visually represented. For this purpose, QGIS and ArcMap were primarily used.

MIKE 11 software is the main tool for rainfall-runoff calibration and simulation of possible scenarios. It is widely known as a modeling package for the simulation of surface runoff, flow, sediment transport, and water quality in rivers, channels, estuaries, and floodplains (Shaikh et al., 2015). It has its own specific modules for different 1D model application areas and problems such as Hydrodynamic (HD), Rainfall-Runoff (RR), Structure Operation (SO), Non-Cohesive Sediment Transport (NST), Advection-Dispersion (AD), Data Assimilation (DA), and Flood Forecasting (FF) Modules. One of the Rainfall-Runoff models is UHM (The Unit Hydrograph Module). It can simulate the runoff by the use of the well-known unit hydrograph techniques. Choosing the module in the software is done based on the availability of data and its suitability for the dictated task which it is necessary to fulfill. After choosing the module, the next step is selection of calculation methods for getting simulated data. To understand all offered methods, utilization of user guides and manuals of the software is of great help and they are available on the website of DHI (Danish Hydraulic Institute), which is the creator of the software. Besides these instructions, theory books in hydrology and hydraulics are very helpful in choosing calculating methods and preparing data for the running simulations, too.

3 Literature Review

The role of any type of vegetation within the catchment is acknowledged as an important factor in the catchment's hydrological cycle for its inevitable impact on runoff production at both local and global scales. At a larger scale, catchment land cover appears to have a second-order impact on runoff, relative to aridity, while at the smaller scale its impact on runoff can be more significant. Since it undoubtedly has participation in this process, land use has gained attention in hydrology. Its impact continues to be investigated to measure its precise effect on runoff values. Integration of this complexity into catchment models also became an interest in the last couple of years and it is an ongoing area of research. Oudin et al. (2008) used data from 1508 catchments and tried to detect if information about land use in the catchment can improve long-term stream flow estimation. At the end of their extensive research, they were able to prove that the inclusion of land cover data in model formulations can to some extent improve its results.

Depending on the distribution of the land cover, infiltration excess, saturation excess or just subsurface response can all happen in one catchment in a variety of time and space. However, it is uncommon for rainfall to exceed the infiltration capacity of the soil when surfaces are covered by vegetation unless it is already saturated, which is not the case for the bare areas where raindrop force is capable of rearranging the soil particles during which crust can be formed on its very surface. This process is called sealing and the result is that larger pores are getting being clogged and infiltration becomes very limited (Beven, 2012; Romkens et al., 1990; Smith et al., 1999). Therefore, studies whose objective is a comparison between different land-use regarding runoff production are of great importance.

There are different reasons which can cause alteration of land use. Natural disasters can be one of them. A research which comes from Slovakia noted an increase of 30% in a runoff after a severe windstorm which caused a decrease in catchments forest cover. They concluded that destruction of the forest led to a lower accumulation of water during the rainy events and its faster drainage towards a watercourse (Štefunková et al., 2019). Another study was set in Los Alamos, New Mexico, and served as an experimental area for comparing runoff production before and after a fire. The selected plot was subjected to severe fire. By the end of this hazard, almost 74% of the area was without any cover, and the other 26% was covered just by ash. On the plot which suffered from fire, runoff amounted to 46% of the total rainfall while on the unburned area it amounted to 23% of the same rainfall volume (Johansen et al., 2001).

It is noted that forests have a strong impact on hydrological landscape properties. Trees have a larger leaf area compared to other vegetation types, more effective root system regarding the water uptake, and consequently causing higher evapotranspiration rates in similar environmental conditions. Thus, they can reduce maximum runoff values by interception which makes it significant for water storage (Wattenbach et al., 2007).

It is difficult to claim with absolute certainty that runoff production is optimal with forest cover compared to other types of land cover and there are still ongoing studies on this topic. However, in many papers decrease records in runoff amounts in favor of forest cover can be found. For example, greater runoff rates are detected in the Comet River in Australia after *Acacia*, *Eucalyptus*, and softwood shrub cover deforestation. Forest cover was reduced by 45% on the area of 16440 km^2 which led to a runoff increase of 40% (Siriwardena et al., 2006). Conversion of grassland to *Eucalyptus* and *Pinus* forest, on the opposite, led to decreasing of specific runoff for 33-43%. Alteration happened between 2002 and 2008 in the Manuel Diaz basin with area of 2097 km^2 and finished with forest cover making around 30% of the basin (Silveira & Alonso, 2008). Harsch et al. (2009) compared amounts of runoff and evapotranspiration between grassland, evergreen coniferous forests, and deciduous forests. Runoff from grasslands was 53% of annual precipitation while 36% was returned to the atmosphere as water vapor. Leachate from the area covered by deciduous forest represented 37%, and evapotranspiration loss was 56% of annual precipitation. Evergreen coniferous forests had produced the smallest amount of runoff, 26%, and water that had evaporated represented 65% of annual precipitation. Gustard and Wessekink (1993) were doing calibration on the model for the Balquhidder catchments (Kirkton and Monachyle basins) in the UK. After they calibrated the model and ran simulations, their results showed that a higher rate of afforestation of the catchments would lead to reduction of the mean flow, shifting of the flow duration curve down, decreasing of annual minima series, and due to the reduction of mean annual runoff, the storage needed to maintain a given yield increased.

According to those studies, differences in the amount of runoff are not exclusively due to land use type, but they can be present within the same type. Such events, in particular, prove that forest cover's influence on runoff production varies with changes in its structure, elevation, precipitation, temperature, and latitude (Ekness & Randhir, 2015).

There are some obvious differences in the anatomy of conifers and broadleaved trees. For the majority of broadleaved trees (some can be evergreen) absence of leaves occurs during winter, which is not the case for the majority of coniferous trees (some can be deciduous). Christiansen et al. (2006; 2010) recognize this characteristic as the leading reason for the difference in the interceptive ability of trees. They stated that the increase in the groundwater level when broadleaves replace conifers is due to a lower interception rate which is dominant in the winter because of lack of leaf area and therefore evaporation from interception storage is minimal. One of the first researches regarding this topic was made by Swank & Douglass, (1974). They were investigating two experimental watersheds where a mature deciduous forest has been converted to a *Pinus strobus* stand after a clear-cut. At the end of the research, it was reported that the conversion to *Pinus strobus* had a strong influence on the annual stream flow level. The level was reduced by around 20 cm. Reductions were largest in the winter period and early growing seasons. They indicate that the presence of needles in the *Pinus strobus* stand during the winter was the reason for the stream water level reduction.

Bell et al. (1990) were observing if reforestation can significantly affect groundwater levels. They proved that the change in groundwater level was directly connected to land cover alteration. This type of research has another perspective than the one which directly tries to measure runoff, but they absolutely confirm the domination of forests considering evapotranspiration and interception. Bosch and Hewlett (1982) got results that coniferous and eucalyptus cover caused the greatest decrease in annual water yield followed by deciduous hardwood, brush, and grass cover. In addition to these studies, various researchers pointed out that conversion from conifers to broadleaves can be a good solution if there is a need for expansion of water yield of the soil in some regions (Komatsu et al., 2008). However, it was also proven that the percolation rate is higher in broadleaved forests. Percolation is the movement of fluids, in this case, water, through a porous medium (soil). The comparison was done between European beech stand with similarly aged Norway spruce stand. Norway spruce, as a representative of conifers again confirmed a higher rate of interception loss compared to European beech. Concerning that percolation was significantly greater in broadleaves than it was in conifers (Christiansen et al., 2006). Another study, for the purpose of which a larger range of species was used, also proved that coniferous stands had a lower rate of percolation than broadleaves stands (Christiansen et al., 2010).

Due to increased afforestation in Denmark, Sonnenborg et al. (2017) were interested if the decrease of agricultural areas in favor of the growth of forest cover causes a great loss in water storage of soil and lower level of stream flows in the catchments. Their investigation confirmed what is already stated by some earlier studies, forests are bigger water consumers than crops, and coniferous forests are even bigger consumers than broadleaved ones. However, the interesting thing is that the change of coniferous to broadleaved forest had different effects for both catchments. The basin with a shallower geology made mostly out of clay with limited permeability (Lejre area) had a more visible change in stream flow water level because surface runoff was more likely to form, whereas in the other basin (Skjern area) the soil was sandy and thus more permeable which caused water to go deeper down the soil profile and affect more groundwater recharge.

4 Study Area

4.1 Jevanský Catchment

Jevanský creek is located in the Prague-East District (Praha-východ), Czech Republic (Figure 1). Watercourse spring is located in Svojetice (49°58′11.4″ N, 14°44′26.5″ E). The length of Jevanský stream is 21.9 km. Creek springs at an altitude of 480 masl. Its confluence is in Stříbrná Skalice at an altitude of 284 masl (49°53′11.4″ N, 14°51′24″ E). It flows into Sázava river and falls under the North Sea basin since it is a direct tributary of Sázava river which flows into Vltava. The total area of Jevanský creek basin is 76.1 km^2. Average annual temperature of the district is 8.1 °C and total annual precipitation is 670 mm for the period of 1980-2010.

Watercourse belongs to the category of significant watercourses. It flows through 9 settlements: Svojetice, Mukařov, Louňovice, Vyžlovka, Jevany, Černé Voděrady, Konojedy, Oplany, Stríbrná Skalice. On its way, it flows through the National Nature Reserve Voděradské bučiny.

The creek has 1 tributary from the right side Zvánovický stream and 2 from the left side Bohumilský and Oplanský stream which have major influence on the watercourse. This spring is of great importance to the area because it feeds a network of water reservoirs. The precise number of ponds fed directly by Jevanský creek is 13. Their names are: Požár, Louňovický rybník, Pařez, Vyžlovský rybník, Jan, Švýcar, Jevanský rybník, Pilský, Sádky, Šáchovec, Propast, Hruškov and Nouzov. There are also some ponds on its tributaries. Zvánovický potok, right tributary of Jevanský creek, feeds the Habrovský pond. Left tributary, Bohumilský potok, feeds Šemricova pond and used to feed extinct ponds Pstruhový, Lamber and Lhotecký.

Geologically, Jevanský brook basin is located in the system of the Bohemian Massif in the Moldanubian region (Central Bohemian pluton unit) and in the area of the Upper Carboniferous and Permian (Blanice furrow unit).

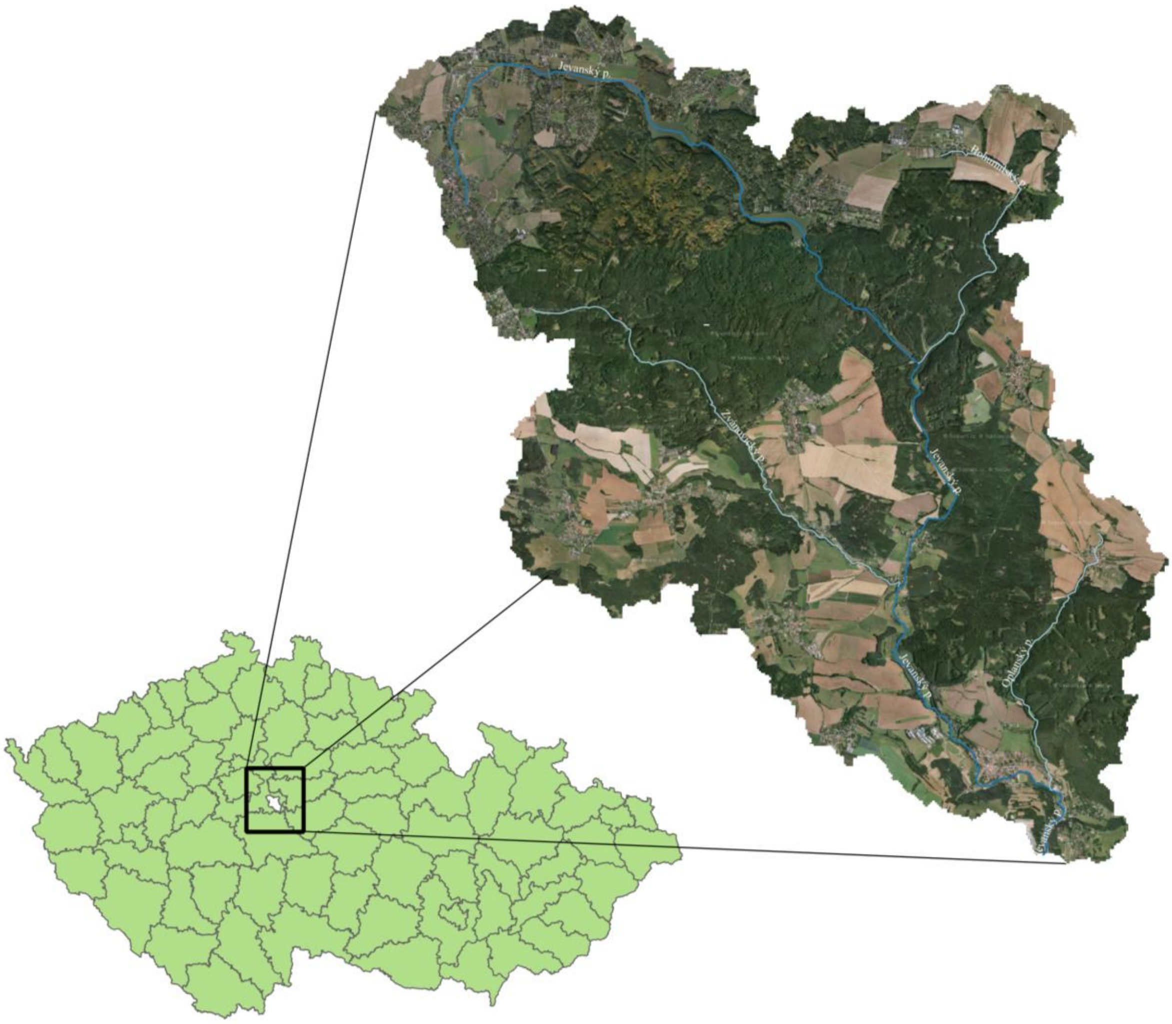


Figure 1: Jevanský basin (Source: original)

4.2 Hydrological Conditions

Jevanský basin has been affected by some significant rain events that finished with floods. The most important flood in the area occurred in 2013 and it ended up with extensive property damage. Due to that, DHI and VRV (Vodohospodárský rozvoj a výstavba a.s.) did a Study of Runoff Conditions including Possible Proposals of Flood Protection Measures in the Sázava River Basin (Studie odtokových poměrů včetně návrhů možných protipovodňových opatření v povodí Sázavy). Jevanský basin, as a part of the Sázava catchment, was the subject of this survey, too. The conclusion was that existent anti-flood measures weren't adequate for the protection of people and their property.

Jevanský creek is a watercourse that has several ponds in the upper part of the basin with a total water volume of 1298000 m^3. The average flow of the stream is Q_a=0.28 m^3/s and Q_{100}=39 m^3/s measures on the profile which goes into the Sázava river.

In some parts of the watercourse, a smaller capacity of sections is determined and even during minor flood conditions a flood could occur. The safety spillway and the drainage channel of some ponds are not in a very good technical condition. Švýcar pond, for example, has the insufficient capacity of the spillway at the flow of Q_{100} which could cause an overflow of the pond. At Q_{20} flow, the dam does not overflow by only a few cm. In Hradec settlement, the area around the bridge is considered critical because small bridges that help people approach particular buildings, affect the capacity of the stream.

4.2.1 Anthropogenic influence on the catchment

The majority of land cover is forests. However, there is inevitable anthropogenic influence that affects the watercourse and its close surrounding. The catchment is rated as mainly heterogeneous considering anthropogenic influence, where medium to high anthropogenic pressure prevails. Marks from this evaluation vary along the stream. In Srbín (Figure 2), a village that is a part of Mukařov municipality, which is nearby Jevanský creeks spring is marked with worse conditions regarding anthropogenic pressure for riverbed and especially surroundings. In this village, forest cover is almost non-existent.

