EART62012: Environmental Monitoring and Modelling

Practical Book

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Chapter 1.

Practical Climate Analysis and Hydrological Modelling in Ethiopia

Question 1 (PB1): *Describe the spatial distribution of rainfall in the Rift Valley shown in the rainfall map produced from the regression analysis.*

Figure 1 below shows the regression rainfall map (left) and DEM of RVLB. The values of rainfall and elevation are represented in colours on each map. As we used regression to calculate the predicted rainfall, we can see that the regions with high elevation show high rainfall.

In general, the northern area shows more rainfall than the southern area, and the central area shows less rainfall than the east and west. The east area tends to show higher rainfall than the west except for some parts of the middle-west region (red-square in figure 1).

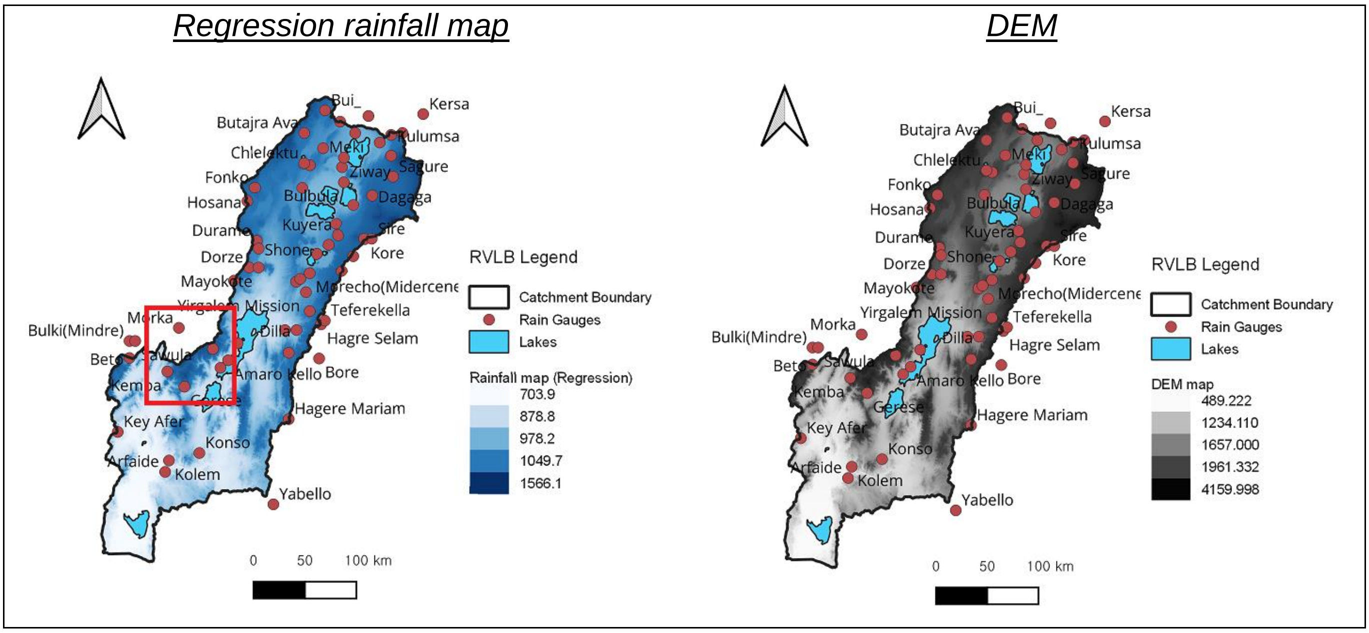

Figure 1. Regression rainfall map (left) and DEM of RVLB

Question 2 (PB2): *Compare the three rainfall maps. Comment on the general trends shown and any differences between these.*

Figure 2 below shows the rainfall maps of RVLB by regression, MQUAD, and cokriging. Lighter blue colour means more rainfall. In general, all three interpolation methods predict less rainfall in the central area than in the east and west, and more rainfall in the northern area than in the southern area.

We can find some differences between the interpolation method. First, two big differences can be found between regression and the other methods (MQUAD and Cokriging shows similar rainfall prediction). We can see regression predicts more rainfall in the northern area but less rainfall in the other areas than the other methods. Secondly, when comparing MQUAD and cokriging, we can find that less rainfall is predicted in general by cokriging than by MQUAD. It seems that reflecting the statistical dependence (spatial autocorrelation) between the rain gauges for the interpolation in cokriging led to less predicted rainfall for the ungauged areas than MQUAD.

