Team 08: Report Week 1

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WP2: Uncertainty in Advanced Hydrological and Hydraulic Modelling
WP3: Climate Change Impacts on Flash Floods
Case Study Upper Skawa Catchment (Poland)

Team 8 - Report Week 1: Flood Modelling, Calibration and Restoration of Catchment

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1 Hydrological Model of Upper Skawa Catchment and its Calibration

1.1 Introduction

The Upper Skawa catchment, situated in southern Poland, is a small mountainous area predominantly covered by non-irrigated arable lands, coniferous, and mixed forests. With a total area of 240.4 km2, it can be divided into six sub-catchments. There are four rain gauges in the catchment area, with one located on-site. Discharge data are available at the Osielec river gauging station, and the nearest meteorological radar is situated in Ramża, approximately 100 km northwest of the research area.

Recent flood events in 2010, 2014, and 2019 resulted in substantial material losses in built-up areas and significant topographical changes in forested areas. The transportation of logs in streams significantly contributes to sediment accumulation, increasing flood risk. Anticipated climate change effects suggest more frequent and intense precipitation events, indicating a likelihood of more severe floods in the future.

The characteristics of the Upper Skawa catchment, such as its relatively small area, mountainous terrain, quick response time, and a limited number of rain gauges, make it representative of similar study areas in Slovakia, the Czech Republic, and other parts of Europe.

1.2 Methodology

In the case of efficiency, teamwork was divided among members. Even though most of the group members completed the calibration individually, it was led by one user at the time. Then, the analyzing of HEC-HMS results and completing the daily report was done collaboratively.

After assessing the data, the calibration process is accomplished setting the following parameters:

- Curve Number
- Curve Number, Lag Time, Initial Abstraction

Initially, all data required ,especially the geometry file containing the topography of the studied catchment, to perform the hydrological simulation are provided to the group. Also, the spatial distribution of meteorological stations including measured precipitation, radar, and GPM are available.

1.3 Setting up the Model

The model provided was mostly set up with a couple of parameters and input data. The methods used were the SCS Curve Number for loss method, the Snyder Unit Hydrograph for transform method, and a recession model was used for baseflow.

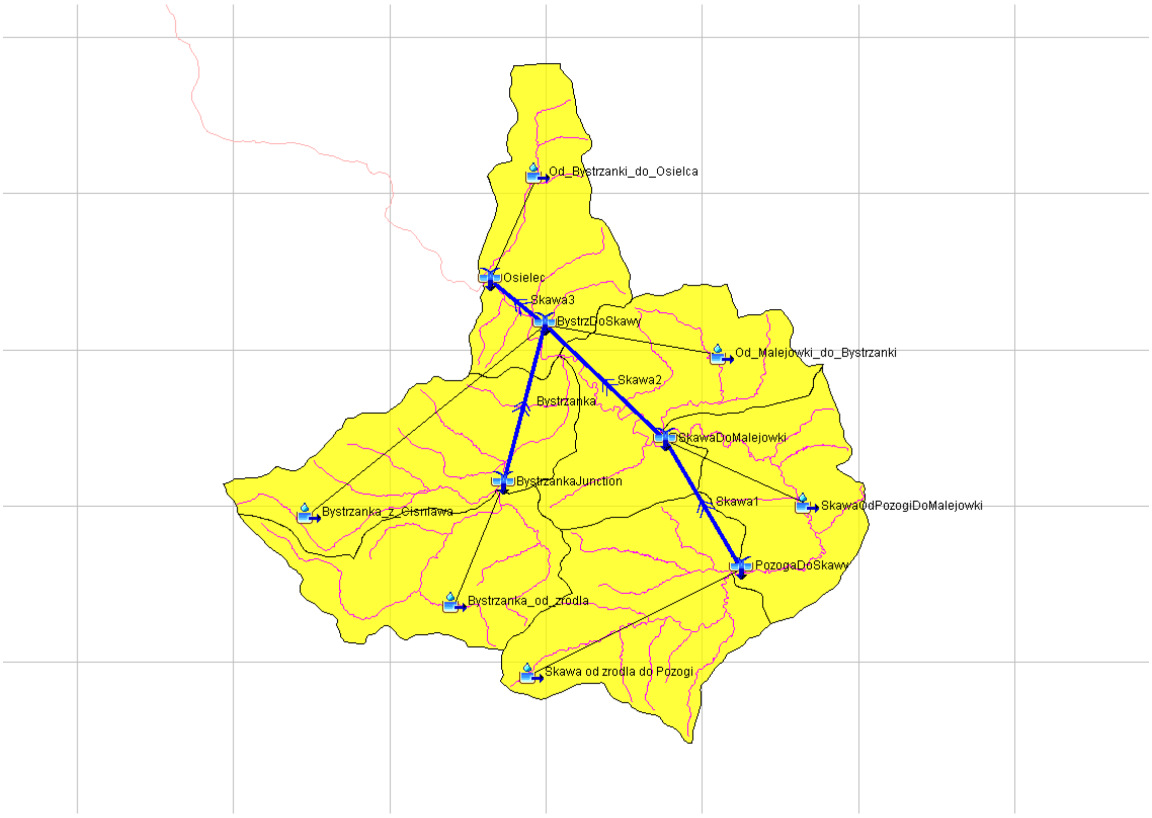

Fig 1. Upper Skawa visualization in HEC-HMS

First, the sub-catchment areas are calculated through Q-GIS and Those values are implemented on HMS.

Table 1 - Subcatchment Initial Parameterization

Label	Name	Area (km²)
SC-6	Osielca	36,73
SC-5	Bystrzanki	45,45
SC-4	Malejowski	33,75
SC-3	Pozogi	44,45
SC-2	Zrodla	36,28
SC-1	Cisniawa	42,06

Then, from multiple data tables, the values of each parameter of the loss, transform and baseflow methods must be filled.