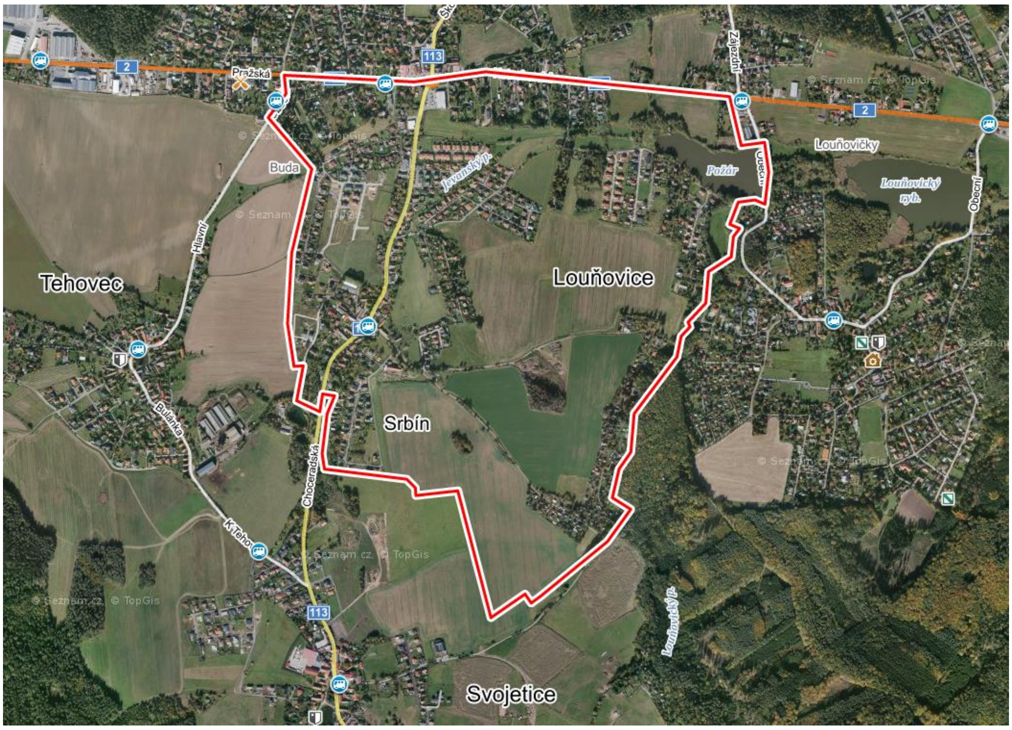


Figure 2: Srbín village indicated by red border (Source: Mapy.cz)

Part of the catchment around the ponds is marked as good and very good considering the state of the floodplain and landscape. The area is located on the surface of the Louňovice, Vyžlovka, and Jevany municipalities. However, the issue of the area is the riverbed that undergoes modification and destruction due to the formation of the reservoir system. From this zone, all down to the confluence, the riverbed has a medium value, due to different alterations done in the past. Between Jevany and Hradec settlement the landscape is mostly composed of meadows and forests which cause good hydromorphological conditions. Closer to the confluence, land cover alters to more urban, which affects both riverbed and floodplain. Therefore, conditions are mostly evaluated as a medium.

4.3 Land Cover

The surface of the Jevanský catchment can be roughly divided into four subareas based on land cover. According to Studie odtokových pomeru vcetne návrhu možných protipovodnových opatrení v povodí Sázavy 2017, there are areas under forest (53.52 %), areas under meadows (9.37 %), and arable land areas (23.39 %). The rest of the area belongs to water bodies.

4.3.1 Forest cover

Forest is a significant part of this basin (Figure 3). The determination of tree species in the catchment was done as a part of a project at the Faculty of Forestry and Wood Sciences. According to this project, it is known that the most abundant tree species in the basin is Norway spruce (*Picea abies*) which is representative of conifers. Except for *Picea abies*, *Fagus sylvatica*, *Pinus sylvestris*, *Quercus petrea*, *Larix decidua*, and *Quercus robur* can be found in greater numbers (Table 1).

Figure 3: Transition from broadleaved to coniferous forest (Source: courtesy of doc. Ing. Evžen Zeman, CSc)

Table 1: Share of different tree species in the total forest area

Tree species		Botanical group	Share [%]
SM	*Picea abies*	Conifer	48.51
BK	*Fagus silvatica*	Broadleaf	16.56
BO	*Pinus sylvestris*	Conifer	15.53
DBZ	*Quercus petrea*	Broadleaf	4.40
MD	*Larix decidua*	Conifer	4.17
DB	*Quercus robur*	Broadleaf	4.11
HB	*Carpinus betulus*	Broadleaf	1.65
JD	*Abies alba*	Conifer	1.59
OL	*Alnus glutinosa*	Broadleaf	1.31
BR	*Betula pendula*	Broadleaf	0.63
KL	*Acer pseudoplatanus*	Broadleaf	0.36
JS	*Fraxinus excelsior*	Broadleaf	0.27
DG	*Pseudotsuga menziesii*	Conifer	0.23
LP	*Tilia cordata*	Broadleaf	0.16
DBC	*Quercus rubra*	Broadleaf	0.13
OS	*Populus tremula*	Broadleaf	0.05
JV	*Acer platanoides*	Broadleaf	0.05
JDO	*Abies grandis*	Conifer	0.05
VJ	*Pinus strobus*	Conifer	0.04
JL	*Ulmus minor*	Broadleaf	0.03
OLS	*Alnus incana*	Broadleaf	0.02
SMO	*Picea omorica*	Conifer	0.02
BOC	*Pinus nigra*	Conifer	0.02
VR	*Salix alba*	Broadleaf	0.02
TPC	*Populus nigra*	Broadleaf	0.01
BKS	*Pinus banksiana*	Conifer	0.01
AK	*Robinia pseudoacacia*	Broadleaf	0.01
JLH	*Ulmus glabra*	Broadleaf	0.01
CER	*Quercus cerris*	Broadleaf	0.01
TR	*Cerasus avium*	Broadleaf	0.01
TP	*Populus alba*	Broadleaf	0.01

Forest cover on the right bank of Jevanský creek is mainly a part of the Voděradské Bučiny National Nature Reserve (Figure 4). Voděradské Bučiny is a National Nature Reserve located on the surface of 5 settlements (Černé Voděrady, Jevany, Louňovice, Vyžlovka and Struhařov). This reserve covers an area of 658 ha. The forest community is predominated by acidophilus beech forest with all its typical flora and fauna. Apart from beech, other species can be found. Along the streams, alder communities are formed. Similar stands are established on waterlogged localities, where alder stands are followed by remote sedge (*Carex remota*). Natural spruce stands are also present in the area. These stands are located in the valleys. Mixtures of fir, Sycamore, and Norway maple with spruce are recorded, too. Ravine maple is mostly inhabited on steeper slopes. Some of the herbs in maple stands are goatsbeard (*Aruncus vulgaris*) and mustard garlic (*Alliaria officinalis*). However, acidophilus beech forest dominates throughout the reserve. Typical plant species that come with beech are wavy hair-grass (*Avenella flexuosa*), white wood-rush (*Luzula luzuloides*), and few-leaved hawkweed (*Hieracium murorum*). Beech forests which are otherwise known as herb-rich are less present. They have greater biodiversity with additional nine-leaved toothwort (*Dentaria enneaphyllos*), coralroot (*Dentaria bulbifera*), woodruff (*Gallium odoratum*), dog's mercury (*Mercurialis perennis*), mezereon (*Daphne mezereum*), etc. (Bernate Pena, 2012).

Forest management in the area was changing in the past. Cutting and replacing of autochthonous fir was done by consecutive reforestation of Norway spruce at the end of the 19th century. Later, at the beginning of the 20th century, clear-felling was abandoned. Reforestation became mostly done by shelterwood felling and border felling. Voděradské Bučiny National Nature Reserve was officially created in 1955. Back then, the reserve was divided into two parts, with and without any forest management for nearly 20 years. Although this arrangement was abandoned in 1971, close to nature forest management continued up to this date. This approach certainly led to the formation of a more natural and heterogeneous stand structure in the reserve (Bílek, 2009).

4.3.1.1 European bark beetle outbreak

The European bark beetle is recorded on terrains across the Jevansky basin. The outbreaks demanded human actions and therefore the clear-cut was applied on those plots.

Ips typographus has not been identified only in the mountain areas of the Czech Republic yet, everywhere else in the country there is clear evidence of its action (Hlásny et al., 2021). According to Hlásny et al. (2021), Praha-východ district, where Jevansky basin is located, was classified as moderately affected by bark beetle in the period 2017-2019. However, they also stated that, due to climate change, this issue will probably increase in the years to come.

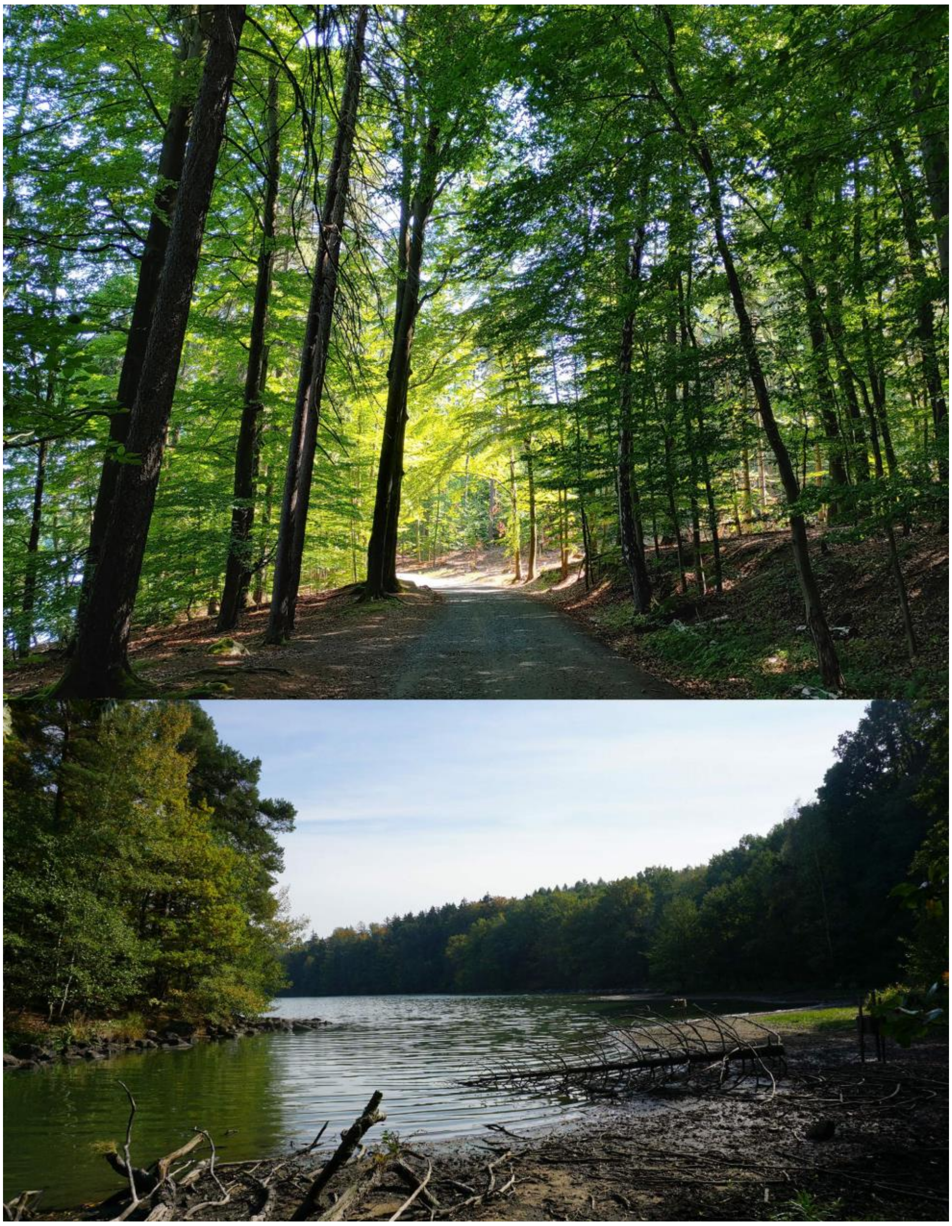


Figure 4: Voděradské Bučiny National Nature Reserve
(Source: https://kacabipohorky.cz/post/voderadske-buciny)

5 Theoretical Background

5.1 MIKE 11

MIKE 11 represents a tool for 1D river and channel modelling made by DHI (Danish Hydraulic Institute). DHI offers several models within the MIKE 11 package. Models which are provided within it are Hydrodynamic (HD), Advection-Dispersion (AD), Sediment Transport (ST), MIKE ECO Lab (Including Water Quality modelling), Rainfall-Runoff (RR), Flood Forecasting (FF), Data Assimilation (DA), and River Ice modelling (Ice). Some of the models are independent in a simulation and, for it to be run, don't need to be related to any other model. On the contrary, some of them require one or more other models for that to be possible.
UHM (Unit Hydrograph Module) is one of the Rainfall-Runoff modules, from MIKE 11 package, ant it was used for this thesis.

5.1.1 Unit hydrograph module

Unit Hydrograph Module is suitable for runoff evaluation from a single storm event.
According to User Guide made by DHI:
"It is made to separate storm rainfall into excess rainfall (runoff) and water loss (infiltration)."
Depending on input data, several methods can be chosen in the module frame. For rainfall excess calculation, a choice between four models can be made. Offered models are the constant loss model, proportional loss model, the SCS loss model and SCS generalized loss model. Unit hydrograph methods are applied for the routing of the rainfall excess and accordingly, the module offers SCS dimensionless hydrograph, SCS triangular hydrograph, or the possibility of defining the hydrograph by the user. And for the evaluation of the lag time, if it is not defined by the user, then the curve number method can be taken (DHI, 2017).

5.1.2 The SCS generalised loss model

Generalised loss model is based on the SCS loss model. The only difference between these two models is that generalised SCS loss model doesn't rely on utilization of initial antecedent moisture content (AMC), but encompasses general antecedent storage depth.

The essence of the SCS method is to transform total rainfall to effective. The transformation depends on the type of soil and land use, among other factors. Therefore, the value of the hydrological complex of the catchment is equal to the ability of the basin to transform precipitation to runoff. The method requires two input parameters, curve number (CN), and initial abstraction depth [m]. Dimensionless curve number (CN) is in direct correlation with the type of land use and hydrological group of soil. Unlike standard SCS method where CN changes in simulation depend on value of AMC, CN value in this model is not changed during simulation.

The main hypothesis of SCS method is:

$$\frac{F_a}{S} = \frac{P_e}{P - I_a} \tag{1}$$

The amount of effective rainfall (P_e) can be equal to or lower than total precipitation (P). Likewise, the portion of retained water (F_a) is equal or lower than the maximum potential retention of the soil (S) in the catchment after the runoff begins (Figure 5). Due to interception and transpiration, there is an initial loss (I_a) of precipitation before it reaches the ground and therefore potential runoff is represented by P-I_a (DHI, 2017).

Total amount of rainfall is represented by the following equation:

$$P = P_e + I_a + F_a \tag{2}$$

The main difference between the standard SCS method and the generalized one is that initial abstraction depth (I_a) is defined directly as an input parameter into the model. However, within the standard SCS, the initial loss is calculated via the Eq. (3) which is derived due to observations and defines the correlation between maximal potential saturation of the soil and retained amount of rainfall:

$$I_a = 0.2 \cdot S \tag{3}$$

Combining Eq. (1) and (2), Eq. (4) for the effective rainfall is derived:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{4}$$

In order to get the potential maximum retention. an empirical equation is derived based on extensive observations:

$$S = \left(\frac{1000}{CN} - 10\right) \cdot 25.4 \tag{5}$$

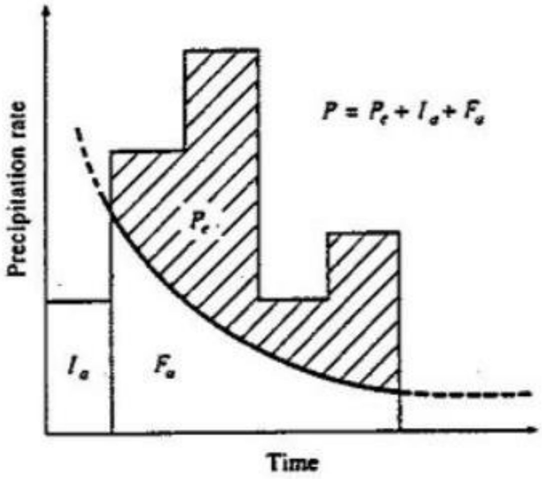


Figure 5: Variables in the SCS method of rainfall abstraction
(Source: DHI, 2017)

5.1.3 The SCS unit hydrograph

A unit hydrograph provides assumption of the excess rainfall and it is unique for every catchment because of its specific properties. However, to encompassed hydrographs within a model, synthetic hydrographs based on empirical data needed to be created. One of them is the SCS dimensionless hydrograph. It was built empirically, based on a large number of distinctive real unit hydrographs (DHI, 2017).