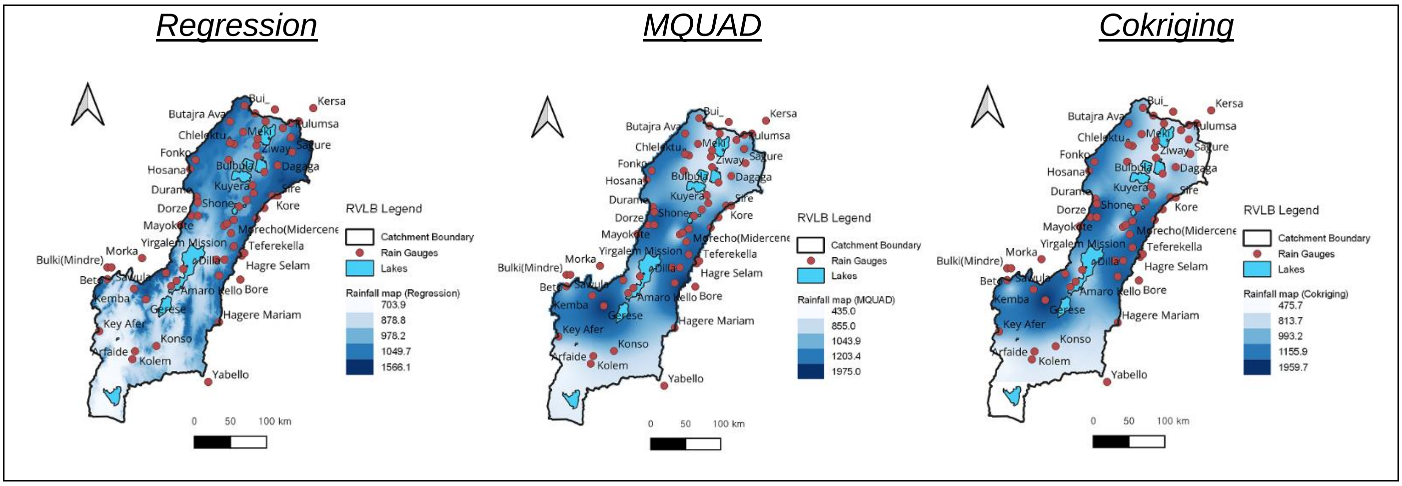

Figure 2. Rainfall maps of RVLB by regression, MQUAD, and cokriging

Question 3 (PB3): *Describe the spatial distribution of the evapotranspiration (ETo) in Rift Valley.*

Figure 3 below shows ETo, DEM, and a satellite image of RVLB. In ETo and DEM, lighter colour means a higher ETo value or elevation. In general, the ETo appears to be higher in the central and southern area of RVLB than the other areas. Compared to DEM, we can find that the regions with high elevation tend to show low ETo. And when we look at the satellite image, high ETo leads to low vegetation (pink colours), but not always, as shown in the red squared area.

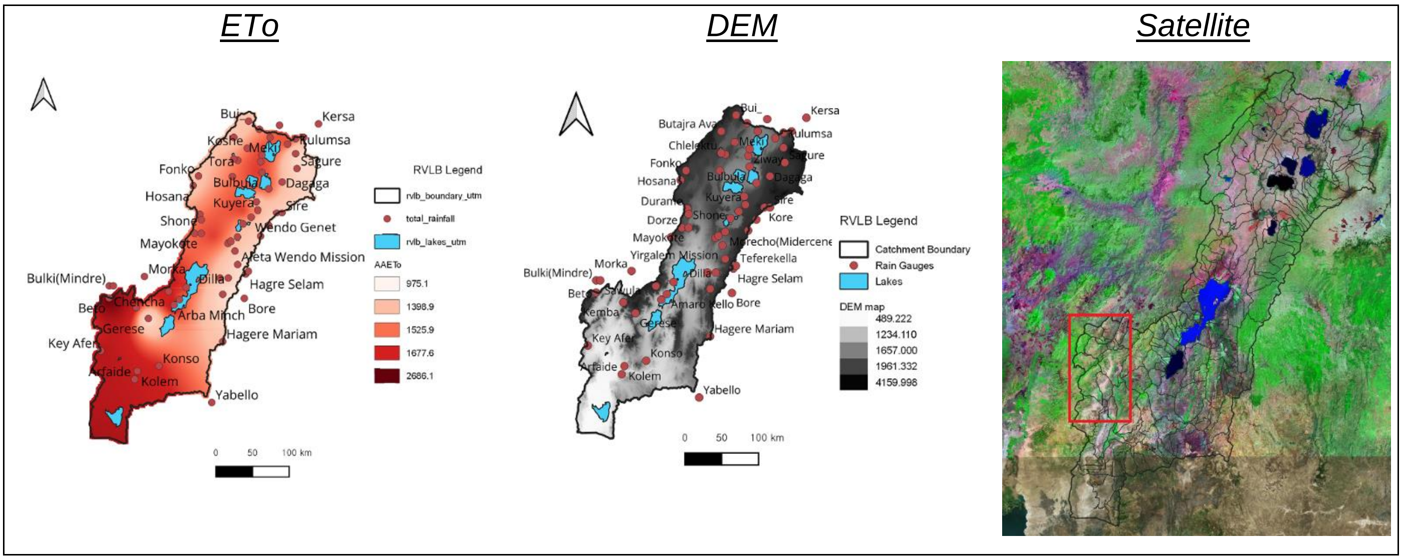

Figure 3. ETo, DEM, and satellite image of RVLB

Question 4 (PB4): *How will climate change impact water availability and agricultural production in the Rift Valley Lakes Basin? What solutions are there to manage this change in water availability?*

According to Godebo (2013), climate change will lead to increased evaporation and reduced rainfall in RVLB. And these changes will cause more stress on water availability and quality than the present, resulting in a reduction in agricultural production or even crop failure.

Various methods can be implemented to deal with this change in water availability. Figure 4 below shows the actual adaptation measures implemented by farmers in RVLB in ratios (Godebo, 2013). The first thing we can think about is crop rotation or using fertilisers. Improving the irrigation system can also be a way to increase the water use efficiency in agriculture. However, there may be disagreements regarding these measures as a fundamental solution to the water availability issue.

Chimdesa (2016) suggests afforestation can be a way to water conservation and reduce soil erosion or land degradation (Amede et al., 2007 cited in Chimdesa, 2016). According to him, it also can help to mitigate climate change. He also emphasises the importance of capacity building, which includes raising public awareness, education, social engagements, government policies and regulations, research, and any other social engagements.

In addition to these measurements, another important thing is to do continuous monitoring and make accurate predictions. It can be the foundation for more effective countermeasures against future water availability problems or any other issues caused by climate change.