Curve Number Loss [Skawa_catchment]

Show Elements: All Elements

Subbasin	Initial Abstraction (MM)	Curve Number	Impervious (%)
Od_Bystrzanki_do_Osielca	17,77	51,73	2,0053
Od_Malejowki_do_Bystrzanki	17,39	51,51	12,093
SkawaOdPozogiDoMalejowki	17,01	52,82	1,6057
Skawa od zrodla do Pozogi	18,39	50,88	1,1063
Bystrzanka_od_zrodla	25,23	43,02	1,4947
Bystrzanka_z_Cisniawa	27,21	41,18	2,2516

Figure 2 - Example of parameters filled in HMS : SCS Loss method

1.4 Running the Model

Prior to the simulations, the uncertainties related to the estimation of precipitation from satellite and radar versus traditionally used rain gauges must be characterised.

Satellite data is subject to more uncertainty in sparsely-gauged regions where satellite precipitation products can not accurately verify the satellite precipitation specifically over complex terrain (Gai, 2023). Rain gauges usually have great accuracy (Villarini et al., 2008). However, they are usually sparsely populated across the catchment, meaning spatially there is a great uncertainty due to changing intensity of rainfall spatially, resulting in the observed data either under/over-valuing rainfall in the area. As the Skawa catchment is mountainous with changing gradients, orographic rainfall is common, therefore the placement of a rain gauge in the catchment will have great effect on the observed data. To decrease uncertainty and to achieve higher quality data a merge of both raingauge and radar is beneficial, even if the radar data is of low quality and quantity (Nanding, 2021). For this report no merging of rain data was performed and instead the results between the two were compared and the data providing the best fit of simulated results was used.

Initially the model was ran using the following simulations:

- simulation run (non-calibrated) for GPM precipitation data
- simulation run (non-calibrated) for radar precipitation data

It was found that both runs provided a poor fit to the observed data. This was observed visually from the output hydrographs and validated using the NSE coefficient, peak flow and volume. For both results the simulated results underestimate the peak flow and the volume of the storm. The simulated and observed data are too different and calibration of the model is recommended.

Table 2 - Non-Calibrated model run results

	Observed	Non-calibrated GMP	Non-calibrated Radar
NSE	N/A	0.185	0.180
Peak Flow (m^3/s)	211.1	61.0	80.2
Volume $(1000m^3)$	19424	7603	8732

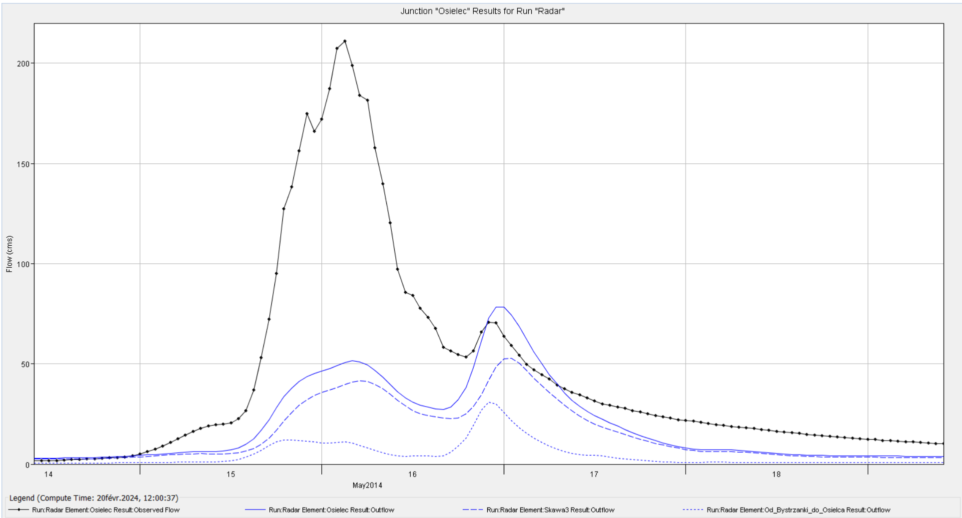

Figure 3 - Non-calibrated results of radar rainfall data

1.5 Optimization and Calibration of Model

HEC HMS has a built-in optimization tool that can adjust the model parameters to create a best fit result between simulated and observed data. Two optimization trials were performed. The first scenario the program was told to optimise only the CN for the sub-basins. For the second scenario, the CN, initial abstraction and lag time were optimised. Both scenarios were performed using the GPM and Radar data.

Scenario 1

By focusing on adjusting Curve Number values, the model may oversimplify the hydrological system. This can lead to a lack of representation of intricate processes influencing runoff generation. For example, the model may not adequately account for variations in antecedent moisture conditions, land slope, and other factors that affect the hydrological response. Consequently, the model's ability to accurately simulate real-world scenarios may be limited, and uncertainties may arise in predicting runoff under different conditions.