The hydrograph is defined by two rainfall characteristics: duration of the unit rainfall (t_r) and lag time (t_l). Lag time represents difference between the middle point of the unit rainfall event and the runoff peak. Therefore, the time to peak (T_p) is defined Eq. (6).

$$T_p = \frac{t_r}{2} + t_l \tag{6}$$

To calculate T_p in the model, it is required to evaluate lag time as a parameter. If it is not defined by the user, lag time is calculated by Eq. (7), and thus topographical data that describe catchment are necessary. CN value, which is used for getting the effective rainfall, is also applied in this equation together with the hydraulic length of the catchment (L) and average catchment slope (Y).

$$t_l = \left(L \cdot 3.28 \cdot 10^3\right)^{0.8} \cdot \frac{\left(\frac{1000}{CN} - 9\right)^{0.7}}{\left(1900 \cdot Y^{0.5}\right)} \tag{7}$$

5.2 SCS Method Adjustments

SCS method is one of the most widely known methods for evaluating surface runoff. It was established back in 1972 by U.S. Soil Conservation Service (these days known as Natural Resources Conservation Service). However, even though it was created 50 years ago, it is still going through some adjustments to make it more flexible and precise for a variety of conditions. One of the possible steps for achieving this goal is the adjustment of CN value.

Hong & Adler (2008) adjusted CN values mostly by using remotely sensed imagery. Their work took into consideration all parameters which were dictated by the traditional method and updated CN values to correspond to recent soil properties, land cover, and topographical data. They were guided by the statement that land cover and soil properties are of much greater importance and, thus, the final product of their effort was a global map and a table with CN values under the fair hydrological conditions (Table 2) which was derived from it.

Table 2: Adjusted CN values for particular land cover types for fair hydrological conditions (Source: Hong & Adler, 2008)

MODIS land cover classification		CN for different HSG (ABCD)				Hydrological condition (poor/fair/good)
ID	Content	A	B	C	D	
0	Water bodies	N/A	N/A	N/A	N/A	N/A
1	Evergreen needles	34	60	73	79	Fair
2	Evergreen broadleaf	30	58	71	77	Fair
3	Deciduous needle leaf	40	64	77	83	Fair
4	Deciduous broadleaf	42	66	79	85	Fair
5	Mixed forests	38	62	75	81	Fair
6	Closed shrublands	45	65	75	80	Fair
7	Open shrublands	49	69	79	84	Fair
8	Woody savannas	61	71	81	89	Fair
9	Savannas	72	80	87	93	Fair
10	Grasslands	49	69	79	84	Fair
11	Permanent wetlands	30	58	71	78	Fair
12	Croplands	67	78	85	89	Fair
13	Urban and built-up	80	85	90	95	Fair
14	Cropland/natural vegetation mosaic	52	69	79	84	Fair
15	Permanent snow and ice	N/A	N/A	N/A	N/A	N/A
16	Barren or sparsely vegetated	72	82	83	87	Fair
17	Missing data	N/A	N/A	N/A	N/A	N/A

Modified from USDA (1986) and NEH-4 (1997) lookup tables.

5.3 Model Performance

Every model simulation has to undergo some statistical analysis to make the model applicable for runoff assessment for periods other than one chosen for the calibration.

Simulation of the UHM model is described by the coefficient of determination (R^2) Eq (8) and water balance error (%WBL) Eq (9). Values of R^2 and WBL values are calculated based on O_i and P_i, which are observed and simulated values, respectively. $\bar{O}$ is the mean observed value and n represents the number of samples. The coefficient shows how the simulated results fit the observed one and, therefore, the rate of model ability to predict future outcomes (Teshome et al., 2020).

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \tag{8}$$

$$\%WBL = \frac{\sum_{i=1}^{n} P_i - \sum_{i=1}^{n} O_i}{\sum_{i=1}^{n} O_i} * 100 \tag{9}$$

6 Methodology

6.1 Rainfall and Discharge Data

Calibration of a rainfall-runoff model requires a record of a rainfall event. During a rainfall event, information about rainfall intensity and discharge of the watercourse is essential.

Distribution of precipitation in time was collected from 4 stations by taking them directly as comma-separated value files (CSV) from the available website database. Discharge data, however, hasn't been available directly. Due to this, the distribution of water depth in the river bed was gathered as CSV and afterward converted into discharge by use of rating curves derived from stream monitoring in the past.

Measurements of the rain gauges and reporting profiles, which were located within the Jevanský basin and its close surroundings, were available on the FIEDLER AMS s.r.o website and Povodňový systém Města Říčany website (Figure 6).

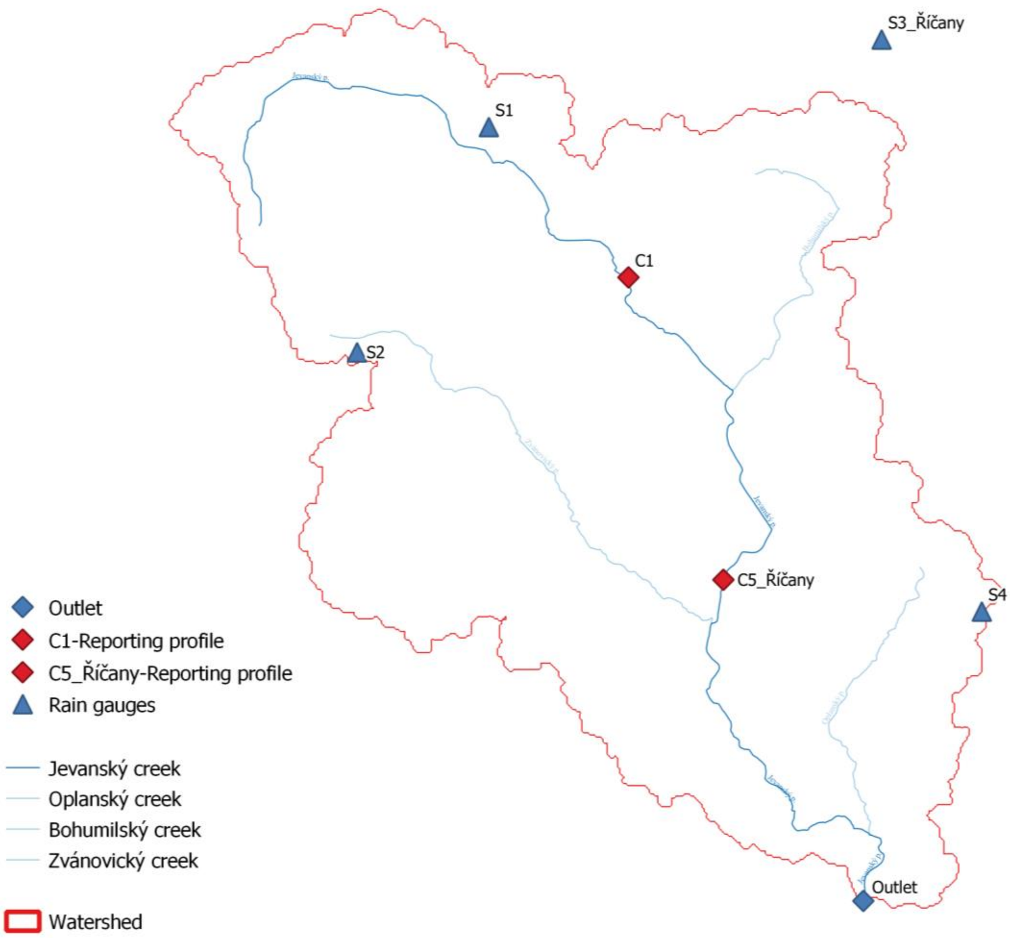


Figure 6: The arrangement of rain gauges and reporting profiles in the area of interest (Source: original)

6.1.1 Rain gauges and reporting profiles

One of the water level data sources is the C1 reporting profile, which is set by FIEDLER AMS s.r.o. The profile is used for monitoring of water level, transferring the data into the server database, and enabling the provision of actual graphs and CSV files which are available via web viewer or cell phones. Rainfall distribution data were gathered from the rain gauges. Reporting profile and rain gauges are placed in the catchment based on the Implementation of Water and Rain Gauge Stations for the Village of Stříbrná Skalice project. Their locations are chosen regarding long-term experience with floods. The project aimed to design and set up a flood local warning system. Rain gauges that provided data required for the thesis in the local warning network of Stříbrná Skalice are S1, S2, and S4.

Figure 7: Reporting profile (C1) at Pilský rybník (Source: original)

Water level gauge station C1 is located at a critical point, downstream of the Jevanský pond with volume 453000 m^3, in Jevany village, at the Jevany bridge, nearby Pilský rybník (Figure 7). The S1 rain gauge is set in the Vyžlovka wastewater treatment plant. The S2 rain gauge is placed in Struhařov, on the land of the gamekeeper's lodge. The S4 rain gauge is located on the site of the gamekeeper's lodge in Oplany, on Oplanský brook, which is the left tributary of the Jevanský creek in the lower part of the village Stříbrná Skalice.

The reporting profiles and rain gauges that are a part of the Local Warning System Říčany, can also be found in the area of interest. Data from these stations were available via Povodňový systém Města Říčany website. Water level data was gathered from the C5_Říčany reporting profile (Figure 8), which is located on the Jevanský stream, upstream from the Propast pond. The S3_Říčany rain gauge, though it’s not within the Jevanský watershed, is considered close enough for it to influence catchments runoff response. It was installed on the roof of the Primary School in Kostelec nad Černými Lesy.

Figure 8: Reporting profile (C5_ Říčany) at Hradec bridge (Source: original)

6.1.2 Watershed delineation

Delineation of the Jevanský catchment (Figure 9) was done in QGIS 3.16 software based on the Developed Elevation Model (DEM) that was taken from U.S. Geological Survey (USGS). Division into subcatchments is usually done to achieve a greater precision, since the conditions of one watershed are not unanimous. Furthermore, delineating two subcatchments was possible based on the reporting profiles C1 and C5_Říčany, which were taken for outlets of the subcatchments. The rest of the catchment was observed as a third subcatchment (Table 3).

Table 3: Division of subcatchments within Jevanský catchment

Subcatchments	Area [km²]	Share [%]
C1	19.65	25.80
C5_ Říčany	19.80	26.00
C4	36.71	48.20
Total	76.17	100.00

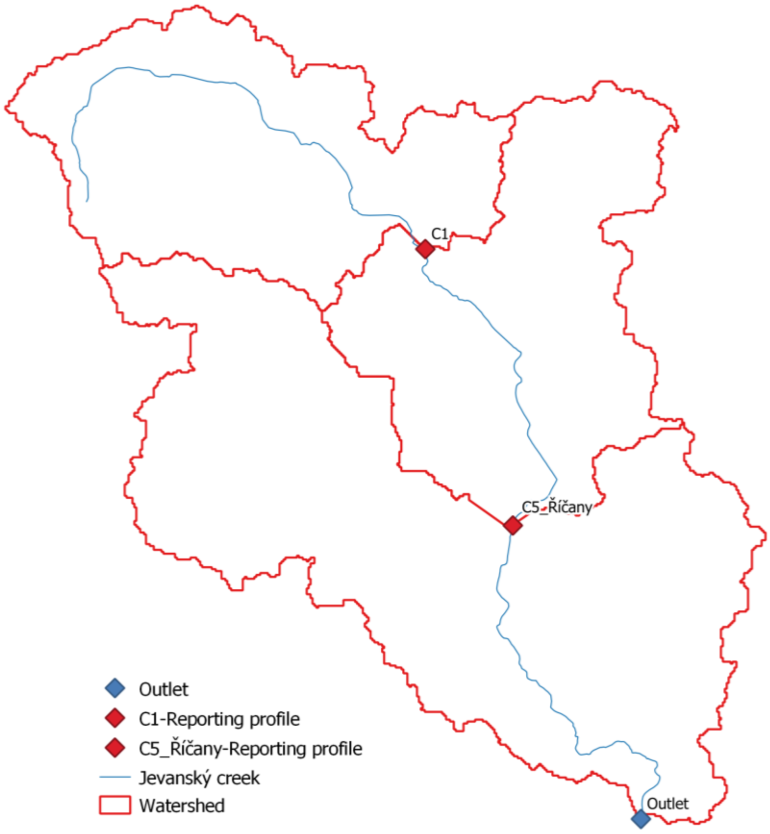


Figure 9: Subcatchments of Jevanský catchment (Source: original)

6.1.3 Rain gauges influence (Thiessen polygon method)

Rain intensity data collected from 4 rain gauges required determining the range of each of the stations (Figure 10) and thus determining the impact of each of the rain gauges on the basin itself. One of the methods is the Thiessen polygon method, where the output is the share of the stations in the catchment area (Table 4).

Table 4: Rain gauge influence for every subcatchment in percent

Subcatchment	Rain gauge	Share [%]
C1	S1	74.00
	S2	25.00
	S3_Říčany	1.00
C5_Říčany	S1	17.00
	S2	18.00
	S3_Říčany	31.00
	S4	34.00
C4	S2	44.00
	S4	56.00

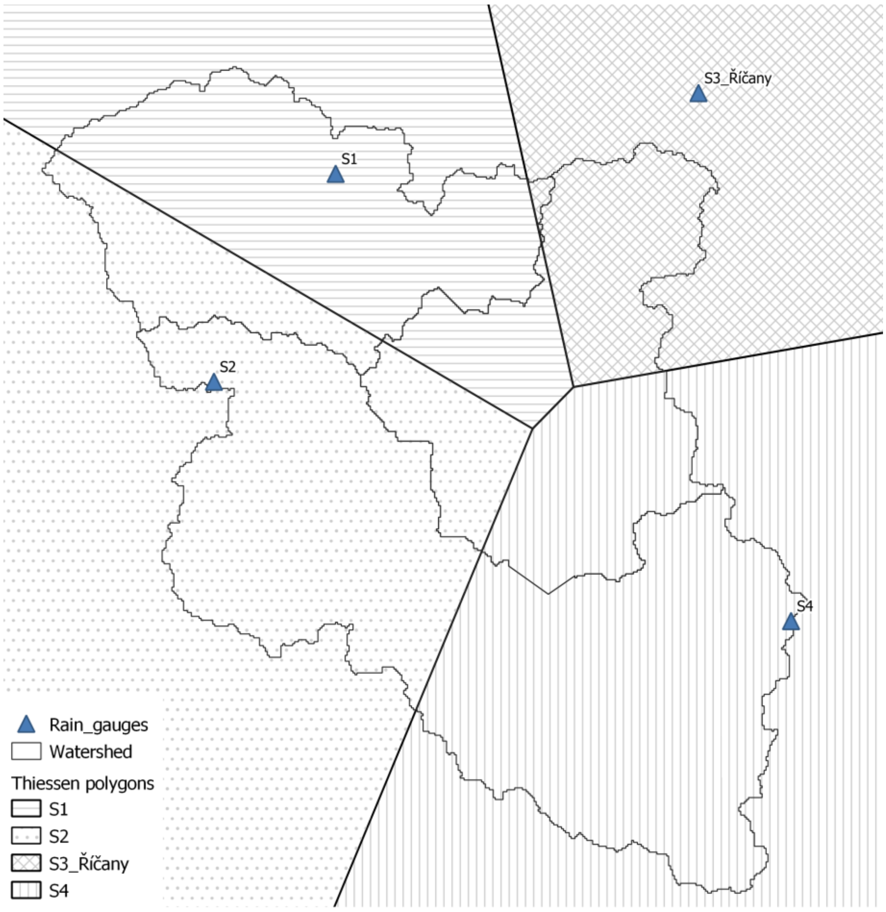


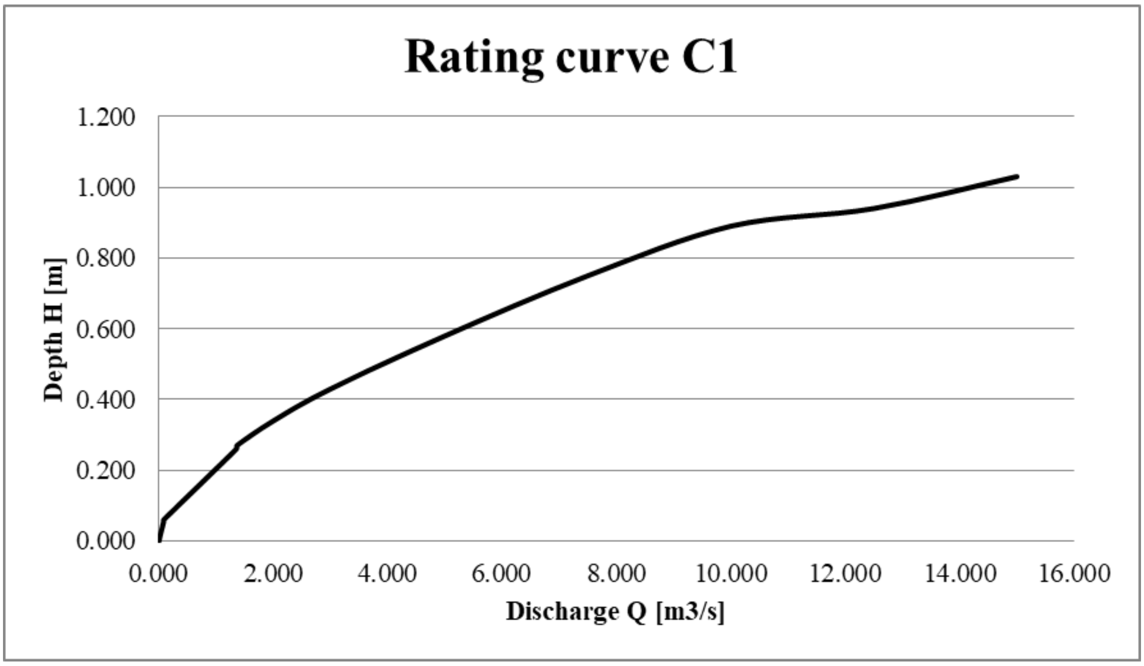
Figure 10: Rain gauge share of influence in the area of interests (Source: original)

6.1.4 Rating curves

Rating curves represent the relationship between the depth of the watercourse (H) and the discharge (Q) that corresponds with that depth. The measurements (Table 5 & 6) and derived rating curves (Graph 1 & 2) were accepted from previous monitoring of the water levels and discharges for C1 and C5_Říčany reporting profiles. Dependency between these two parameters was later defined in the form of polynomial trendline of 4^{th} and 3^{rd} degrees. Analysis of the results was done having the best fit of the trendline in mind. For the C1 measuring point, the function of the 4^{th} degree was adopted Eq. (10), and, for the C5_Říčany that was 3^{rd} degree polynomial Eq. (11). Recorded water depth from the chosen rainfall events for model calibration, therefore, could be transferred to discharge by utilization of the derived equations.