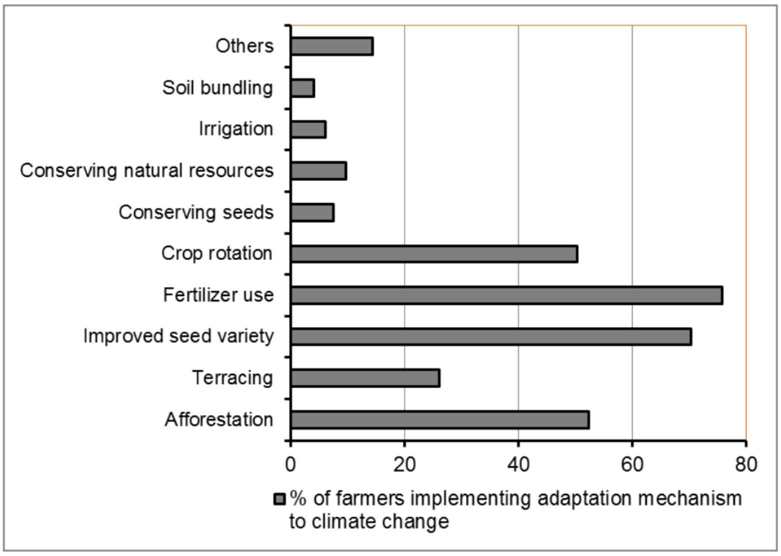

Figure 4. Different adaptation measures that farmers implement to deal with climate change and/or restore soil fertility (Godebo, 2013)

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Chapter 2.

Practical Hydrological Analysis UK

Question 1 (PB1): *Describe the hydrographs for the two floods in November 2000 and December 2002 recorded at the South bridge river gauge.*

The hydrographs in Figures 5 and 6 show two peaks appearing 100 hours apart. The first peak is smaller than the second one, and the peaks in December 2002 are higher than in November 2000, with a longer time period. The simulation model tends to overestimate the flows in November 2000 and the ones in December 2002.

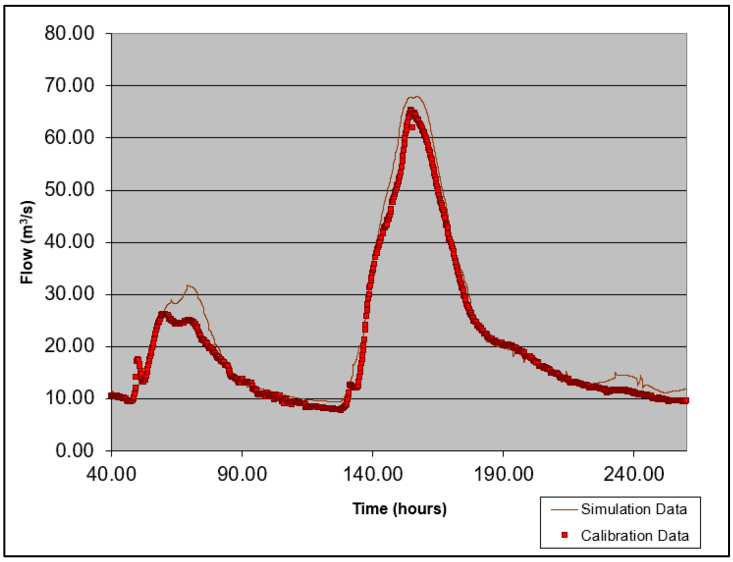

Figure 5. Hydrographs for the flood at the South bridge river gauge in November 2000

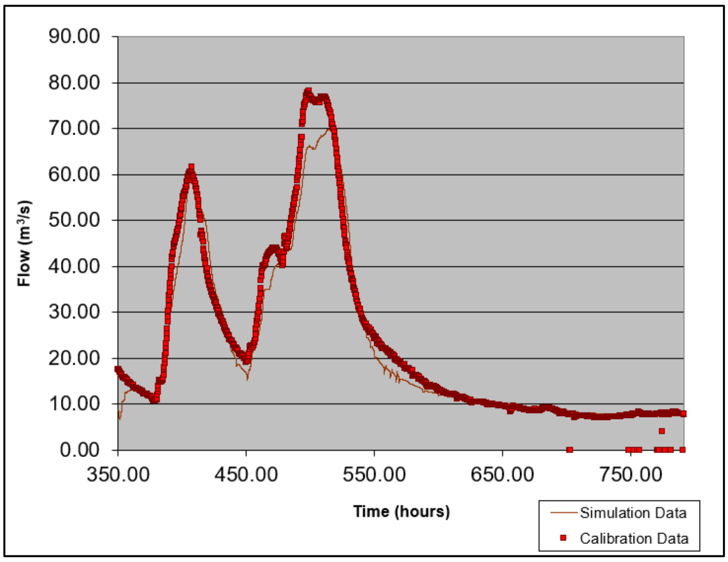

Figure 6. Hydrographs for the flood at the South bridge river gauge in December 2002

Question 2 (PB2):

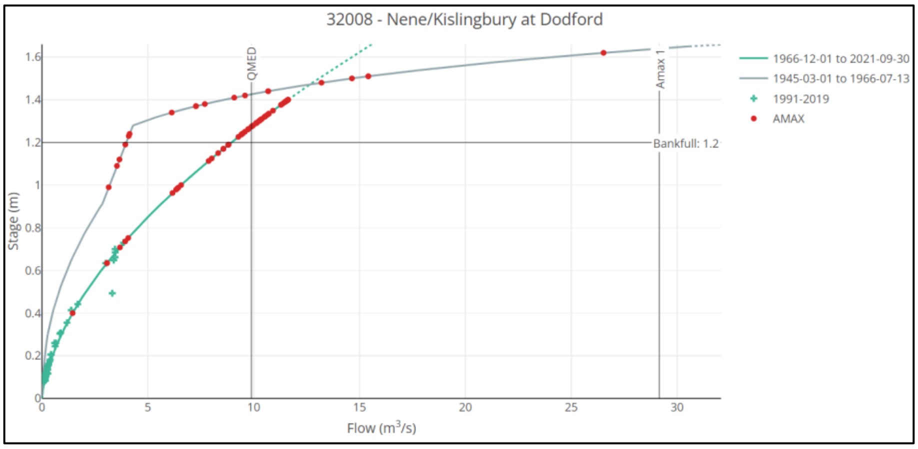

Figure 7. Peak flow rating curve of the river gauge at Dodford

a) How is flow estimated from continuous recorded water level?