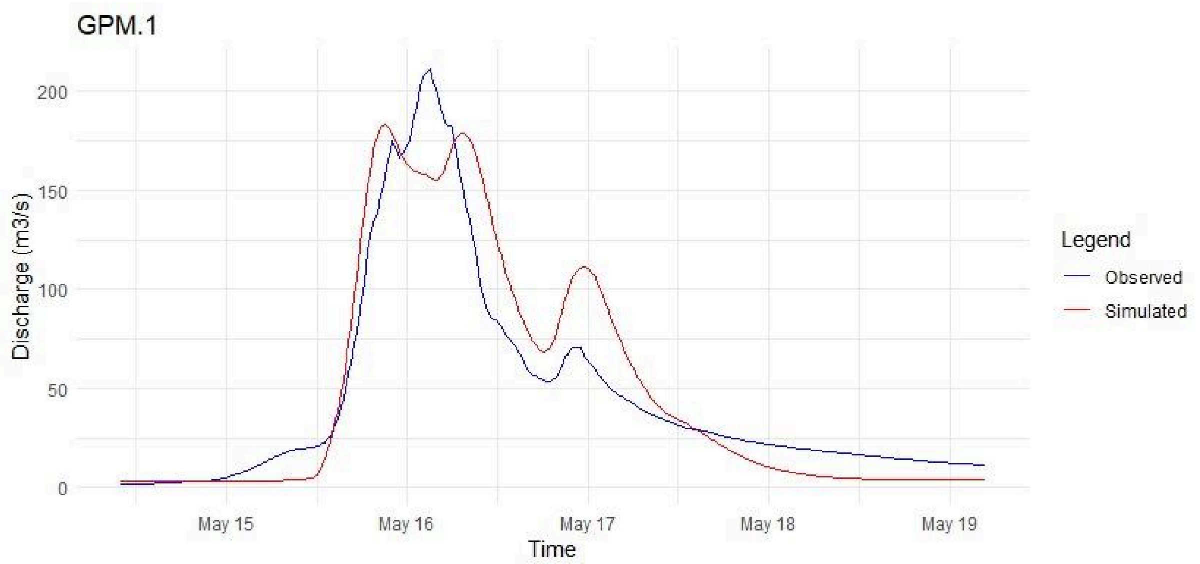

Figure 4 - Calibrated results from Scenario 1 and GPM rainfall

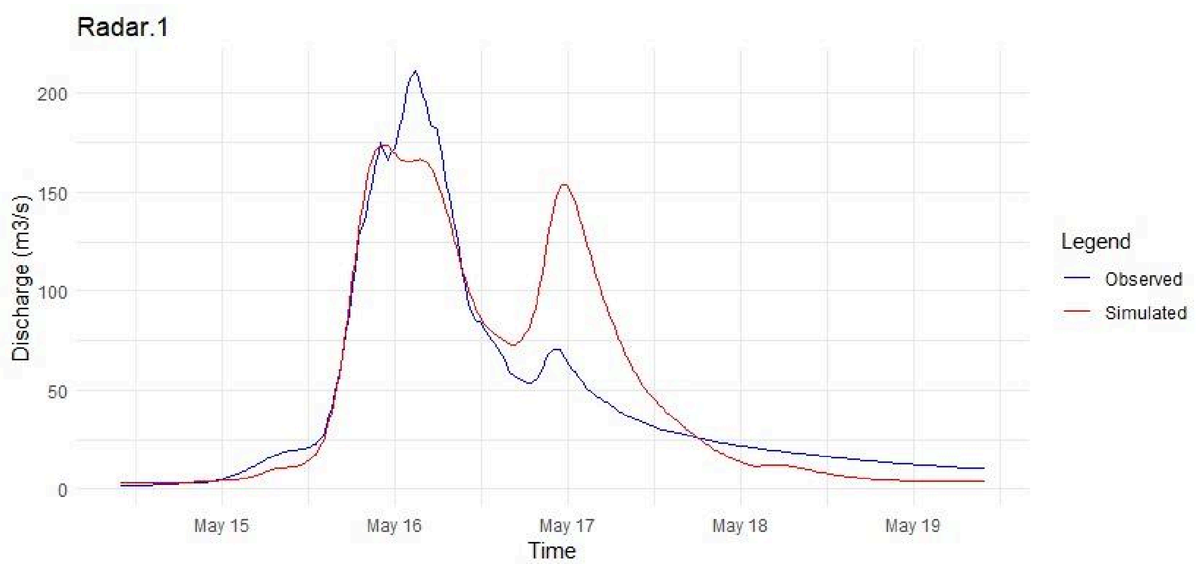

Figure 5 - Calibrated results from Scenario 1 and Radar rainfall

<u>Scenario 2</u>

The Scenario 2 optimization focused on the parameters CN, Initial abstractions and Lag time. The three parameters were adjusted simultaneously by the software.