Table 5: Values of observed water levels and discharge

H	Q
[m]	[m^3/s]
0.000	0.000
0.010	0.011
0.055	0.079
0.060	0.079
0.260	1.350
0.270	1.360
0.340	2.000
0.430	3.000
0.580	5.000
0.750	7.500
0.890	10.000
0.940	12.500
1.030	15.000

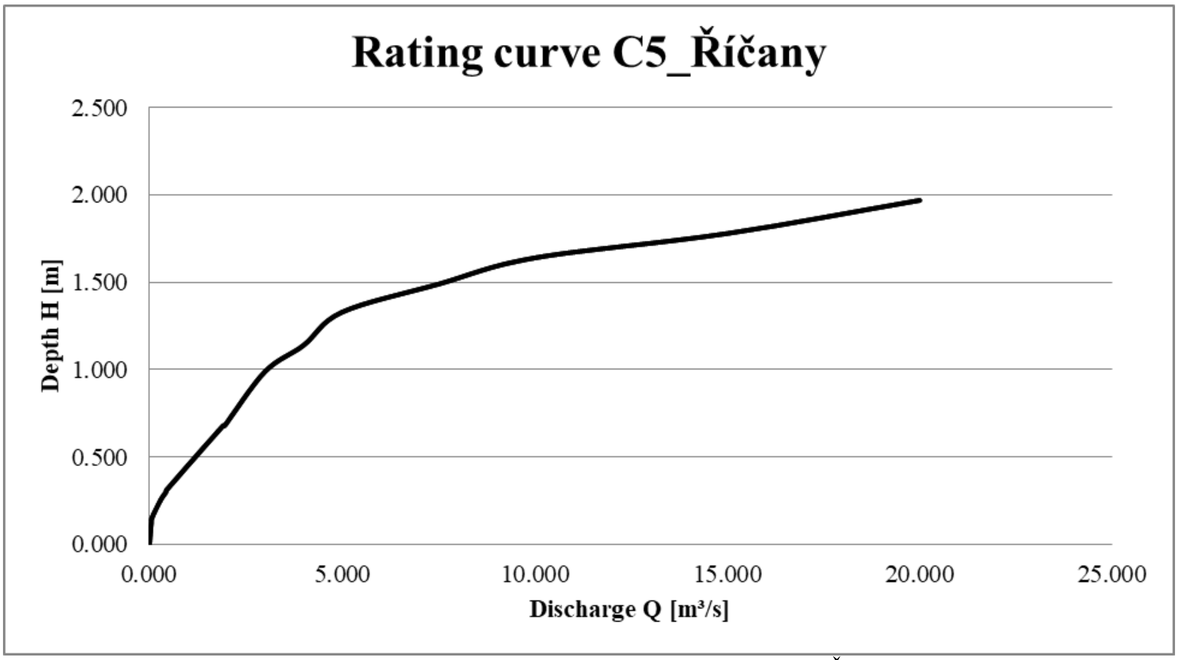


Graph 1: Rating curve for the reporting profile C1

$$Q = - 925.47 \cdot H^4 + 382.4 \cdot H^3 - 23.143 \cdot H^3 + 1.6297 \cdot H - 0.0013 \quad (10)$$

Table 6: Values of observed water levels and discharge

H	Q
[m]	[m³/s]
0.000	0.000
0.130	0.046
0.150	0.056
0.255	0.287
0.300	0.427
0.310	0.434
0.680	1.910
0.680	1.950
0.990	3.000
1.140	4.000
1.330	5.000
1.490	7.500
1.640	10.000
1.780	15.000
1.970	20.000



Graph 2: Rating curve for the reporting profile C5_ Říčany

$$Q = - 5.4001 \cdot H^3 + 9.2258 \cdot H^2 + 0.9696 \cdot H - 0.0212 \qquad (11)$$

6.2 CN Parameters

6.2.1 Hydrological groups of soil1

In order to get the CN value for every type of land cover, it was necessary to detect which hydrological group the soil in the basin belongs to. For this purpose, Hydrologická skupina půd raster map (2018) from the Výzkumný ústav meliorací a ochrany půdy (VÚMOP) data base was obtained. Within this map, there are four main types of hydrological groups of soil (A, B, C, and D) and two subgroups (B/D and C/D). Determination of exact hydrological groups for the area of interest was done by vectorization of the raster map in ArcMap software (Figure 11).

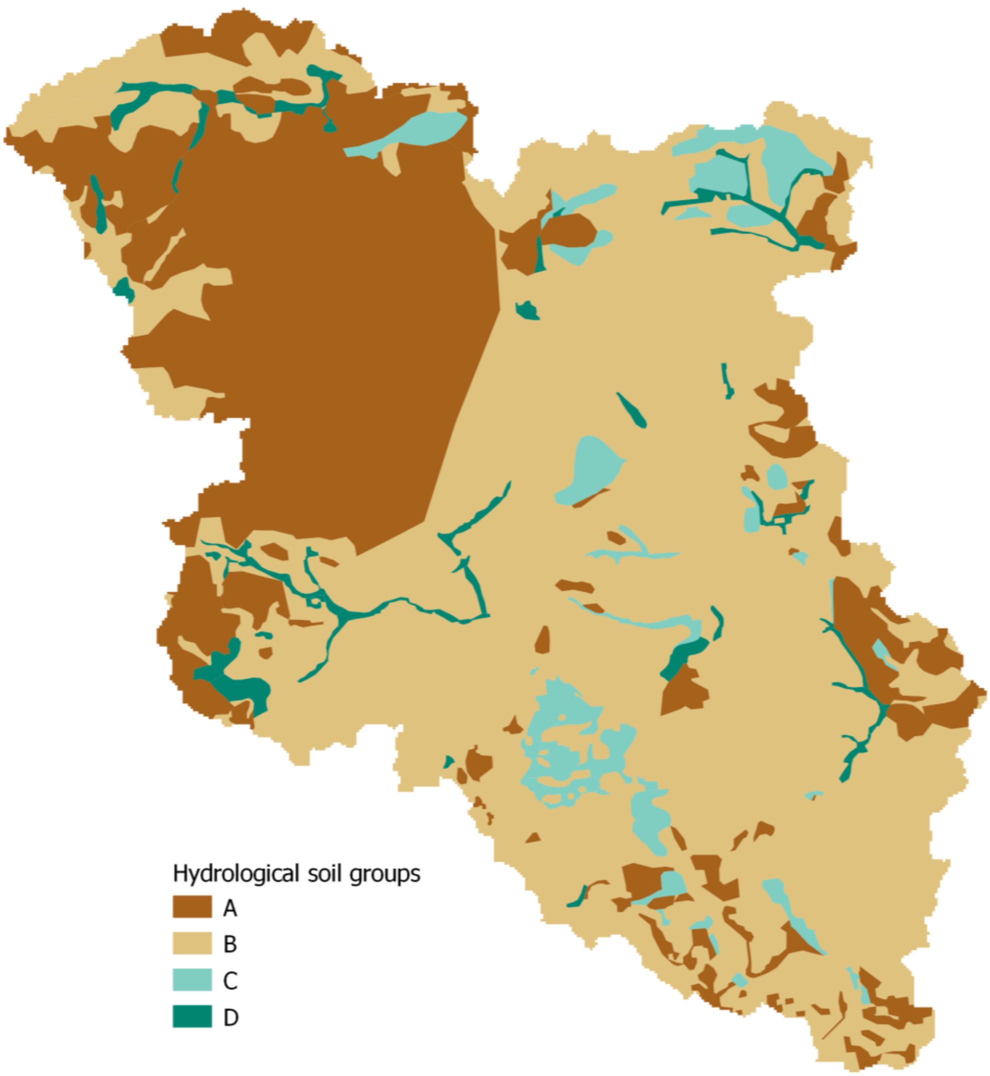


Figure 11: Visual representation of hydrological groups across Jevansky basin (Source: original)

Division of soils into hydrologic groups was done mostly based on its permeability rate which correlated to the ability to produce runoff on its surface. According to VÚMOP classification the main features of every group are:

- Group A: Soil has a high infiltration rate (>0.20 mm/min) and thus a low contribution for runoff production. It has a deep profile and is mostly made out of sand and gravel.
- Group B: Soil has a medium infiltration rate (0.10-0.2 mm/min). Medium depth of the soil profile. Made out of sandy clay and silty clay. Medium to well-drained soil.
- Group C: Soil with a low infiltration rate (0.05-0.10 mm/min). Made out of silty clay and clay with low permeability layers.
- Group D: Soil with a very low infiltration rate (<0.05 mm/min). Soil made mostly out of clay, or with high groundwater level, or soil with clay layer on or just below the surface, or shallow soils set on almost impermeable subsoil.

Classification done by VÚMOP corresponds to the one made by the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS, 2009), therefore, the data obtained from its database was used in the process of evaluation of CN value for the Jevanský catchment.

6.2.2 CORINE Land Cover

The source of land cover for the area of interest was CORINE Land Cover (CLC) base. ESRI Geodatabase (v2020_20u1), which contained polygons for every type of land cover within the whole area of Europe, was downloaded from the website. In order to obtain polygons just for the area of interest, an intersection of already made watershed and obtained land cover of Europe was executed (Figure 12). Forest cover represents 52.16 % of the total basin (Table 7).

Table 7: Share of the land cover types in the Jevanský catchment

Land cover type	Area [m²]	Share [%]
Broadleaved forest	3431370.78	4.51
Coniferous forest	25068318.30	32.92
Mixed forest	11221721.70	14.73
Discontinuous urban fabric	6490047.28	8.52
Industrial or commercial units and public facilities	243841.87	0.32
Land principally occupied by agriculture, with significant areas of natural vegetation	4866731.23	6.39
Complex cultivation patterns	249634.79	0.33
Non-irrigated arable land	18692261.05	24.54
Pastures, meadows and other permanent grasslands under agricultural use	3768766.93	4.95
Sport and leisure facilities	476404.88	0.63
Transitional woodland/shrub	1097018.43	1.44
Water bodies	553882.76	0.73

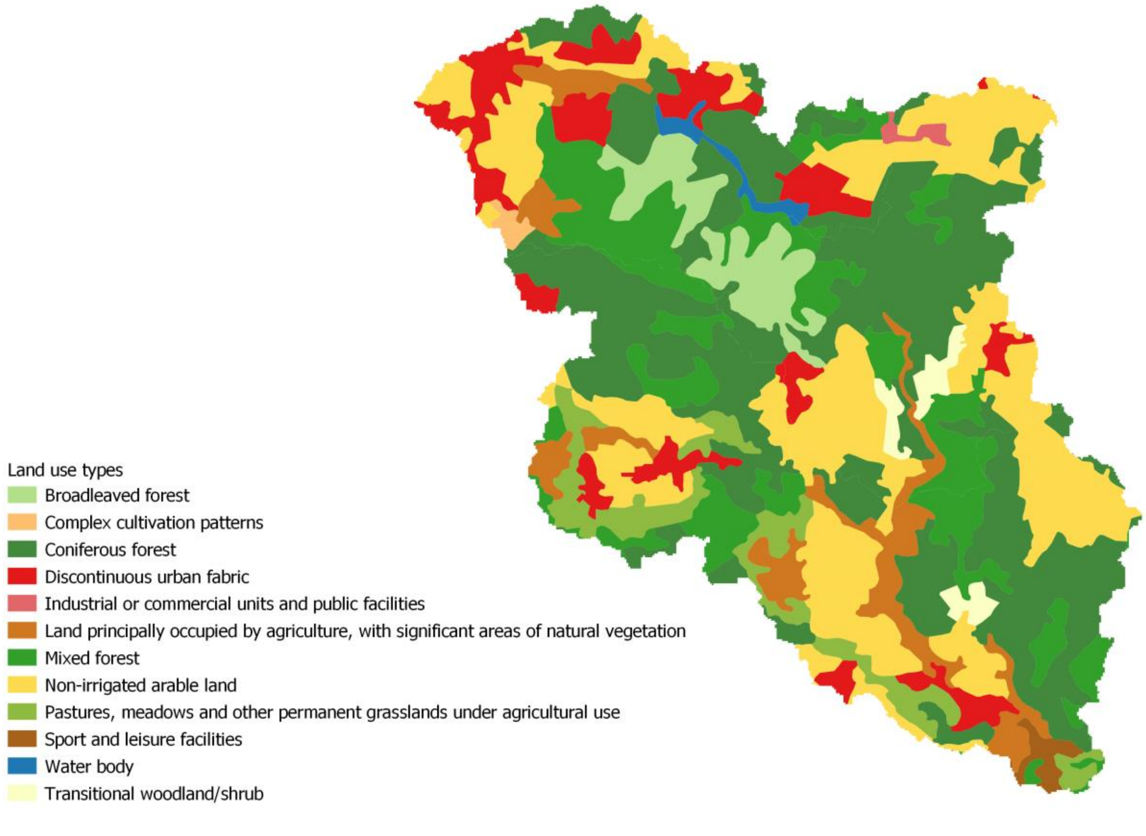


Figure 12: Land use types of Jevanský catchment (Source: original)

6.2.3 Average CN values

Considering one of the thesis aims, which was to detect differences in the runoff regarding the change in coniferous or broadleaved forest cover, the challenge was to find unique values for forest types. It was clear that standard CN values, which were representing all forest types with one value, weren't acceptable because they don't reflect the influence of a particular forest type. Therefore, CN values, which Hong & Adler (2008) derived from their analyses, were taken for the model calibration.

$$CN_n = \frac{\sum(CN_p \cdot A_p)}{\sum_{i=1}^{n} A_p} \tag{12}$$

Based on spatial data of hydrological soil type and land cover type calculation of average CN for every subcatchment could be evaluated. Taking the area (A_p) of every land cover category, the hydrological characteristics of the soil on which a particular type is located, and CN (CN_p) value for every possible combination of these two into account, average CN (CN_n) value was assigned for every land use Eq. (12) within the scale of subcatchment. Afterwards, in the same manner, relying on average CN value of every land use type in the subcatchment, and the area value, which a certain type occupies, the representative CN value of subcatchments C1, C5_ Říčany, and C4 was computed (Table 8, 9 & 10).