By extrapolating the water level and flow record, we can get the rating curve to estimate the flow corresponding to a specific water level. In Figure 7, we can use the rating curve to get the flow value (x) corresponding to a specific water stage level (y).

b) What are common problems with a rating relationship at river gauges?

We get rating curves based on the records, but records with high flows or levels are usually rare or difficult to get. Therefore, rating curves tend to get less reliable for extreme values (Domeneghetti et al., 2012 and Pappenberger et al., 2006 cited in Gensen, 2022). Also, rating curves just show the mathematical relationship between water flow and level, not any conditions behind the records.

c) How can a rating relationship be improved through data collection or modelling techniques?

The rating relationship can be improved by collecting more data, especially one with high water flow or level values. Also, we can add some new data sources, such as satellite images, for topographic data. Meanwhile, we also can try various modelling techniques. We can try linear and non-linear models to determine which gives us better prediction performance. More advanced or sophisticated modelling techniques, such as artificial neural networks (ANN), can also help improve the rating relationship.

d) What effect would a poorly defined rating curve at a river gauge have on design flow estimates for building flood defences?

When the rating curve underestimates the water level, it leads to poor flood defence that does not properly protect against flooding.

Question 3 (PB3): *Briefly describe each flood frequency curve at each gauge and compare the differences between these flood frequencies.*

Figures 8 and 9 below show the flood frequency curves for River Nene at Dodford and South Bridge, respectively. Each curve shows the peak flow according to return periods from 2 to 200 years. The higher the return period, the higher the peak flow. The peak flow at South Bridge is higher than Dodford for any return period.

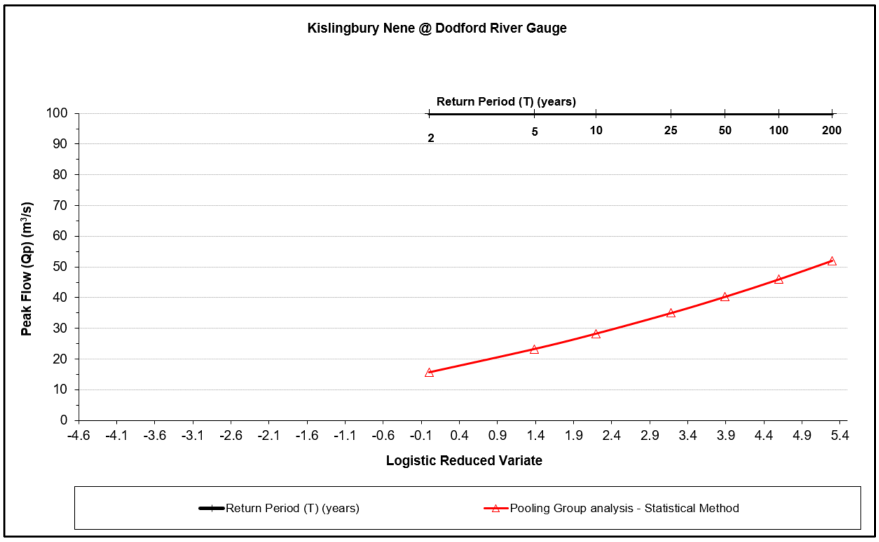

Figure 8. Flood frequency curve for River Nene at Dodford river gauge

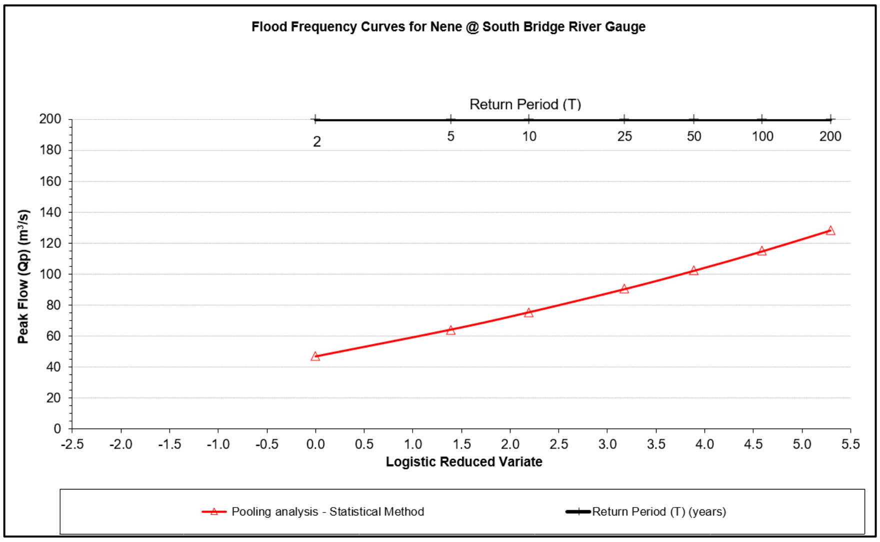

Figure 9. Flood frequency curve for River Nene at South bridge river gauge

Question 4 (PB4): *How does ReFH flood frequency curve compare with the flood frequency curve produced from the FEH statistical method at each curve?*

In Figure 10 (Dodford), the ReFH curve is similar to the FEH curve, showing little difference in peak flow of less than 5m^3/s. ReFH predicts higher peak flow for two years return period and less peak flow for return periods from 10 to 200 years than FEH.