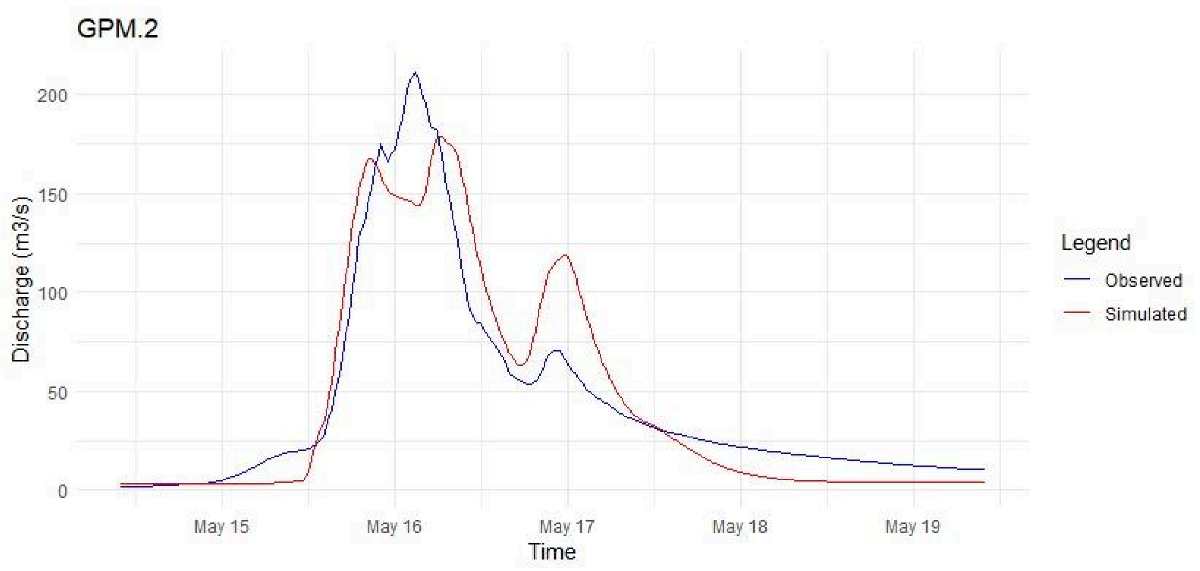

Figure 6 - Calibrated results from Scenario 2 and GMP data

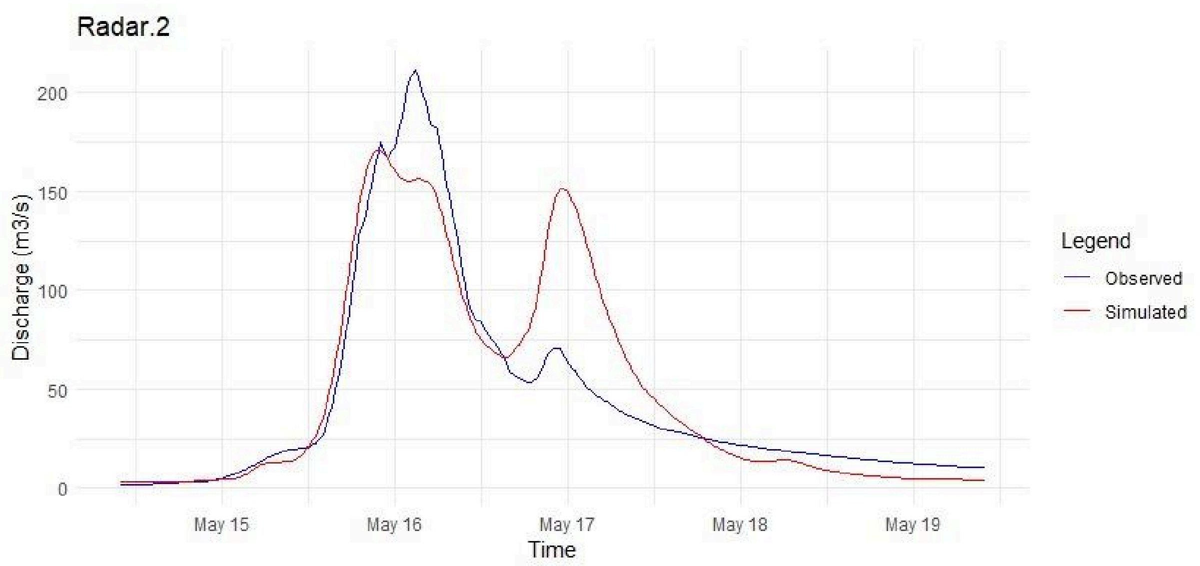

Figure 7 - Calibrated results from Scenario 2 and Radar data

Uncertainty in parameter interactions: Simultaneously calibrating multiple parameters introduces the challenge of understanding and capturing interactions between Curve Numbers, Initial Abstraction, and Lag Time. The optimal value for one parameter might depend on the values of others, leading to potential trade-offs. This interdependence can make it challenging to find a unique set of parameter values that collectively improve model performance across different hydrological conditions.

The inclusion of additional parameters increases the model's complexity, raising the risk of overfitting. Overfitting occurs when the model becomes too tailored to the specific dataset used for calibration, compromising its ability to generalise to new, unseen data. This can result in a false sense of accuracy during the calibration phase, but the model may perform poorly when applied to different hydrological conditions.

As shown in the table below is a summary of the four scenarios, the key factors identified when comparing the simulated models are the Nash-Sutcliffe Number, Peak flow, total volume, RMS, volume difference %, and the peak discharge. For the NSE value, a number closest to 1 would represent the best model compared to the observed flow, in the case of the four simulations this would be Scenario 2 (CN+Tlag) GMP with a value of 0.855. This number shows the model to almost match the observed flow and shows a good representation of flow in the catchment. The model which best recreated the peak flow compared with the observed data is also Scenario 2 (CN+ Tlag) GMP. For the closest time to observed peak discharge Scenario 2 (CN+Tlag) Radar was the best, with a difference of 5 hours between the observed and the model's time of peak discharge. The difference between both Scenario 2 models was only 1 hour 45 minutes, therefore this minimal difference should take less importance when comparing the models to each other and to the observed data. Finally when evaluating the RMS error Scenario 2 (CN+Tlag) GMP is the best fit model again, with a value of 19.8, compared to Scenario 2 Radar of 23.5, the lower value shows the better performing model. Therefore when comparing the models to the key factors the best fit model out of the four was Scenario 2 (CN+Tlag) GMP.

Table 3 - Statistical Results of Calibration Runs

	Observed	Scenario 1 GPM	Scenario 1 Radar	Scenario 2 GPM	Scenario 2 Radar
NSE	N/A	0.732	0.719	0.855	0.797
Peak Flow (m^3/s)	211.1	165.3	165.6	180.9	156.4
Volume $(1000m^3)$	19424	25730	24754	21885	21815
Volume % Difference	N/A	32.5%	27.4%	12.7%	12.3%
RMS Error	N/A	27.0	27.6	19.8	23.5
Time of peak obs vs sim (hrs)	0:00	-6:00	-24:00	-6:45	-5:00

Both Scenario 2 models undervalued peak flow rate, with Scenario 2 GMP having the closest flow rate, but still under-estimating the flow rate by 30.2 m^3/s. This is still a great difference of flow rate and can't be explained by the parameters. External factors from attaining the rainfall data may explain the great difference in peak discharges. As data obtained by radar and satellite is an estimation using many parameters and factors, there is great chance it may undervalue figures during periods of intense rainfall. The data sources of radar and satellite will have missed rainfall in the catchment for a decrease of flow to occur in the models. This could be due to the topography of the catchment. As the catchment is mountainous, orographic rainfall occurs, meaning if the radar cannot detect the cloud coverage due to the mountains, once the clouds move past the mountain and is in the radars detection area, most of the rainfall will have already fallen in the catchment, resulting in a greater discharge, but with a lower rainfall value from the radar.