Table 8: Average CN value for the C1 subcatchment

Land cover type	Area [km²]	CN	Area · CN	Average CN
Coniferous forest	4.60	41	189.36	60
Broadleaved forest	2.00	42	83.83	
Mixed forest	3.51	42	148.91	
Discontinuous urban fabric	4.00	83	333.77	
Industrial or commercial units and public facilities	0.07	85	6.36	
Non-irrigated arable land	3.63	74	269.96	
Land principally occupied by agriculture, with significant areas of natural vegetation	1.05	66	68.73	
Complex cultivation pattern	0.25	72	18.06	
Water bodies	0.54	100	54.33	

Table 9: Average CN value for the C5_ Říčany subcatchment

Land cover	Area [km²]	CN	Area · CN	Average CN
Coniferous forest	7.38	60	439.99	68
Broadleaved forest	1.46	59	86.48	
Mixed forest	2.58	63	161.64	
Discontinuous urban fabric	0.64	85	54.25	
Industrial or commercial units and public facilities	0.17	88	15.11	
Non-irrigated arable land	6.34	79	498.59	
Land principally occupied by agriculture, with significant areas of natural vegetation	0.44	73	32.30	
Transitional woodland/shrub	0.76	65	49.88	
Water bodies	0.01	100	1.47	

Table 10: Average CN value for the C4 subcatchment

Land cover	Area [km²]	CN	Area · CN	Average CN
Coniferous forest	13.09	52	683.50	63
Broadleaved forest	0.00	42	0.01	
Mixed forest	5.14	55	280.25	
Discontinuous urban fabric	1.87	86	159.58	
Sport and leisure facilities	0.47	62	29.31	
Non-irrigated arable land	8.71	77	668.31	
Land principally occupied by agriculture, with significant areas of natural vegetation	3.36	66	220.43	
Pastures	3.75	66	248.55	
Transitional woodland/shrub	0.33	63	21.13	

6.2.4 Topographical parameters

In order to design a unit hydrograph, apart from the lag time and CN values, the hydraulic length of the catchment and the average catchment slope (%) are required. According to expert recommendations in DHI, instead of the average slope, absolute slope (I_a) was calculated by Eq. (13). For the purpose of model calibration, these 2 parameters were defined for every subcatchment (Table 11 & 12) mostly by using QGIS software tools.

Table 11: Hydraulic length of each subcatchment

Subcatchment	Length
	[km]
C1	8.12
C5_Říčany	7.10
C4	6.64
Total	21.86

Table 12: Absolute slope of each subcatchment

Subcatchment	Length (L)	Highest point along watercourse (I_h)	Lowest point along watercourse (I_l)	Slope (Y)
	[m]	[msal]	[msal]	[%]
C1	8120.00	480.00	380.39	1.23
C5_Říčany	7100.00	380.39	321.86	0.82
C4	6640.00	321.86	284.00	0.57

$$Y = \frac{I_h - I_l}{L} \cdot 100 \tag{13}$$

6.3 Design Precipitations

For the simulation of various land cover scenarios, design precipitation data were used. Data were gathered from the application Návrhová šestihodinová srážka (https://rain1.fsv.cvut.cz). Design precipitations of order IV catchments for 6 hours precipitation with a return period of 2, 5, 10, 20, 50, and 100 years were available on the website. For every return period, there is CSV file with A, B, C, D, E, and F type of hyetograph and probability of every type occurring on the specific catchment.

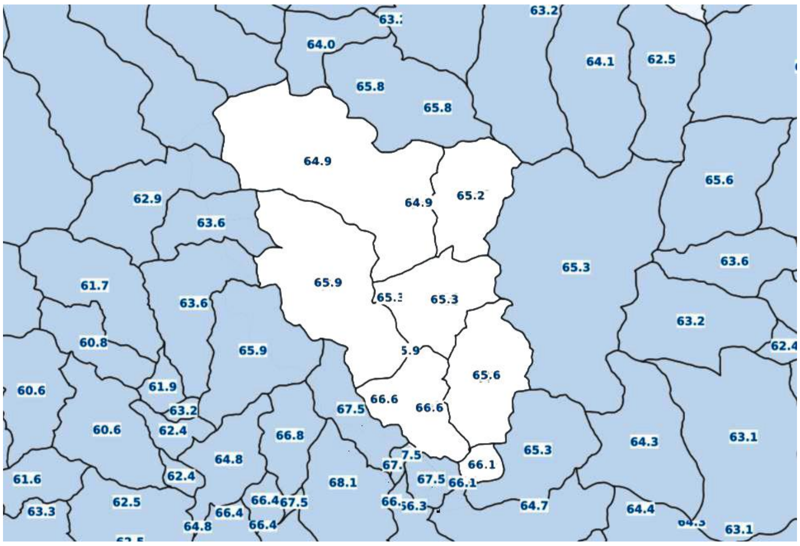


Figure 13: 6 hours precipitation for 100 year return period within Jevanský basin map (Source: https://rain1.fsv.cvut.cz/?PROJECT=rain/rain6h/webapp)

Considering the map, that was made for IV order streams, based on the spatial distribution of each of the catchments within the Jevanský basin (Figure 13), it was possible to get design precipitation for the Jevanský basin. Return periods, 10, 50, and 100 years, were taken for the following simulations. One of the information stated in the CSV, apart from the distribution of the precipitation for every type of hyetograph (Figure 14), was that there were probabilities of every type occurrence. Type F was most likely to happen, and therefore this type was chosen. Values of 6 hours precipitation for Jevanský basin are:

- p_{10}= 44.3 mm
- p_{50}= 58.9 mm
- p_{100}= 65.6 mm

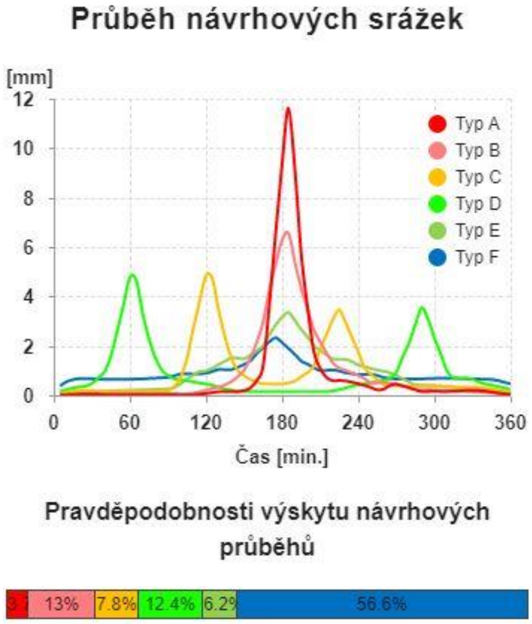


Figure 14: Hyetograph types of design precipitations
(Source: https://rain1.fsv.cvut.cz/?PROJECT=rain/rain6h/webapp)

7 Model Calibration, Validation and Simulation

7.1 Model Calibration

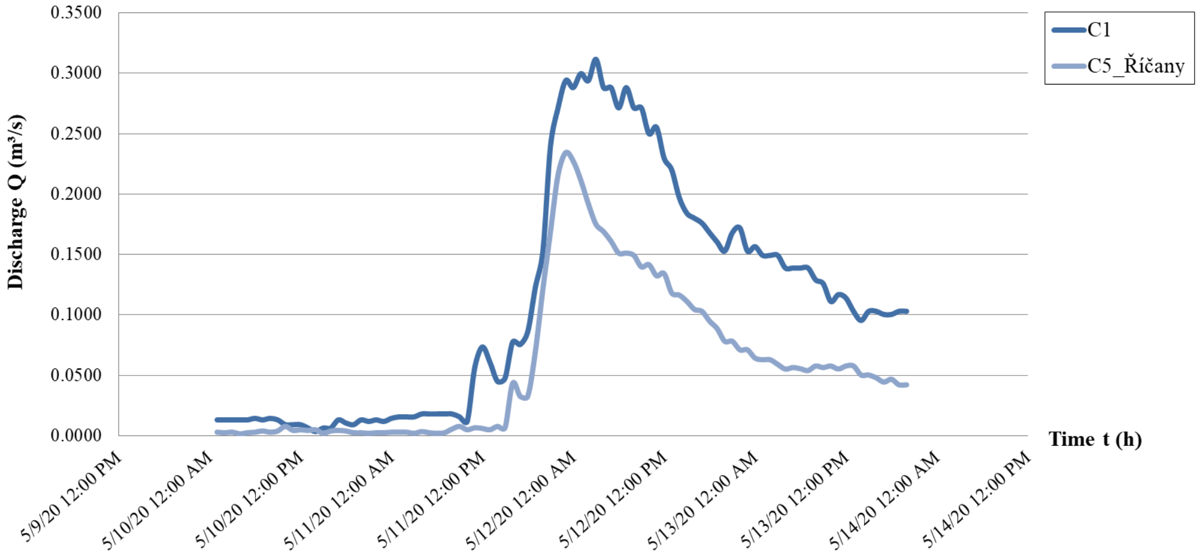
Every calibration involves modification of variable parameters until the simulation results are identical to the observed ones. The main interest is to make a model which will successfully represent the real natural environment and respond in the same manner.
In this particular case, the idea was to calibrate the model regarding runoff production for a chosen rain event.

7.1.1 Subcatchments

Subcatchments, C1 and C5_Říčany, were used for the calibration. This decision was made due to the availability of water level measurements. Parameters were inserted into the model separately, however, during the calibration process, they were observed as one unit.

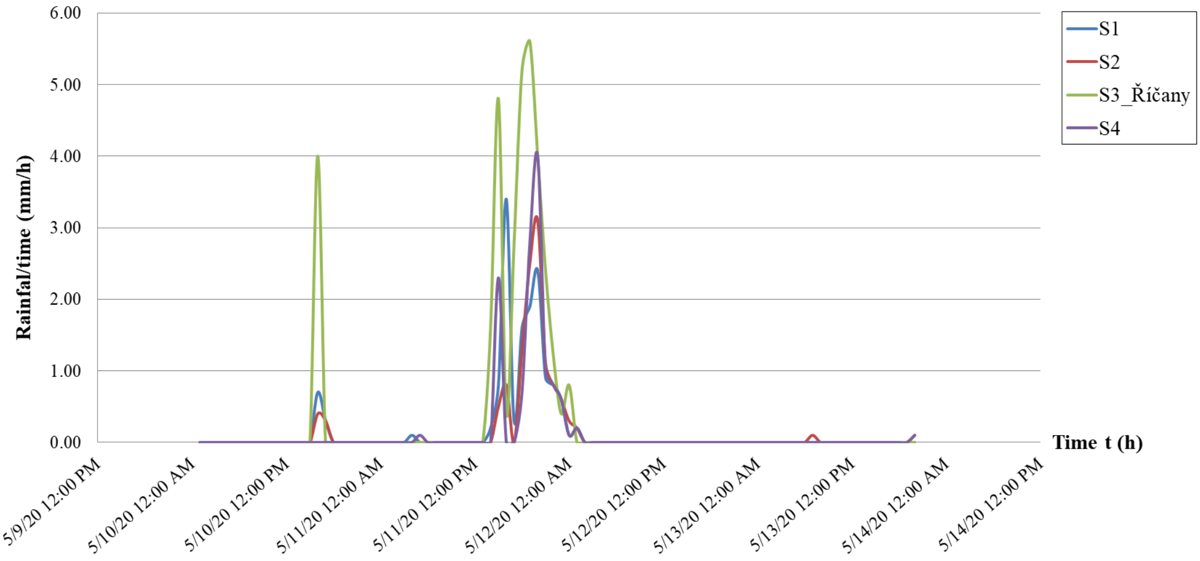
7.1.2 Time series

Several rain events were recorded in the last year. Recording of the events included the taking of rainfall distribution from 4 rain gauges and water level from 2 reporting profiles from the website immediately after every rain event. The time series chosen for the calibration was from 5/10/2020 at 1:00:00 AM to 5/13/2020 at 8:00:00 PM.



Graph 3: Change in discharge at C1 and C5_Říčany (5/10/-5/14/2020)

The water level measurements were taken as instantaneous values for every hour and were afterwards converted to discharge values through the rating curves (Graph 3). Equations derived from rating curves were presented in the previous chapter. Rainfall data (Graph 4), on the other hand, were taken as step-accumulated for every hour. The term step-accumulated was referred to the sum of the precipitation that occurred during the entire hour. The table of entire time series for this time period can be found in Appendix I.



Graph 4: Rainfall distribution from S1, S2, S3_ Říčany and S4 (5/10/-5/14/2020)

The model demanded the influence of every rain gauge to be inserted in the form of share regarding the subcatchment area. Influences were previously determined by the Thiessen polygon method.

7.1.3 Calibration process

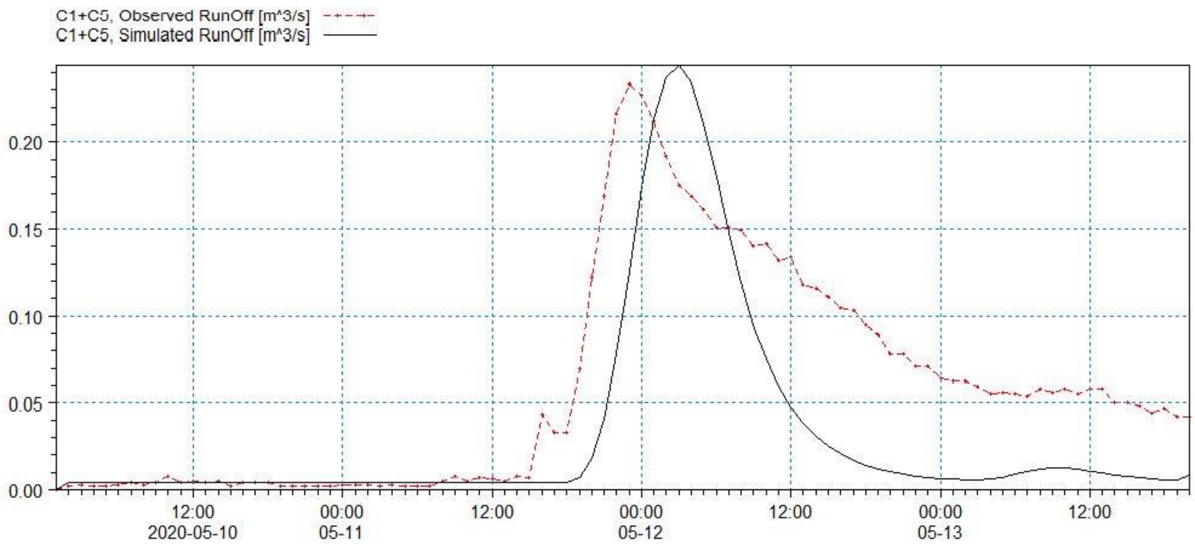
The calibration process was performed manually. The process represented extensive parameters adjustment whose alteration was driven by trial and error principle and assessment of the graphical representation of simulated and observed results, in this case, runoff.

The area adjustment factor was 1 because there weren't any significant discrepancies in the precipitation distribution over subcatchments. Base flow was obtained by observation of the trendline (Graph 3). This parameter represented average flow before it increments due to precipitation.

Hydrograph type was SCS dimensionless. For the enlargement and loss model, SCS generalized method was chosen. It required parameters: CN and initial abstraction depth. CN was previously specified by analyzing hydrological soil groups and land use. Further, parameters necessary for lag time evaluation were hydraulic length, slope, and CN. All parameters were explained in the previous chapter.

After input of all the parameters needed for simulation, lag time was initially calculated to be close to 7 hours for the sub-catchment C1, and close to 6 hours for subcatchment C5_ Říčany.

Hence, there was no measured value of initial abstraction depth, it was obtained after several trial and error attempts and value of 11 was accepted. However, this simulation showed great discrepancies in the simulated and observed results (Graph 5). Difference between simulated and observed accumulated runoff was statistically analyzed. R^2 was equal to 0.415 and %WBL was 47.1 %. After a consultation with a more experienced researcher about the calibration and validation of rainfall-runoff models, it was concluded that these values couldn't be accepted as good enough to consider the UHM model calibrated. Thus, further alternation of parameters had to be done and get a better fit of observed and simulated values.