In Figure 11 (South Bridge), the ReFH predicts higher peak flow than FEH (more than 20 m^3/s) for any return period. The bigger the return period, the larger the gap in peak flow values.

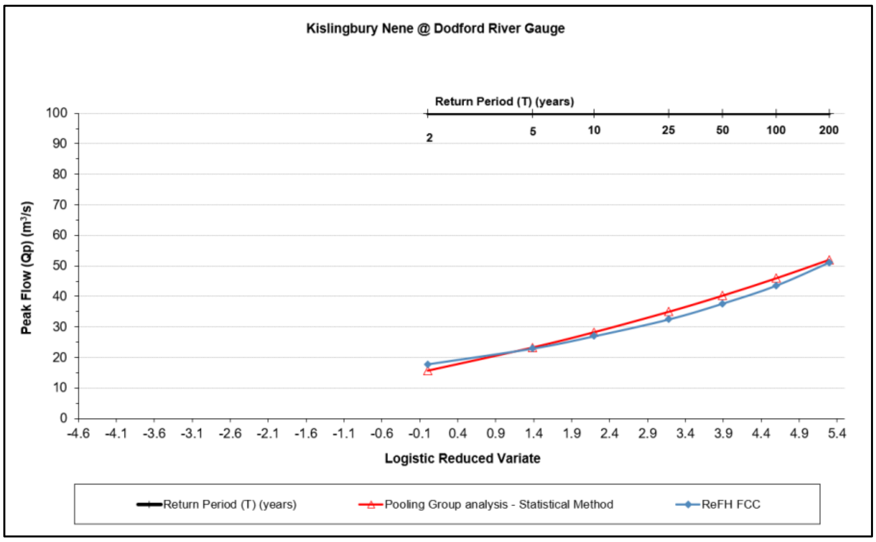

Figure 10. ReFH and FEH curves at Dodford river gauge

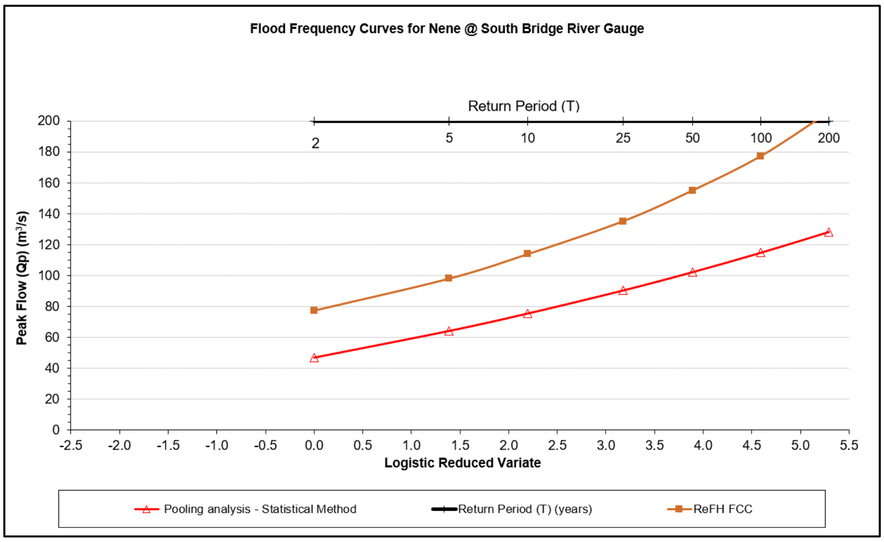

Figure 11. ReFH and FEH curves at South bridge river gauge

Question 5 (PB5): *What are the limitations of the FEH Revitalised (ReFH) rainfall-runoff method in UK flood studies? In which types of catchments does this method perform poorly?*

According to Kjeldsen et al. (2005), the ReFH method has several issues to consider as below:

1) For return periods of more than 150 years, the ReFH model does not guarantee its performance because no calibration or validation has been carried out.
2) The ReFH model might perform poorly for catchments larger than 750 km^2 because no validation has been carried out.
3) Care needs to be taken when applying the ReFH model to any urban catchments because we lack previous observations; Only seven out of the 100 catchments fell into the summer (urban catchment) category regarding the previously observed flood events.
4) Caution is required when applying the model to any permeable catchments because calibration results in very large C_{max} values, which are considered unrealistic.
5) The ReFH model needs to consider the volume of the flood and seasonality to improve its performance.

As shown in Figure 11 in the previous page, we can see that the ReFH model performs poorly for South Bridge.