The choice of calibration strategy should align with the specific goals of the modelling study and the available data, recognizing that uncertainties are inherent in the modelling process. Regular validation with independent datasets can help assess the model's robustness and improve confidence in its predictive capabilities.

2 Analysis of the Impact of Catchment Restoration on Runoff Formation

2.1 Overview of the Catchments Land Use

Urbanisation brings great challenges to the land and hydrological systems of a catchment. An increase of suburbanisation in small and middle sized cities has had a great impact on land use in many areas across Poland, including areas within the Skawa catchment (Majewska et al., 2020) . An increase in urbanisation within the catchment will correspond to an increase in impermeable surfaces as materials such as concrete will be used for civil engineering projects, such as buildings, roads and artificial surfaces. This increase in impermeability in the catchment will result in a greater runoff rate, increasing the volume of water entering the river due to a lack of infiltration. A decreasing forestation and vegetation due to urbanisation will also decrease interception and decrease the time taken for the rain to reach the surface. A combination of both as well as other important factors will greatly affect the discharge of the river in the catchment and given the catchment's mountainous terrain and intense precipitation , the region's annual flash floods will be exacerbated.

2.2 Analysis of Land Cover Change

The Corine Land Cover Data is an open resource inventory used to identify land use over time in a catchment. Data from 1990, 2012 and 2018 was downloaded and visualised based on the catchments boundary. The total area of catchment is 240.4 km^2.Table 1 includes each land use area percentage for three years. These can then be subdivided into three main areas based on their relative distinctive curve numbers, these three areas are: urbanised, crop, and forestry. These are shown in red, yellow and red respectively in Table 4 below:

Table 4. Areas of Land Covers in 1990, 2012 and 2018

CLC Code	Land cover	1990		2012		2018		Pattern
		Area [km²]	%	Area [km²]	%	Area [km²]	%	
112	Discontinuous urban fabrics	1.62	0.67	13.96	5.81	14.10	5.87	
121	Industrial or commercial units	0	0	0.33	0.14	0.28	0.12	
131	Mineral extraction sites	0.32	0.13	0.58	0.24	0.56	0.23	
211	Non-irrigated arable land	55.69	23.13	71.47	29.73	70.74	29.43	
231	Pastures	11.25	4.67	12.88	5.36	12.86	5.35	
242	Complex cultivation patterns	48.05	19.96	12.84	5.34	12.46	5.18	
243	Land principally occupied by agriculture	18.19	7.56	8.05	3.35	8.10	3.37	
311	Broad-leaved forest	6.95	2.89	7.97	3.32	7.82	3.25	
312	Coniferous forest	67.88	28.19	69.51	28.91	69.02	28.71	
313	Mixed forest	30.58	12.70	37.44	15.57	37.26	15.50	
321	Natural grasslands	0.23	0.09	0.17	0.07	0.19	0.08	
324	Transitional woodland-shrub	0	0	5.18	2.15	5.36	2.23	

A map comparing 1990,2012, and 2018 was then created to show a clearer representation of a change in land use over the 28 year period in figure 8 below:

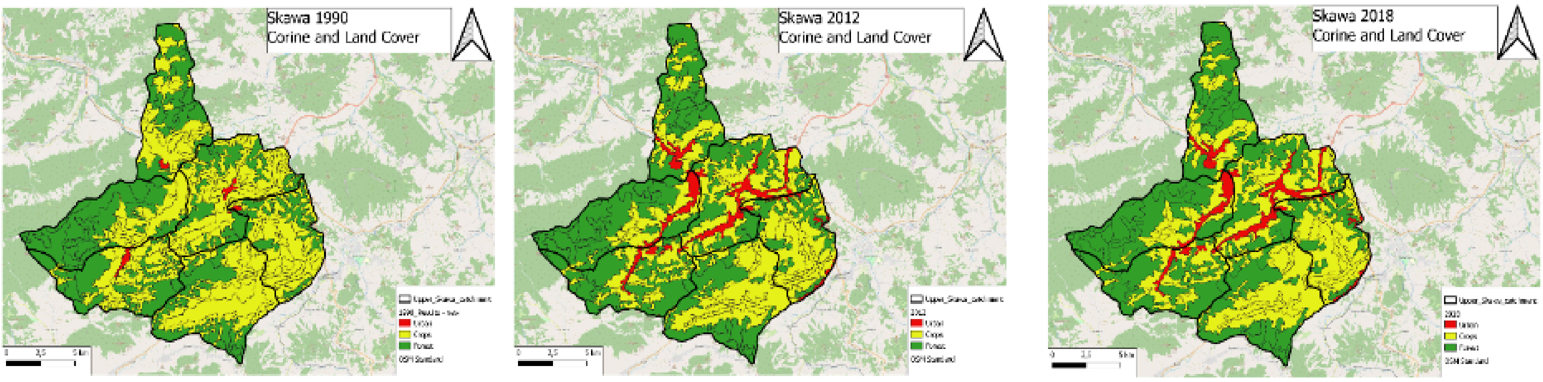

Figure 8 - Map of Changing Land use in the Upper Skawa Catchment

As shown in the images, there is a distinct increase of urban sprawl across the catchment as well as an increase in deforestation. A decrease in crop use is also prominent, however these changes in land use may be better visualised and evaluated in the chart in figure 9 below:

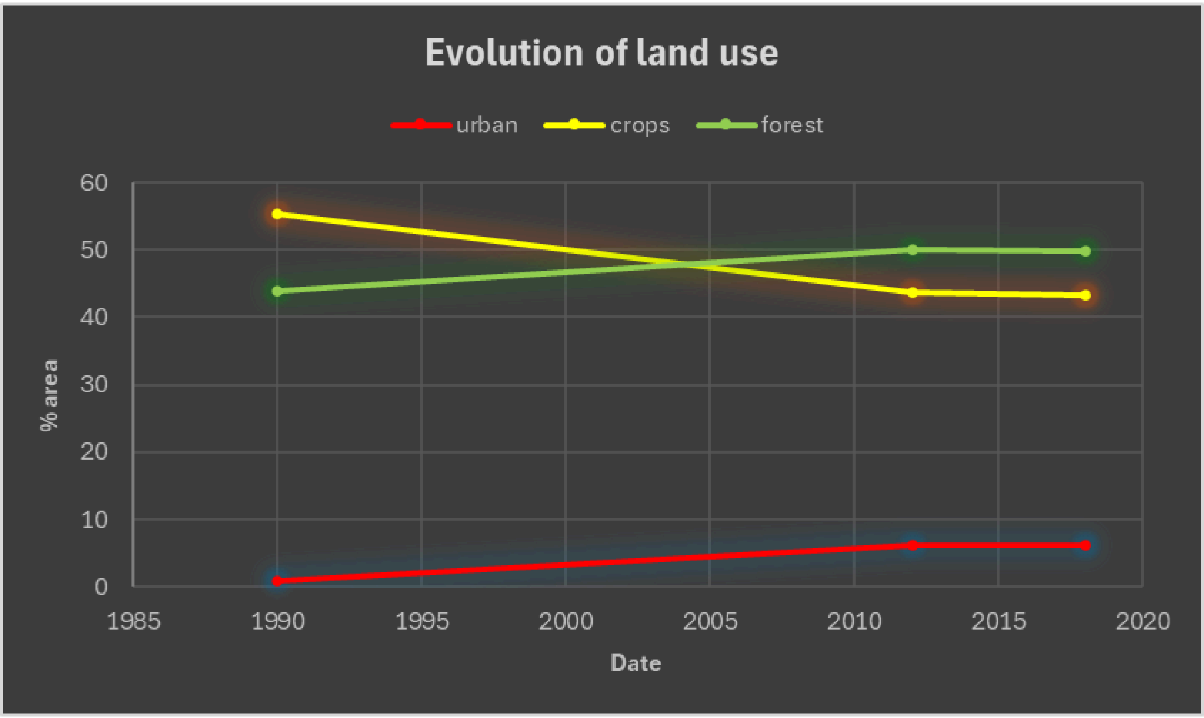

Figure 9 - Chart of the Evolution of Land Use in the Upper Skawa Catchment

We can observe that the part of urban land use is only 6 % while the rest is composed of crops and forest. Whenever, the urban and forest land use have slightly increased while the crops have decreased. These changes have important future implications and impacts on the Skawa catchment.

2.3 Impact of Catchment Restoration on Runoff Formation

The continuous urbanisation of the catchment reduces the area of non-irrigated land, which creates more runoff than all of the other land use whilst farming method is changed from Non-irrigated arable land to complex cultivation patterns. Subcatchment 3 doesn't have any urbanisation so it's not the main concern. During the period, urban areas are expanding and their contribution to higher runoff value can be noticed based on the CN and except 2 subcatchments (sc3, sc6) we see that others are facing higher CN.

Table 5. The changes of CN value in 1990, 2012, and 2018

Subcatchment	CN from CLC database			Change Over Time		
	1990	2012	2018	1990-2012	2012-2018	1990-2018
Bystrzanka z Cisnowa	44.01	47.12	47.24	7.06%	-0.27%	7.35%
Bystrzanka od źródła	43.58	44.60	45.31	2.34%	-1.59%	3.97%
Skawa od źródła	41.52	34.34	34.79	-17.31%	-1.31%	-16.23%
Od Pozogi do Malejówki	67.38	67.98	67.21	0.88%	1.13%	-0.26%
Od Malejówki do Bystrzanki	66.58	68.47	68.37	2.85%	0.15%	2.69%
Od Bystrzanki do Osielca	71.59	67.33	68.41	-5.95%	-1.61%	-4.43%

Shown above is the change in land use is apparent, with the highest change occurring in the Skawa od źródła sub-catchment, with a decreasing curve number from 41.52 to 34.79, indicating an increase in permeable surfaces and water drainage. The Bystrzanka z Cisnowa sub-cacthment had the largest increase of curve number with an increase from 44.01 to 47.24, indicating an increase of impermeable surfaces and surface runoff. Overall however it appears that the change in land use will not affect surface runoff and is not an imminent danger of increasing flood risk in the area, as the overall curve number is decreasing in the catchment over the last 28 years.

It is important however to be prepared for different situations in the future due to global warming and a changing climate could increase overall rainfall and flood risk in the catchment. This is why different simulations have been run with different inputs and situations to understand flow rates and risks to the local population, biodiversity and the change in the hydrological system it will create. It is therefore crucial to identify in the different scenarios, what is the best change in land use in the catchment to reduce discharge of the water during a flood event and its overall volume. This is to find ways in which to reduce risk to the local population as well as important infrastructure and the catchments local wildlife as well.