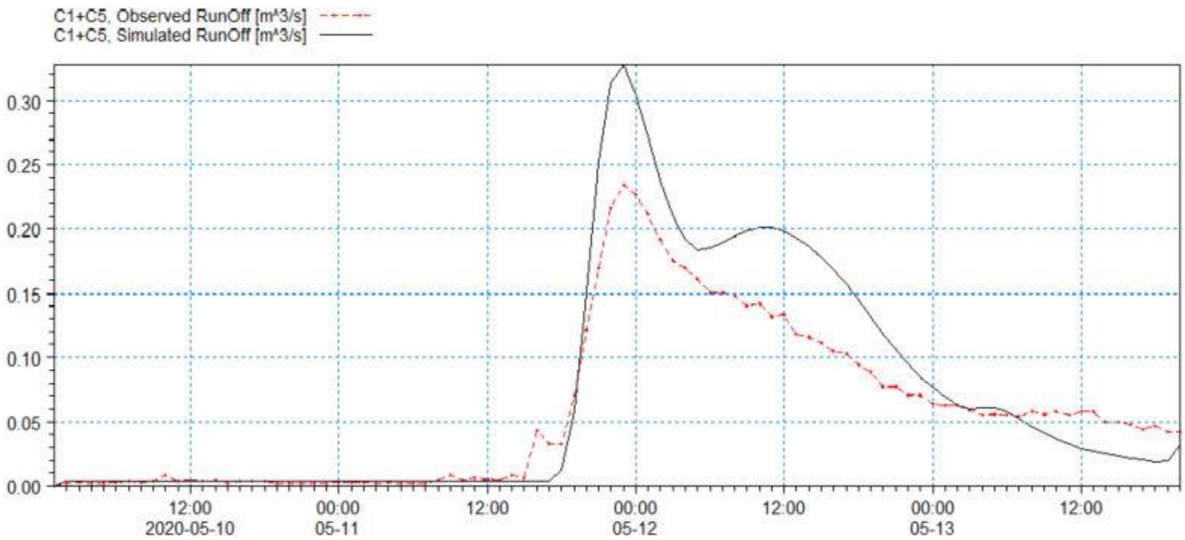


Graph 5: Simulated and observed hydrograph of initial simulation

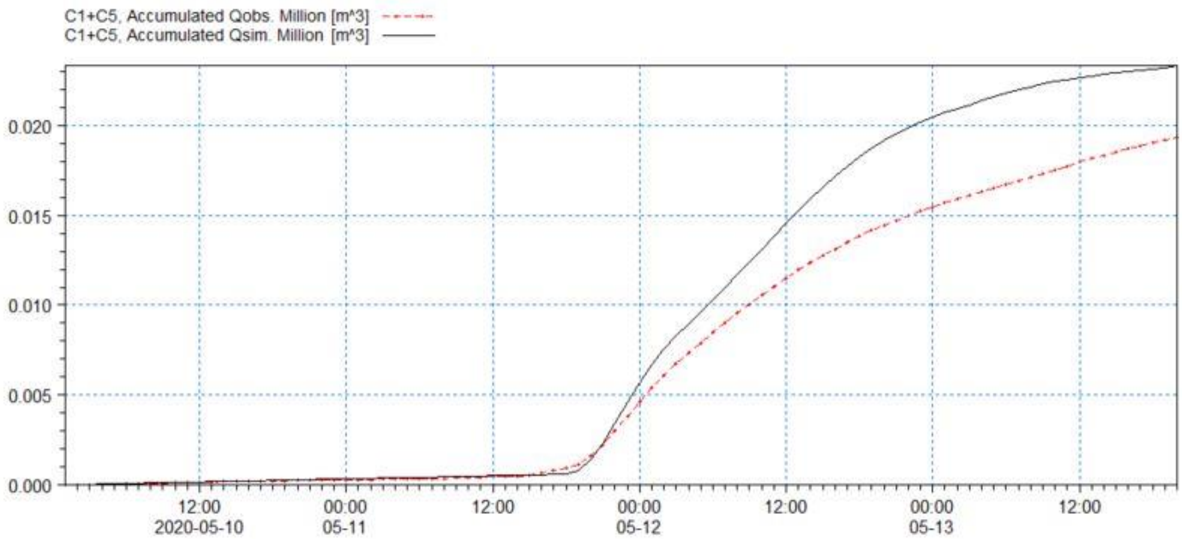
Further calibration was intended to be done just by modifying the parameters, CN, and initial abstraction depth. However, it wasn't possible to get an acceptable fit of observed and simulated runoff value (hydrograph) just with these alternations. Therefore, it was decided to make changes to the slope, too. After extensive modification of the parameters, the best fit was obtained.

It was assumed that the cause of the impossibility of successful calibration, in the beginning, was that there was a pond system before the measuring station C1. Due to the system of reservoirs placed upstream, inconsistencies in the flow can occur. Lag in the appearance of waves, i.e. a lag in the reaction of a watercourse, could happen because the tanks were the first to capture excessive water. Equally, the opposite scenario could happen if there was a rapid increase in the flow because the tanks were with opened outflows to prevent overflow in the event of heavy rains. Consequently, the decision about slope alteration was made and it helped with getting a well-calibrated model.

The quality of the result could be checked by graphical representation of observed and simulated results for runoff and accumulated rainfall excess (Graph 6 & 7) and coefficients, R^2=0.722, and %WBL=-20.8 %.



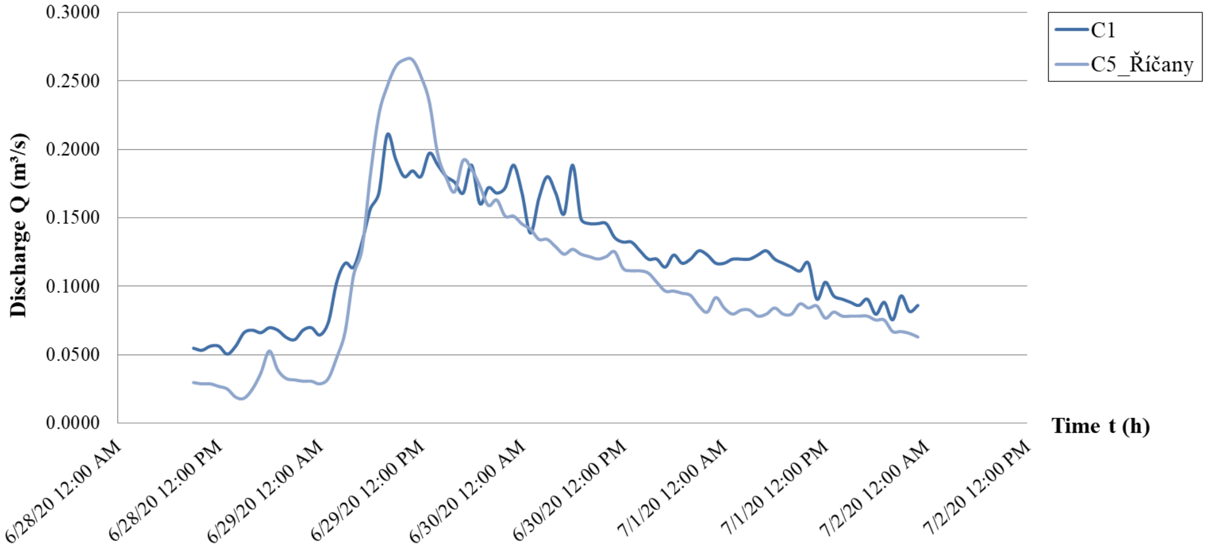
Graph 6: Hydrograph delivered after the model calibration



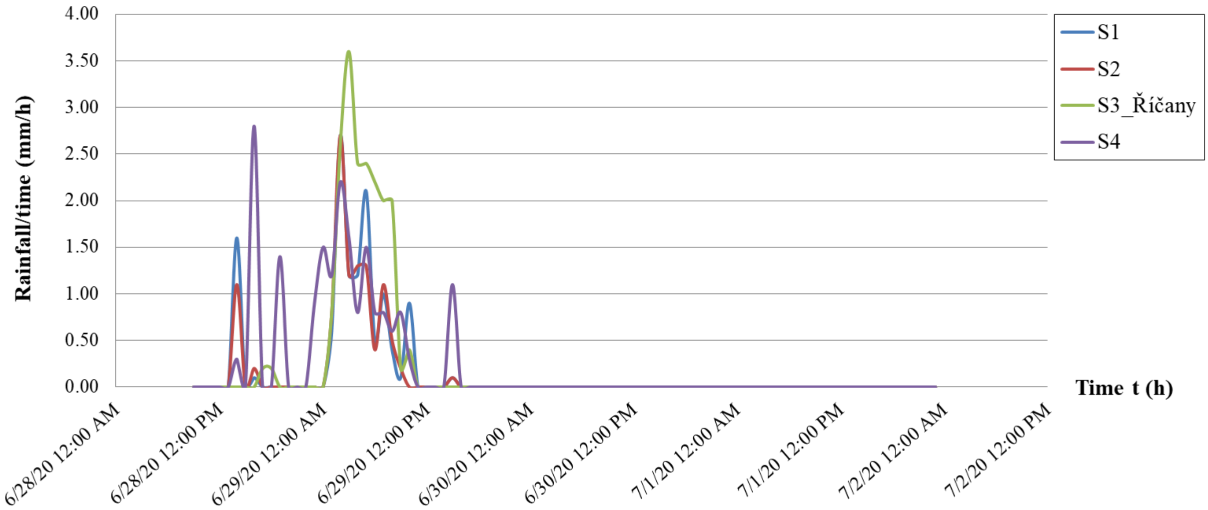
Graph 7: Accumulated rainfall excess after the model calibration

7.2 Model Validation

Validation represented repeating of calibration with calibrated parameters, but with another rainfall event. The period chosen for this step was from 6/28/2020 at 9:00:00 AM to 7/1/2020 at 11:00:00 PM (Graph 8 & 9). The table of the entire time series for this time period can be found in Appendix II.

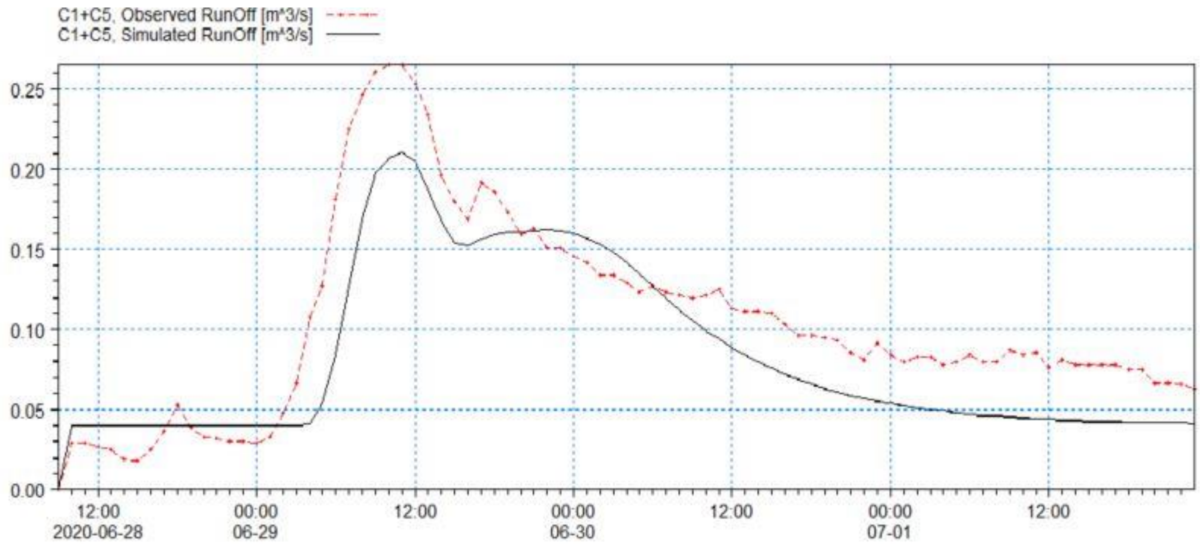


Graph 8: Change in discharge at C1 and C5_Říčany (6/28/-7/2/2020)

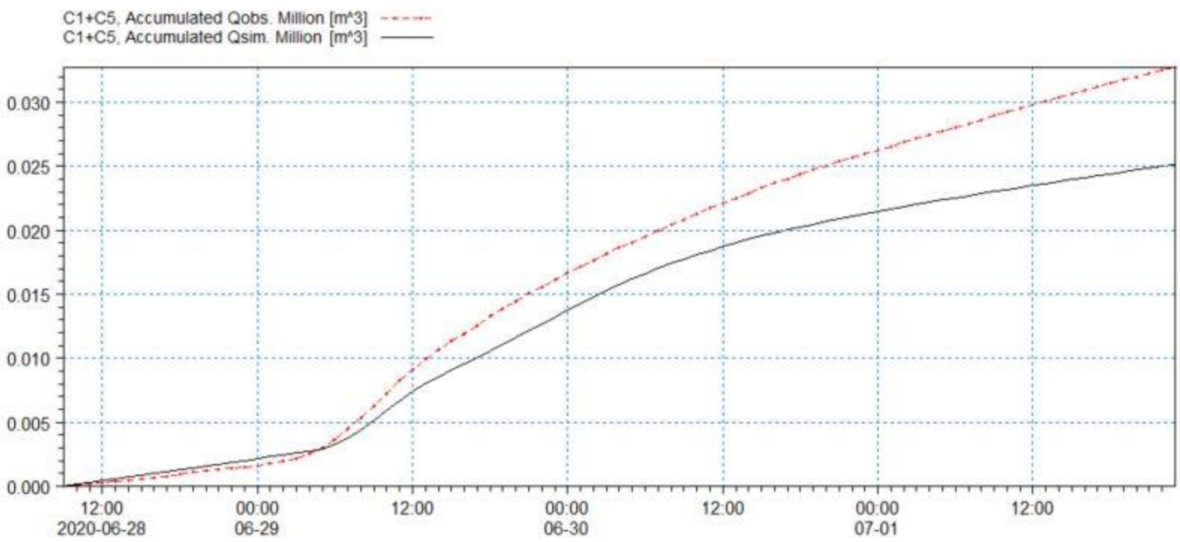


Graph 9: Rainfall distribution from S1, S2, S3_ Říčany and S4 (6/28/-7/2/2020)

Results of the model validation were presented both graphically (Graph 10 & 11) and as coefficients R^2= 0.700, and %WBL= 20.1 %.



Graph 10: Hydrograph delivered after the model validation



Graph 11: Accumulated rainfall excess after the model validation

7.3 Calibrated Parameters

Input parameters for C1 and C5_ Říčany were modified through calibration (Table 13).

Table 13: Calibrated parameters

Subcatchment	CN	Initial abstraction depth	Slope
		[mm]	[%]
C1	64.00	6.50	5.00
C5	74.00	9.50	0.10

Consequently, new CNs were defined for every land cover type within subcatchments (Table 14 & 15). Parameters of the C4 subcatchment remained the same.

Table 14: Calibrated CN values for every land cover type in subcatchment C1

Land cover type (Subcatchment C1)	Calibrated CN	Average CN
Coniferous forest	45	64
Broadleaved forest	46	
Mixed forest	46	
Discontinuous urban fabric	90	
Industrial or commercial units and public facilities	92	
Non-irrigated arable land	80	
Land principally occupied by agriculture, with significant areas of natural vegetation	71	
Complex cultivation pattern	78	
Water bodies	100	

Table 15: Calibrated CN values for every land cover type in subcatchment C5_Říčany

Land cover type (Subcatchment C5_Říčany)	Calibrated CN	Average CN
Coniferous forest	66	74
Broadleaved forest	65	
Mixed forest	69	
Discontinuous urban fabric	93	
Industrial or commercial units and public facilities	96	
Non-irrigated arable land	86	
Land principally occupied by agriculture, with significant areas of natural vegetation	80	
Transitional woodland/shrub	71	
Water bodies	100	

7.4 Model Simulation

Preparation for the simulation started with changing the CN values to get several possible scenarios (Table 16). Land type share for scenario_1, ascenario_2, scenario_3, and scenario_4 can be found in Appendix III. Scenario_0 represents the current state, so it corresponds to the shares in Chapter 6.

Table 16: CN values of subcatchments in case of land cover shifting

Scenario		CN		
		C1	C4	C5_ Říčany
Scenrario_0	Current land cover	64	63	74
Scenario_1	All pure coniferous-evergreen forests and mixed forests were replaced by broadleaved-deciduous forests.	67	66	77
Scenario_2	All pure broadleaved-deciduous forests and mixed forests were replaced by coniferous-evergreen forests.	63	63	74
Scenario_3	All forest cover was replaced by barren or sparsely vegetated surfaces.	79	76	83
Scenario_4	All pure coniferous-evergreen forests are replaced by barren or sparsely vegetated surfaces.	71	72	80

Afterwards, every scenario was simulated with design precipitations of 10, 50, and 100 years return period. Complete tables with precipitation distribution within 6 hours can be found in the Appendix IV.

8 Results

Results were derived by changing the CNs of subcatchments followed by a run of a UHM model simulation. The purpose was to indicate the effective rainfall i.e. runoff changes caused by land use shift. Hydrographs and accumulated rainfall excess values (Table 17) for each simulation demonstrated changes in effective rainfall by alteration of forest cover of the Jevanský basin. Hydrographs were produced for every scenario for the return periods of 10, 50, and 100 years. Hydrographs for 5 scenarios for return period of 10, 50 and 100 years can be seen here (Graph 12, 13 & 14). From each hydrograph, maximum runoff values i.e. hydrograph peaks were read (Table 18). The time when peak occurred for simulated rain events which started at 1:00:00 AM (Table 19) was also recorded.