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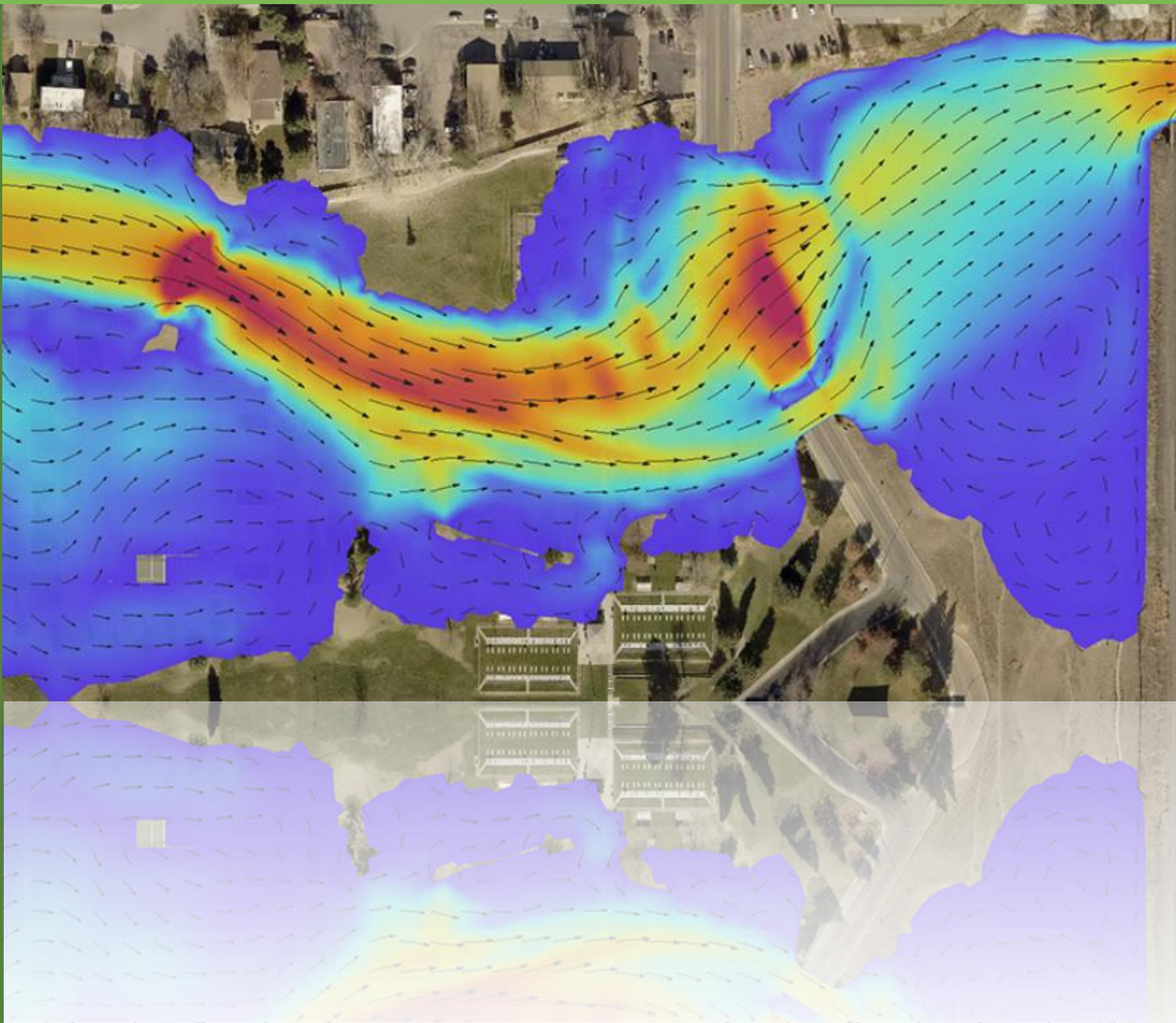
Chapter 3.

Practical Hydraulic River Modelling



Question 1 (PB1): *Describe the river channel and floodplain between node Upton_13090 and next the node Upton_12590.*

The width and depth of the river channel of Upton_13090 are about 9.07m and 109.8m, respectively. The width of the river channel of Upton_12590 is 10.19m, and the depth is 91m. The distance between the two nodes is 499.761m. The floodplain is the area with the lowest elevation around the nodes (Figure 13, left), which is farmlands (right).

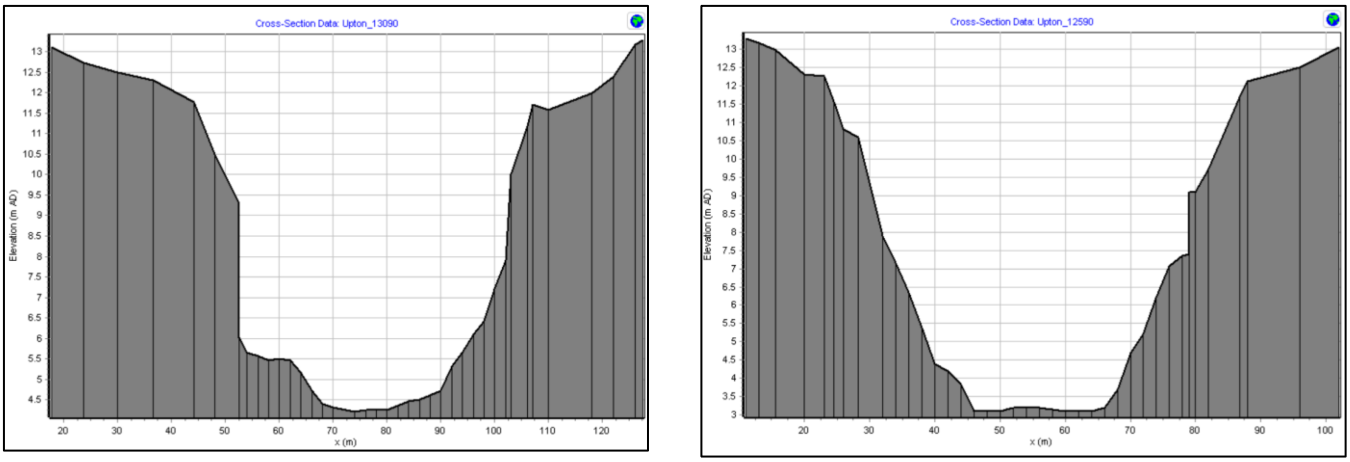


Figure 12. The river cross-sections of Upton_13090 (left) and Upton_12590 (right)