Re-naturalisation can be seen as important way in which the catchment can adapt to climate change, There are many ways in which restoration can be applied and analysed in the catchment, these include:

1. Ecological Restoration
2. Riparian Restoration
3. Wetland Restoration
4. Forest Restoration
5. Grassland Restoration
6. Urban Restoration
7. Aquatic Restoration
8. Land Reclamation

The impact of these restoration processes will decrease the overall runoff in the catchents, especially with an increase of both ecological, forest and grassland restoration. Increasing forestation in the catchment will increase interception and increase the time for rain to reach the ground to flow into the river, an increase in grassland and ecological restoration will help reduce curve number in the catchment, thus reducing runoff and peak discharge during periods of intense rainfall.

Three situations were created and simulated to see their effects on the peak discharge during a flood event as well as its total volume. Scenario 1 encouraged slow urbanisation of the catchment as well as a natural process of change. The simulation of the model compared to the 2018 baseline is shown in figure 10 below:

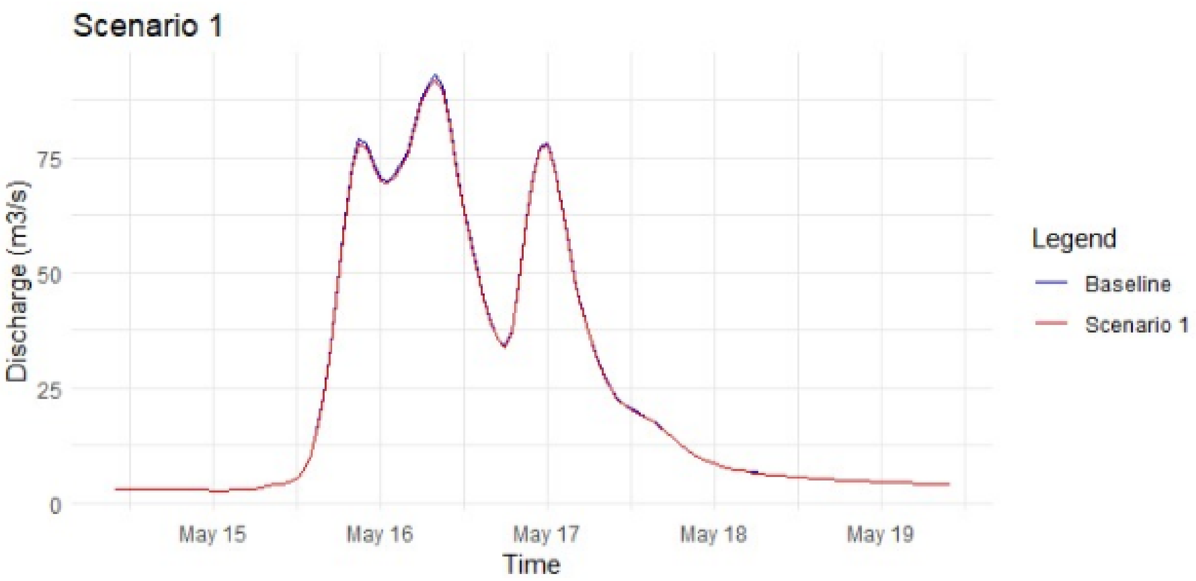

Figure 10 - Comparison of Scenario 1 to the Baseline Discharges

As shown there is minimal difference between the baseline and the first scenario, therefore showing a slow urbanisation rate as well as increase of natural processes of change shows only a decrease of 1.1 m^3/s and a decrease of 90 (1000) m^3 of water during the flood event period.

Scenario 2 had a change in farming method from Non-irrigated arable land to complex cultivated pattern. This was done as a realistic change in land management in the area as it is a more socially acceptable way of reducing the curve number in the catchment as agricultural production is not cut off, just changed towards something else. There will be push back as changing land use in the area will still affect the local population and push back from the population will occur, however compared to other factors that could be changed this may be the optimal option to keep the people happy whilst also reducing the curve number and subsequently the surface runoff in the catchment. This would have the impact of decreasing the curve number at a quicker pace than the first scenario. The result of scenario 2 is shown in figure 11 below:

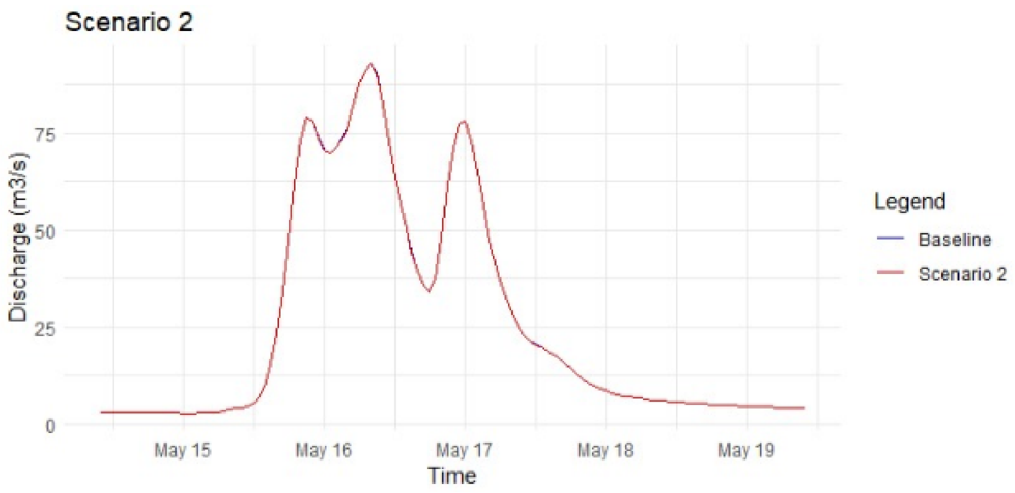

Figure 11 - Comparison of Scenario 2 to the Baseline Discharges

Shown in figure 11 above there is also minimal change between the simulation and the 2018 baseline flow. There was a decrease of peak discharge of only 0.1m^3/s, which in the model could be uncertainty error and may be seen as a negligible change in peak flow. There is a decrease of 10779 (1000)m^3 of volume however in the event, which is a far greater amount than shown in scenario 1, when comparing both models both have the benefit of reducing the impact of flooding in the catchment.