Table 17: Accumulated rainfall excess for 5 different land use scenarios and return periods of 10, 50, and 100 years

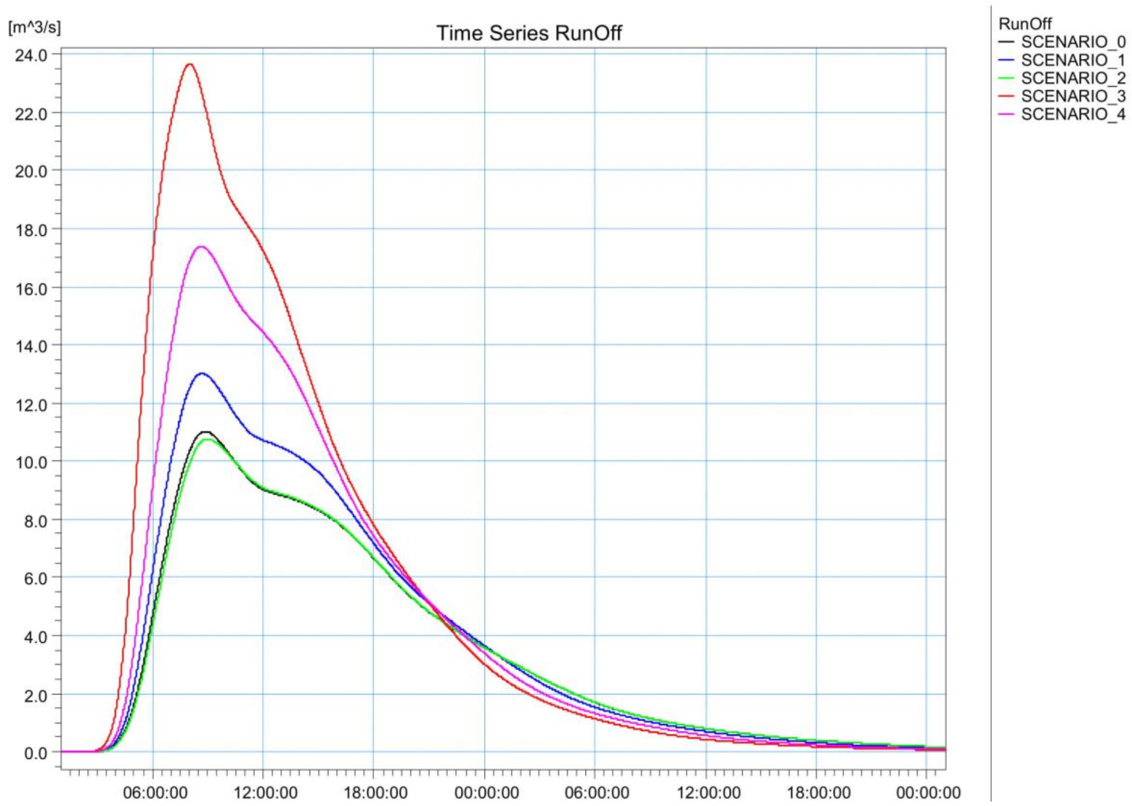
Scenario		Accumulated runoff [mm]		
		p_10	p_50	p_100
Scenario_0	Current land cover.	7.9	14.2	17.6
Scenario_1	All pure coniferous-evergreen forests and mixed forests were replaced by broadleaved-deciduous forests.	8.8	15.7	19.3
Scenario_2	All pure broadleaved-deciduous forests and mixed forests were replaced by coniferous-evergreen forests.	7.8	14.1	17.4
Scenario_3	All forest cover was replaced by barren or sparsely vegetated surfaces.	12.4	21.4	26
Scenario_4	All pure coniferous-evergreen forests are replaced by barren or sparsely vegetated surfaces.	10.4	18.3	22.3

Table 18: Maximum runoff for 5 different land use scenarios and return periods of 10, 50, and 100 years

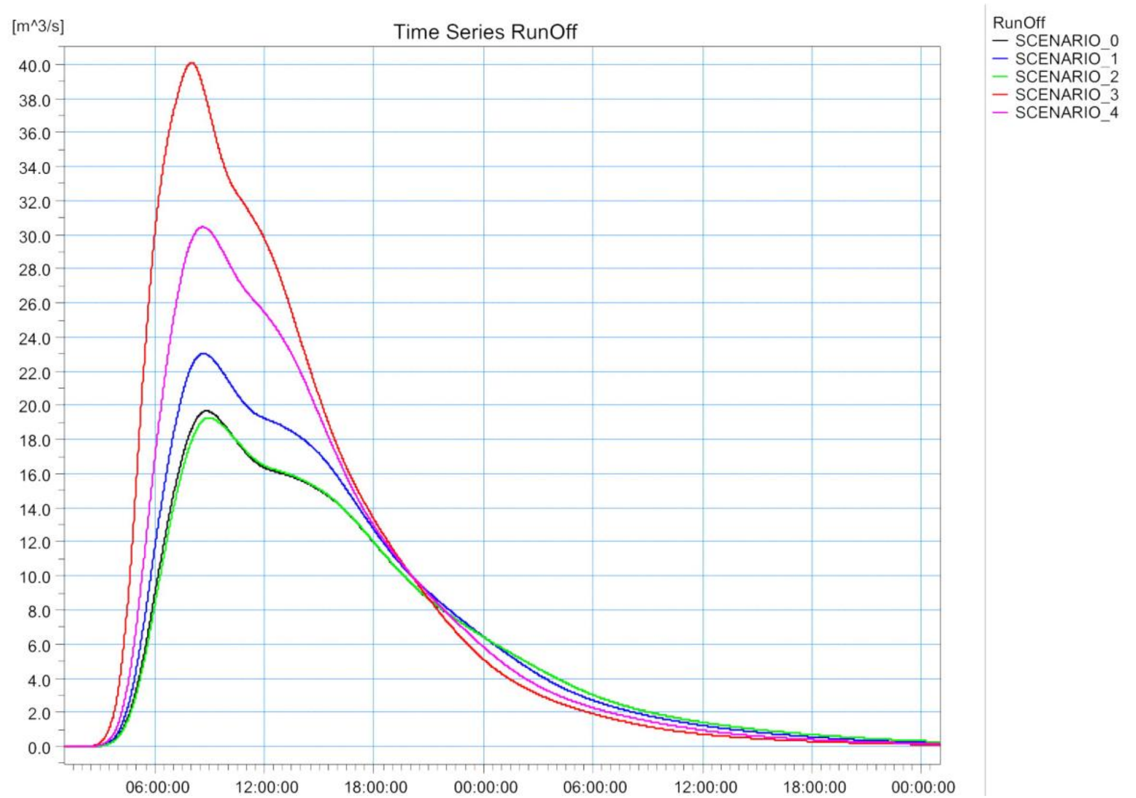
Scenario		Maximum runoff [m³/s]		
		p_10	p_50	p_100
Scenario_0	Current land cover.	11.02	19.67	24.21
Scenario_1	All pure coniferous-evergreen forests and mixed forests were replaced by broadleaved-deciduous forests.	13.01	23.03	28.27
Scenario_2	All pure broadleaved-deciduous forests and mixed forests were replaced by coniferous-evergreen forests.	10.75	19.26	23.73
Scenario_3	All forest cover was replaced by barren or sparsely vegetated surfaces.	23.65	40.07	48.34
Scenario_4	All pure coniferous-evergreen forests are replaced by barren or sparsely vegetated surfaces.	17.39	30.46	37.19

Table 19: Time of maximum runoff occurrence for 5 different land use scenarios and return periods of 10, 50, and 100 years

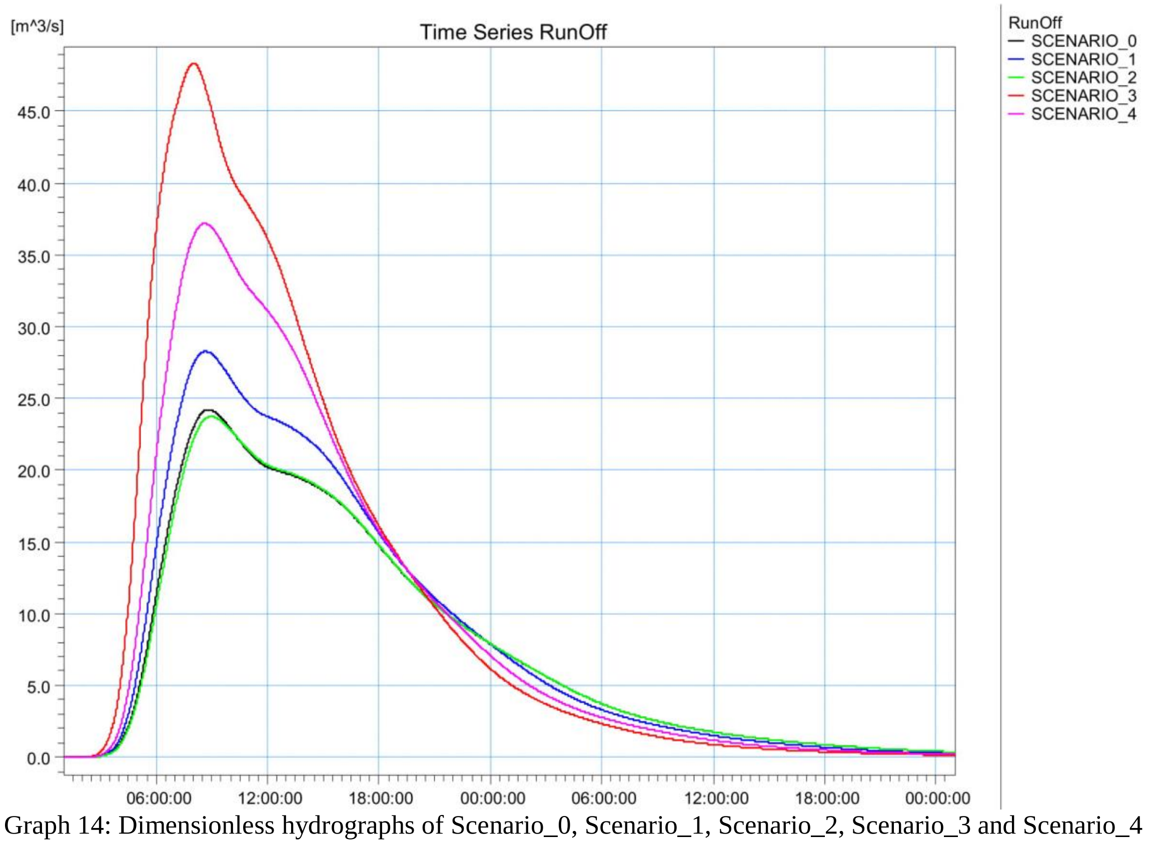
Scenario		Time of maximum runoff [hh:mm]		
		p_10	p_50	p_100
Scenario_0	Current land cover.	8:51 AM	8:48 AM	8:48 AM
Scenario_1	All pure coniferous-evergreen forests and mixed forests were replaced by broadleaved-deciduous forests.	8:41 AM	8:40 AM	8:38 AM
Scenario_2	All pure broadleaved-deciduous forests and mixed forests were replaced by coniferous-evergreen forests.	8:59 AM	8:57 AM	8:56 AM
Scenario_3	All forest cover was replaced by barren or sparsely vegetated surfaces.	8:00 AM	8:00 AM	8:00 AM
Scenario_4	All pure coniferous-evergreen forests are replaced by barren or sparsely vegetated surfaces.	8:37 AM	8:37 AM	8:36 AM



Graph 12: Dimensionless hydrographs of Scenario_0, Scenario_1, Scenario_2, Scenario_3 and Scenario_4 for the return period of 10 years



Graph 13: Dimensionless hydrographs of Scenario_0, Scenario_1, Scenario_2, Scenario_3 and Scenario_4 for the return period of 50 years



Graph 14: Dimensionless hydrographs of Scenario_0, Scenario_1, Scenario_2, Scenario_3 and Scenario_4 for the return period of 100 years

9 Discussion

Results which were obtained from the model simulation showed an expected increment in runoff amount in the case of absolute removal of total forest cover in the Jevanský catchment. Values of the accumulated runoff for Scenario_0 and Scenario_3 differ for 36.29 %, 33.64 %, and 32.31 % for the 10, 50, and 100 years return periods, respectively, with Scenario_3 having greater values (Table 17). This is clearly evidence that existing forest cover has a significant role in runoff reduction on the surface of the Jevanský basin.

Regarding the forest type, coniferous forests showed a greater affinity to reduce runoff compared to broadleaved forests. By observing Scenario_0, Scenario_1, and Scenario_2, it can be visible that the lowest peak values are in the coniferous forests prevalence, while, in the case of broadleaved predominance, runoff amounts are greatest. Differences in runoff amount between Scenario _1 and Scenario_2 are 11.36 %, 10.20 %, and 9.84 %, for return periods of 10, 50, and 100 years, respectively (Table 17). Insignificant dissimilarity of runoff accumulation for Scenario_0 and Scenario_2 is most likely due to the existing overpowering of the pure coniferous stand to broadleaved in the current catchment land use, which is 1:6 in favour of conifers.

Scenario_4 was done because of the possible European bark beetle outbreak when there is the necessity of removing all pure coniferous forest by clear-cutting and, therefore, this outcome, as a worst-case scenario regarding bark beetle spread, was presented in the results. This case has lower runoff amounts than absolute deforestation. However, the noticeable difference compared to the current situation is present and not favourable at all. Runoff amounts in Scenario_4 are greater for 24.04 %, 22,40 %, and 21.07 %, for 10, 50, and 100 years return period, respectively, compared to the current land use situation in the Jevanský basin.

Maximum runoff flow is following the trend of the runoff amount. Compared to Scenario_0, Scenario_1 has greater values and Scenario_2 lower. By analysis of the hydrographs, it is visible from the graphs (Graph 12, 13 & 14), that out of Scenario_0, Scenario_1, and Scenario_2, Scenario_1 has the highest runoff peak.

Scenario_3 has the highest peak compared to all scenarios. This scenario not only has the highest maximum runoff value, but the appearance of the peak is the fastest. Time to peak is lower from the Scenario_0 by 51 minutes for the return period of 10 years (Table 18). Scenario_3 maximum runoff values are around 2 times greater for all return periods than the values obtained in Scenario_0. The runoff response of Scenario_3 corresponds to results that were obtained from the study which was set in Chile and had aimed to assess changes in the runoff and peak flow before and after deforestation in the catchment. Iroumé et al. (2006) concluded that forest reduction leads to higher runoff and peak flows.

The presented results were obtained by simulation of the rainfall-runoff model. The UHM model in its simulations uses just a few parameters that gave some uncertainties in this evaluation. That was especially apparent in the calibration process. Due to a low number of input parameters which define catchment reaction to rainfall (CN, slope, and hydraulic length), it was not possible to describe the system of reservoirs in the upper part of the basin. The system affects water level discrepancies and, thus, the value of the slope had to be modified to make the model calibrated. It is worth mentioning that, due to the complexity of the steps in estimating the CN values, and the usage of modified CN values by Hong & Adler (2008) which are not frequently used, and represent the data on a vast, global scale, the accuracy of the results could be questioned.

To complete catchment analysis, the next logical step would be to connect this model with a hydrodynamic model of the Jevanský creek. Caused by runoff response of changed land cover in the basin, the change in the watercourse discharge could be evaluated and make a wider picture of the forest cover alteration.

10 Conclusion and Recommendations

Forest cover represents 50 % of the Jevanský creek basin. However, even if catchment has such a high share of the forest it doesn't mean that forest could prevent floods. According to a study which was done after the flood in 2013 it was obvious that anthropogenic influence was present in the basin and often very close to the riverbed which can be crucial for the flood to occur. However, through this analysis, the idea was to point out the role of forest in the Jevanský catchment and determine if the removal of the shift from one forest type to another affects flood risk.

Overall conclusion was that its change affects runoff production in the catchment. Coniferous forests compared to broadleaved forests showed lower values of accumulated runoff, and lower hydrograph peaks for the return time period of 10, 50, and 100 years. Total deforestation caused higher values of the accumulated runoff and maximum runoff values compared to the current land use, and the highest overall values. A significant increment in the runoff amount is also present in the case of all coniferous forests that have undergone a clear cut in the simulations.

In order to understand the influence of forest on runoff in the catchment better, a recommendation would be to use a more multi-parameter-based model which would help in obtaining more precise calibration and validation. Therefore, e.g. the evapotranspiration values, temperature and radiation would be used as input parameters that would describe the basin with greater precision. Besides that, a higher rain gauge density i.e. rainfall data from more rain gauges within the catchment and data of measured discharges from a higher number of reporting profiles would further contribute to the understanding of this important issue.