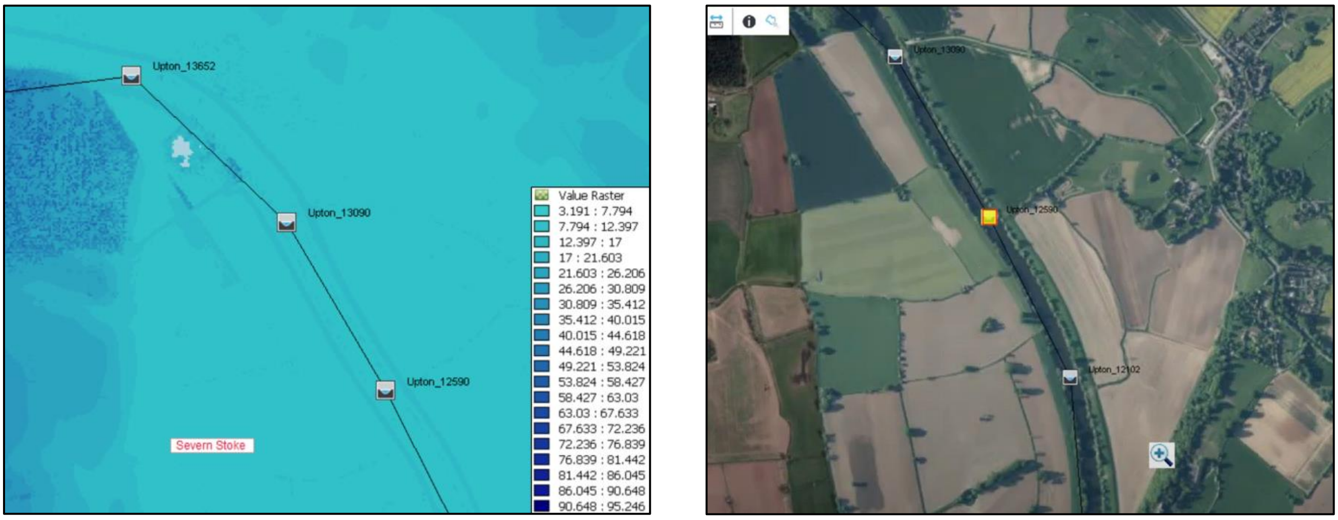


Figure 13. The floodplain around Upton_13090 and Upton_12590 (left: DEM, right: Satellite)

***Question 2 (PB2):** Does this floodplain have the potential to store floodwaters during extreme floods?*

The left map of Figure 14 shows the floodplain by the DEM of the area to study (the lightest blue-coloured area). The flood risk area stays within the floodplain in Figure 14 (right). Therefore, the floodplain might potentially store floodwaters during extreme floods.

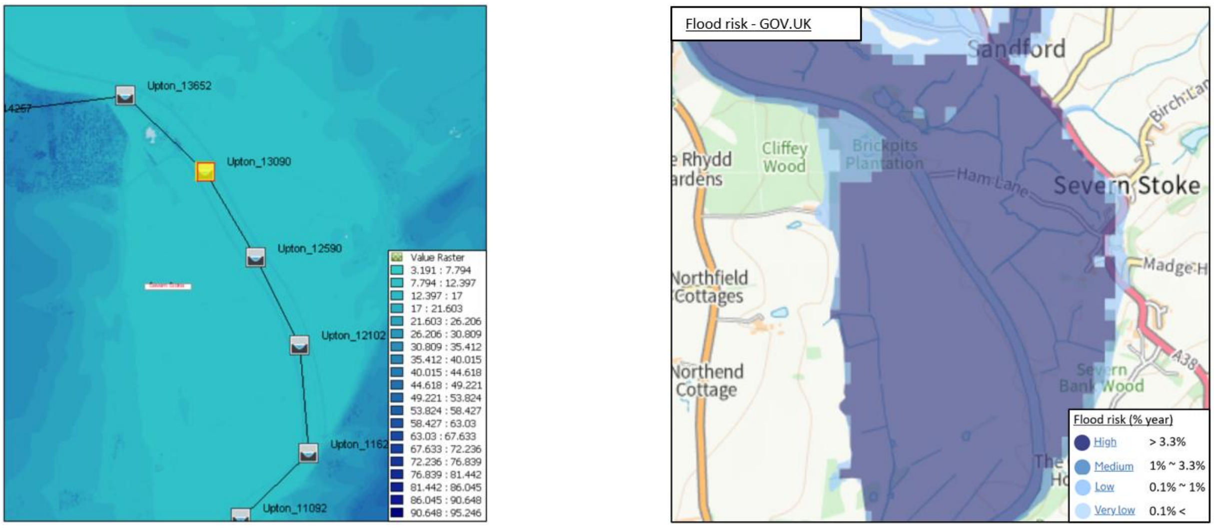


Figure 14. DEM around Upton_13090 & 12590 (left) and Flood risk map of the area (right)

***Question 3 (PB3):** Does node Upton_13090 river cross-section extends far enough in terms of distance on the left floodplain to fully represent this floodplain area and its flood storage potential?*

The left floodplain of Upton_13090 extends by 35.25m in the river cross-section (Figure 15, right), but the actual width of the left floodplain is 324.01m (left). Therefore, the river cross-section of the model does not reflect the actual extent of the left floodplain, underestimating the potential of the floodplain.