Finally scenario 3 is based on converting 20% of non-irrigated arable lands to mixed Forest. This should increase interception and increase the time for the rain to reach the catchment ground, slowing the flow rates of surface runoff into the river, thus decreasing the river's overall peak discharge. An increase of mixed forest will also increase infiltration and amount of water held by the forest and vegetation. This results in CN values to decrease, although not greatly, it shall still have an impact on peak discharge rate as well as total volume in the catchment. This can be considered as a long-term plan for the area, as it will take many years to let the forestation grow and decrease the Curve Number of the catchment. The comparison of the baseline to the scenario is shown in figure 12 below:

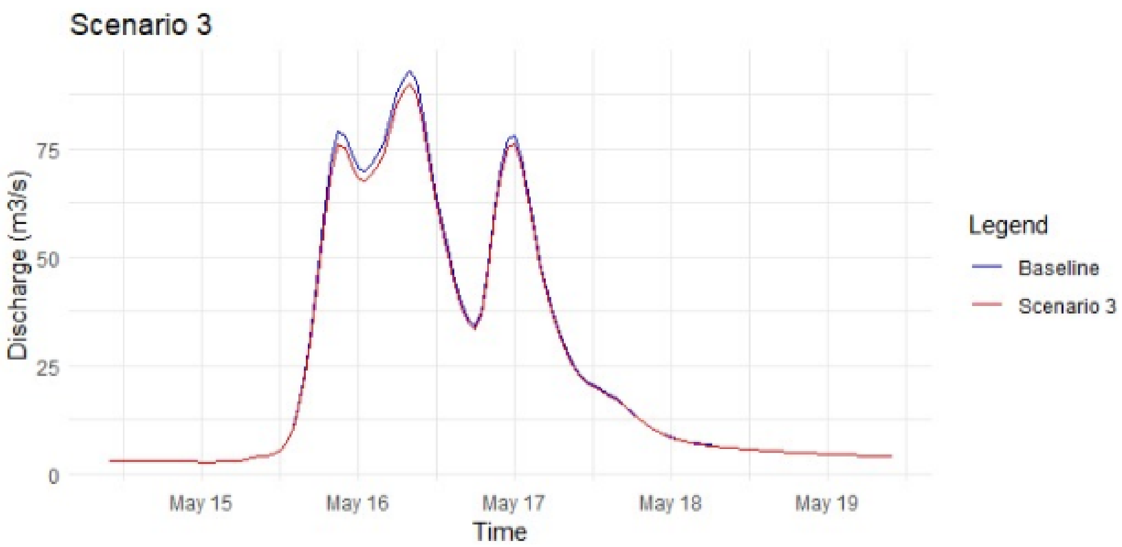

Figure 12 - Comparison of Scenario 3 to the Baseline Discharges

Scenario 3 can be seen as the best fit to decrease both volume and peak discharge in the catchment. A decrease of 3.1m^3/s and a decrease of 293 (1000)m^3 of volume. This is better in both factors compared to scenario 1 and 2, making it the optimal solution for the future, to help prevent flooding in the catchment during periods of intense rainfall in the future.

A summary of the three scenarios are shown in table 6 below:

Table 6. Summary of Scenarios 1,2,3 compared to the Baseline Peak Discharge and Volume

Characteristics	2018 Baseline	Scenario 1	Scenario 2	Scenario 3
Peak Discharge (m^3 /s)	92.9	91.8	92.8	89.8
Volume (1000 m^3)	11072	10982	11064	10779

All scenarios were compared to the 2018 baseline to compare the future impacts of changing land use on the most up to date data there is on the current land use in the catchment. As shown in the comparison between all scenarios, scenario 3 is the optimal situation to reduce peak discharge and volume during periods of intense rainfall.

There are benefits and problems with all three scenarios. The first is best in the short term as scenarios 2 and 3 are more long term as a change in agricultural practices as well as a change to forestation will take a couple decades to have a great effect on surface runoff and peak discharge. This could be too far in the future, with an increasing risk of a changing climate, there is great uncertainty of future rainfall as well as rate of change of the population in the catchment, meaning changing land use for the long term could be beneficial under the right circumstances but could have a negative impact in the short term if an increase in flood events and changing climate increases in the short term. This doesn't mean scenario 1 is the best option however as there is little to no decrease in peak discharge as well as volume compared to the other two longer term solutions. with a decrease of only 1.1m^3/s compared to scenario 3s decrease of 2m^3/s there is a need to evaluate the risks for the near future with the benefits of a higher decrease of peak flow and volume in the future.

3 References

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4 Appendix

Group's First Week Minutes:

- Starting the report.
- Setting up the model by entering required data:

  Subcatchments Areas were calculated using QGIS.

  Initial Abstraction, CN, imperviousness, Lag time, peaking coefficient, initial discharge, recession constant, and threshold flow were entered into the model.

- The non-calibrated model was operated using two different rainfall data sets (GPM and radar data).
- HEC-HMS auto-calibration was used to calibrate the model by three parameters (CN, Tlag, and Initial abstraction) for two different data sets of rainfall.
- GPM is a better data set to be used for the modelling based on NSE as Performance metric, Peak discharge, and Runoff volume.
- Land cover analysis of 1990, 2012, and 2018 was done after merging the landuses and dividing them into 3 types including Urban, Crop, and Forest.
- The Forest restoration scenarios were proposed and implemented with different portions of crop land and forest area.
- The results were analysed to finally come to the conclusion.
- preparing presentation .