11 References

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11.1 Web Sources

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12 Appendices

Appendix I: Time series (5/10/2020 at 1:00:00 AM to 5/13//2020 at 8:00:00 PM)

Appendix II: Time series (28/6/2020 at 9:00:00 AM to 7/1/2020 at 11:00:00 PM)

Appendix III: Land cover for 4 scenarios

Appendix IV: Precipitation (6 hours) for the return period of 10, 50, and 100 years

Appendix I: Time series (5/10/2020 at 1:00:00 AM to 5/13//2020 at 8:00:00 PM)

Time	P [mm]	Time	P [mm]	Time	P [mm]
5/10/2020 1:00	0.0000	5/11/2020 17:00	1.4619	5/13/2020 9:00	0.0000
5/10/2020 2:00	0.0000	5/11/2020 18:00	2.6885	5/13/2020 10:00	0.0000
5/10/2020 3:00	0.0000	5/11/2020 19:00	3.0938	5/13/2020 11:00	0.0000
5/10/2020 4:00	0.0000	5/11/2020 20:00	1.2346	5/13/2020 12:00	0.0000
5/10/2020 5:00	0.0000	5/11/2020 21:00	0.8804	5/13/2020 13:00	0.0000
5/10/2020 6:00	0.0000	5/11/2020 22:00	0.5036	5/13/2020 14:00	0.0000
5/10/2020 7:00	0.0000	5/11/2020 23:00	0.2459	5/13/2020 15:00	0.0000
5/10/2020 8:00	0.0000	5/12/2020 0:00	0.2777	5/13/2020 16:00	0.0000
5/10/2020 9:00	0.0000	5/12/2020 1:00	0.0000	5/13/2020 17:00	0.0000
5/10/2020 10:00	0.0000	5/12/2020 2:00	0.0000	5/13/2020 18:00	0.0000
5/10/2020 11:00	0.0000	5/12/2020 3:00	0.0000	5/13/2020 19:00	0.0870
5/10/2020 12:00	0.0000	5/12/2020 4:00	0.0000	5/13/2020 20:00	0.3682
5/10/2020 13:00	0.0000	5/12/2020 5:00	0.0000		
5/10/2020 14:00	0.0000	5/12/2020 6:00	0.0000		
5/10/2020 15:00	0.4098	5/12/2020 7:00	0.0000		
5/10/2020 16:00	0.7195	5/12/2020 8:00	0.0000		
5/10/2020 17:00	0.0000	5/12/2020 9:00	0.0000		
5/10/2020 18:00	0.0000	5/12/2020 10:00	0.0000		
5/10/2020 19:00	0.0000	5/12/2020 11:00	0.0000		
5/10/2020 20:00	0.0000	5/12/2020 12:00	0.0000		
5/10/2020 21:00	0.0000	5/12/2020 13:00	0.0000		
5/10/2020 22:00	0.0000	5/12/2020 14:00	0.0000		
5/10/2020 23:00	0.0000	5/12/2020 15:00	0.0000		
5/11/2020 0:00	0.0000	5/12/2020 16:00	0.0000		
5/11/2020 1:00	0.0000	5/12/2020 17:00	0.0000		
5/11/2020 2:00	0.0000	5/12/2020 18:00	0.0000		
5/11/2020 3:00	0.0471	5/12/2020 19:00	0.0000		
5/11/2020 4:00	0.0199	5/12/2020 20:00	0.0000		
5/11/2020 5:00	0.0000	5/12/2020 21:00	0.0000		
5/11/2020 6:00	0.0000	5/12/2020 22:00	0.0000		
5/11/2020 7:00	0.0199	5/12/2020 23:00	0.0000		
5/11/2020 8:00	0.0000	5/13/2020 0:00	0.0000		
5/11/2020 9:00	0.0000	5/13/2020 1:00	0.0000		
5/11/2020 10:00	0.0000	5/13/2020 2:00	0.0000		
5/11/2020 11:00	0.0000	5/13/2020 3:00	0.1001		
5/11/2020 12:00	0.0000	5/13/2020 4:00	0.0000		
5/11/2020 13:00	0.0671	5/13/2020 5:00	0.0000		
5/11/2020 14:00	1.8182	5/13/2020 6:00	0.0200		
5/11/2020 15:00	2.0066	5/13/2020 7:00	0.0000		
5/11/2020 16:00	0.4545	5/13/2020 8:00	0.0000		

Appendix II: Time series (28/6/2020 at 9:00:00 AM to 7/1/2020 at 11:00:00 PM)

Time	P [mm]	Time	P [mm]
6/28/2020 9:00	0.0000	6/30/2020 8:00	0.0000
6/28/2020 10:00	0.0000	6/30/2020 9:00	0.0000
6/28/2020 11:00	0.0000	6/30/2020 10:00	0.0000
6/28/2020 12:00	0.0000	6/30/2020 11:00	0.0000
6/28/2020 13:00	0.0000	6/30/2020 12:00	0.0000
6/28/2020 14:00	1.0336	6/30/2020 13:00	0.0000
6/28/2020 15:00	0.0000	6/30/2020 14:00	0.0000
6/28/2020 16:00	0.6450	6/30/2020 15:00	0.0000
6/28/2020 17:00	0.0259	6/30/2020 16:00	0.0000
6/28/2020 18:00	0.0259	6/30/2020 17:00	0.0000
6/28/2020 19:00	0.2789	6/30/2020 18:00	0.0000
6/28/2020 20:00	0.0000	6/30/2020 19:00	0.0000
6/28/2020 21:00	0.0000	6/30/2020 20:00	0.0000
6/28/2020 22:00	0.0000	6/30/2020 21:00	0.0000
6/28/2020 23:00	0.1793	6/30/2020 22:00	0.0000
6/29/2020 0:00	0.2989	6/30/2020 23:00	0.0000
6/29/2020 1:00	0.7855	7/1/2020 0:00	0.0000
6/29/2020 2:00	2.5874	7/1/2020 1:00	0.0000
6/29/2020 3:00	1.5906	7/1/2020 2:00	0.0000
6/29/2020 4:00	1.2958	7/1/2020 3:00	0.0000
6/29/2020 5:00	1.8592	7/1/2020 4:00	0.0000
6/29/2020 6:00	0.7600	7/1/2020 5:00	0.0000
6/29/2020 7:00	1.1097	7/1/2020 6:00	0.0000
6/29/2020 8:00	0.6671	7/1/2020 7:00	0.0000
6/29/2020 9:00	0.2724	7/1/2020 8:00	0.0000
6/29/2020 10:00	0.5355	7/1/2020 9:00	0.0000
6/29/2020 11:00	0.0000	7/1/2020 10:00	0.0000
6/29/2020 12:00	0.0000	7/1/2020 11:00	0.0000
6/29/2020 13:00	0.0000	7/1/2020 12:00	0.0000
6/29/2020 14:00	0.0000	7/1/2020 13:00	0.0000
6/29/2020 15:00	0.2863	7/1/2020 14:00	0.0000
6/29/2020 16:00	0.0000	7/1/2020 15:00	0.0000
6/29/2020 17:00	0.0000	7/1/2020 16:00	0.0000
6/29/2020 18:00	0.0000	7/1/2020 17:00	0.0000
6/29/2020 19:00	0.0000	7/1/2020 18:00	0.0000
6/29/2020 20:00	0.0000	7/1/2020 19:00	0.0000
6/29/2020 21:00	0.0000	7/1/2020 20:00	0.0000
6/29/2020 22:00	0.0000	7/1/2020 21:00	0.0000
6/29/2020 23:00	0.0000	7/1/2020 22:00	0.0000
6/30/2020 0:00	0.0000	7/1/2020 23:00	0.0000
6/30/2020 1:00	0.0000		
6/30/2020 2:00	0.0000		
6/30/2020 3:00	0.0000		
6/30/2020 4:00	0.0000		
6/30/2020 5:00	0.0000		
6/30/2020 6:00	0.0000		
6/30/2020 7:00	0.0000		

Appendix III: Land cover for 4 scenarios

- Scenario_1

	Land cover type	Area [m²]	CN	Average CN
C1	Broadleaved forest	10099810	50	67
	Discontinuous urban fabric	4003446	90	
	Industrial or commercial units and public facilities	74820	92	
	Non-irrigated arable land	3628150	80	
	Land principally occupied by agriculture, with significant areas of natural vegetation	1048852	71	
	Complex cultivation pattern	251661	78	
	Water bodies	543262	100	
C4	Broadleaved forest	18225980	59	66
	Discontinuous urban fabric	1866388	86	
	Sport and leisure facilities	472599	62	
	Non-irrigated arable land	8705103	77	
	Land principally occupied by agriculture, with significant areas of natural vegetation	3357379	66	
	Pastures	3748251	66	
	Transitional woodland/shrub	334298	63	
C5_Říčany	Broadleaved forest	11424782	71	77
	Discontinuous urban fabric	638747	93	
	Industrial or commercial units and public facilities	170889	96	
	Non-irrigated arable land	6344095	86	
	Land principally occupied by agriculture, with significant areas of natural vegetation	443336	80	
	Complex cultivation pattern	763425	71	
	Water bodies	14726	100	

- **Scenario_2**

	Land cover type	Area [m²]	CN	Average CN
C1	Coniferous forest	10099810	42	63
	Discontinuous urban fabric	4003446	90	
	Industrial or commercial units and public facilities	74820	92	
	Non-irrigated arable land	3628150	80	
	Land principally occupied by agriculture, with significant areas of natural vegetation	1048852	71	
	Complex cultivation pattern	251661	78	
	Water bodies	543262	100	
C4	Coniferous forest	18225980	52	63
	Discontinuous urban fabric	1866388	86	
	Sport and leisure facilities	472599	62	
	Non-irrigated arable land	8705103	77	
	Land principally occupied by agriculture, with significant areas of natural vegetation	3357379	66	
	Pastures	3748251	66	
	Transitional woodland/shrub	334298	63	
C5_Říčany	Coniferous forest	11424782	65	74
	Discontinuous urban fabric	638747	93	
	Industrial or commercial units and public facilities	170889	96	
	Non-irrigated arable land	6344095	86	
	Land principally occupied by agriculture, with significant areas of natural vegetation	443336	80	
	Complex cultivation pattern	763425	71	
	Water bodies	14726	100	

- **Scenario_3**

	Land cover type	Area [m²]	CN	Average CN
C1	Barren or sparsely vegetated	10099810	74	79
	Discontinuous urban fabric	4003446	90	
	Industrial or commercial units and public facilities	74820	92	
	Non-irrigated arable land	3628150	80	
	Land principally occupied by agriculture, with significant areas of natural vegetation	1048852	71	
	Complex cultivation pattern	251661	78	
	Water bodies	543262	100	
C4	Barren or sparsely vegetated	18225980	79	76
	Discontinuous urban fabric	1866388	86	
	Sport and leisure facilities	472599	62	
	Non-irrigated arable land	8705103	77	
	Land principally occupied by agriculture, with significant areas of natural vegetation	3357379	66	
	Pastures	3748251	66	
	Transitional woodland/shrub	334298	63	
C5_Říčany	Barren or sparsely vegetated	11424782	82	83
	Discontinuous urban fabric	638747	93	
	Industrial or commercial units and public facilities	170889	96	
	Non-irrigated arable land	6344095	86	
	Land principally occupied by agriculture, with significant areas of natural vegetation	443336	80	
	Complex cultivation pattern	763425	71	
	Water bodies	14726	100	

- **Scenario_4**

	Land cover type	Area [m²]	CN	Average CN
C1	Barren or sparsely vegetated	4595355	75	71
	Broadleaved forest	1995833	46	
	Mixed forest	3508621	46	
	Discontinuous urban fabric	4003446	90	
	Industrial or commercial units and public facilities	74820	92	
	Non-irrigated arable land	3628150	80	
	Land principally occupied by agriculture, with significant areas of natural vegetation	1048852	71	
	Complex cultivation pattern	251661	78	
	Water bodies	543262	100	
C4	Barren or sparsely vegetated	13087891	79	72
	Broadleaved forest	305	42	
	Mixed forest	5137784	55	
	Discontinuous urban fabric	1866388	86	
	Sport and leisure facilities	472599	62	
	Non-irrigated arable land	8705103	77	
	Land principally occupied by agriculture, with significant areas of natural vegetation	3357379	66	
	Pastures	3748251	66	
	Transitional woodland/shrub	334298	63	
C5_Říčany	Barren or sparsely vegetated	7384609	82	80
	Broadleaved forest	1455686	65	
	Mixed forest	2584487	69	
	Discontinuous urban fabric	638747	93	
	Industrial or commercial units and public facilities	170889	96	
	Non-irrigated arable land	6344095	86	
	Land principally occupied by agriculture, with significant areas of natural vegetation	443336	80	
	Complex cultivation pattern	763425	71	
	Water bodies	14726	100	

Appendix IV: Precipitation (6 hours) for the return periods of 10, 50 and 100 years

- **Distribution of precipitation (hyetograph type F) for the return period of 10 years**

Time [hh:mm]	P [mm]	Time [hh:mm]	P [mm]
1:00	0.257	4:00	1.294
1:05	0.372	4:05	1.130
1:10	0.430	4:10	0.944
1:15	0.461	4:15	0.859
1:20	0.461	4:20	0.762
1:25	0.456	4:25	0.678
1:30	0.447	4:30	0.687
1:35	0.439	4:35	0.700
1:40	0.439	4:40	0.669
1:45	0.439	4:45	0.620
1:50	0.443	4:50	0.594
1:55	0.443	4:55	0.571
2:00	0.447	5:00	0.576
2:05	0.452	5:05	0.580
2:10	0.465	5:10	0.545
2:15	0.474	5:15	0.492
2:20	0.483	5:20	0.465
2:25	0.496	5:25	0.452
2:30	0.536	5:30	0.447
2:35	0.589	5:35	0.447
2:40	0.598	5:40	0.447
2:45	0.585	5:45	0.452
2:50	0.594	5:50	0.461
2:55	0.607	5:55	0.465
3:00	0.660	6:00	0.470
3:05	0.713	6:05	0.470
3:10	0.709	6:10	0.470
3:15	0.709	6:15	0.465
3:20	0.775	6:20	0.456
3:25	0.851	6:25	0.452
3:30	0.952	6:30	0.447
3:35	1.156	6:35	0.439
3:40	1.316	6:40	0.434
3:45	1.480	6:45	0.408
3:50	1.590	6:50	0.359
3:55	1.453	6:55	0.319

- **Distribution of precipitation (hyetograph type F) for the return period of 50 years**

Time [hh:mm]	P [mm]	Time [hh:mm]	P [mm]
1:00	0.342	4:00	1.72
1:05	0.495	4:05	1.502
1:10	0.571	4:10	1.255
1:15	0.613	4:15	1.143
1:20	0.613	4:20	1.013
1:25	0.607	4:25	0.901
1:30	0.595	4:30	0.913
1:35	0.583	4:35	0.931
1:40	0.583	4:40	0.889
1:45	0.583	4:45	0.825
1:50	0.589	4:50	0.789
1:55	0.589	4:55	0.76
2:00	0.595	5:00	0.766
2:05	0.601	5:05	0.772
2:10	0.618	5:10	0.724
2:15	0.63	5:15	0.654
2:20	0.642	5:20	0.618
2:25	0.66	5:25	0.601
2:30	0.713	5:30	0.595
2:35	0.783	5:35	0.595
2:40	0.795	5:40	0.595
2:45	0.777	5:45	0.601
2:50	0.789	5:50	0.613
2:55	0.807	5:55	0.618
3:00	0.878	6:00	0.624
3:05	0.948	6:05	0.624
3:10	0.942	6:10	0.624
3:15	0.942	6:15	0.618
3:20	1.031	6:20	0.607
3:25	1.131	6:25	0.601
3:30	1.266	6:30	0.595
3:35	1.537	6:35	0.583
3:40	1.749	6:40	0.577
3:45	1.967	6:45	0.542
3:50	2.115	6:50	0.477
3:55	1.932	6:55	0.424

- **Distribution of precipitation (hyetograph type F) for the return period of 100 years**

Time [hh:mm]	P [mm]	Time [hh:mm]	P [mm]
1:00	0.38	4:00	1.916
1:05	0.551	4:05	1.673
1:10	0.636	4:10	1.397
1:15	0.682	4:15	1.273
1:20	0.682	4:20	1.128
1:25	0.676	4:25	1.004
1:30	0.663	4:30	1.017
1:35	0.649	4:35	1.036
1:40	0.649	4:40	0.991
1:45	0.649	4:45	0.918
1:50	0.656	4:50	0.879
1:55	0.656	4:55	0.846
2:00	0.663	5:00	0.853
2:05	0.669	5:05	0.859
2:10	0.689	5:10	0.807
2:15	0.702	5:15	0.728
2:20	0.715	5:20	0.689
2:25	0.735	5:25	0.669
2:30	0.794	5:30	0.663
2:35	0.872	5:35	0.663
2:40	0.886	5:40	0.663
2:45	0.866	5:45	0.669
2:50	0.879	5:50	0.682
2:55	0.899	5:55	0.689
3:00	0.977	6:00	0.695
3:05	1.056	6:05	0.695
3:10	1.05	6:10	0.695
3:15	1.05	6:15	0.689
3:20	1.148	6:20	0.676
3:25	1.26	6:25	0.669
3:30	1.41	6:30	0.663
3:35	1.712	6:35	0.649
3:40	1.948	6:40	0.643
3:45	2.191	6:45	0.604
3:50	2.355	6:50	0.531
3:55	2.152	6:55	0.472