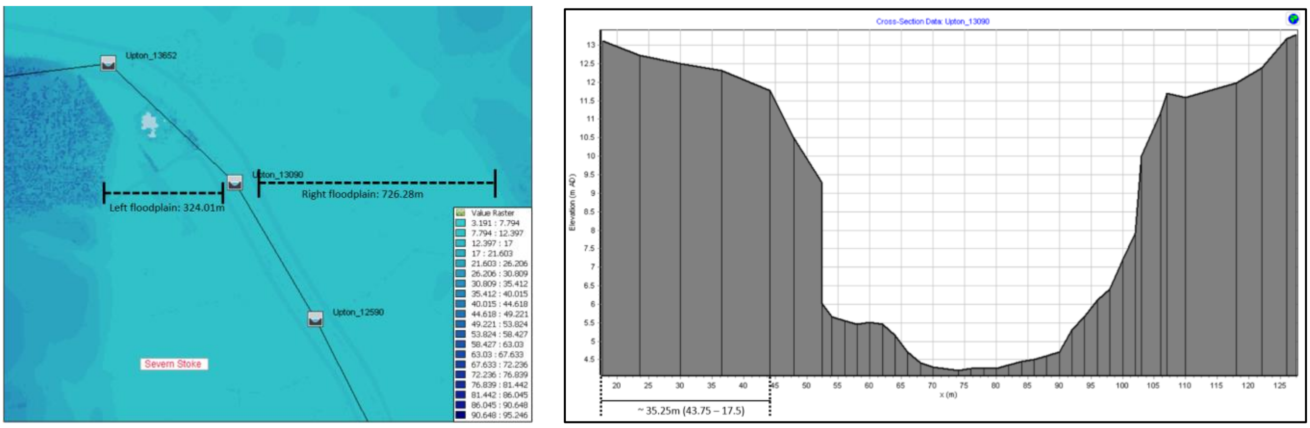


Figure 15. DEM and the river cross-section of Upton_13090

Question 4 (PB4): *Do the left and right floodplains extend far enough in the model to allow floodwater to be stored fully on each floodplain during an extreme flood? Also at this location, is the maximum flood water level at Upton_12590 over or underestimated and why?*

The left and right floodplain extends by 11.5m and 15m, respectively, in the model (Figure 16). However, Figure 17 shows that the actual widths are much wider than in the model (589.38m, 405.1m). Therefore, the model does not reflect the floodplain's actual extent and storage capacity, not allowing floodwater to be stored fully on each floodplain. As a result, this model overestimates the maximum flood water.

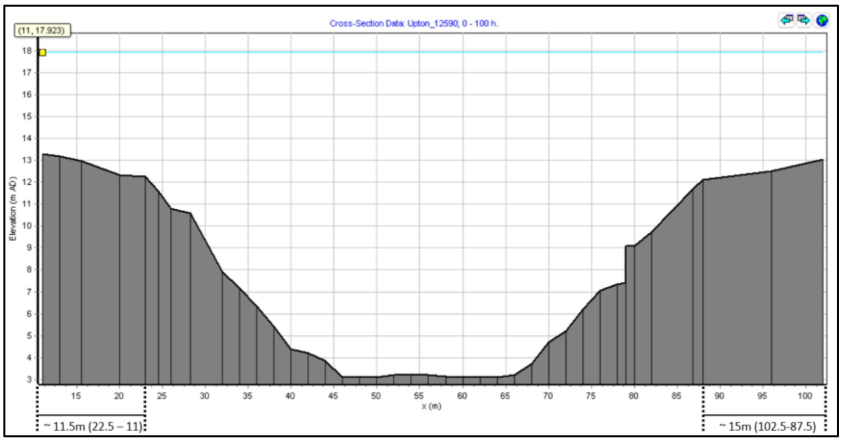


Figure 16. The river cross-section and maximum flood water level (light blue line) of Upton_12590

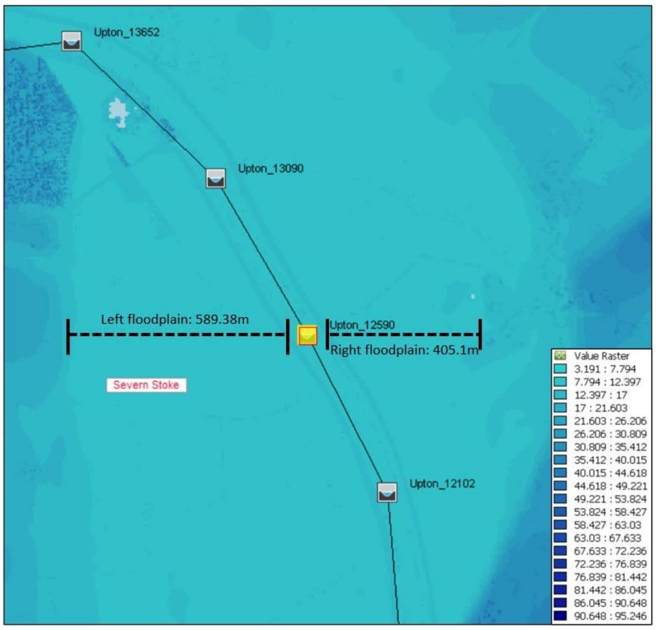


Figure 17. The DEM and the extent of the floodplain around Upton_12590

Question 5 (PB5): *Would you build your defences for the houses based on the 1D model results or would you do further modelling, if so what type of modelling would you recommend?*

The 1D model does not reflect the actual floodplain and overestimates the maximum floodwater level. A 2D model can show the flood water's movement and reflect the actual floodplain.

Question 6 (PB6): *How does the extent of the Upton_002 model compare to the Upton_001 model? For unit Upton_12590 how much wider is the cross-section? Use the measurement tool or plot the cross-section.*

The extent of Upton_002 is wider than Upton_001 for every node (Figure 18). For Upton_12590, the cross-section in Upton_002 is 1700.935m wider than Upton_001 (Figure 19) by reflecting the actual extent of the floodplains.

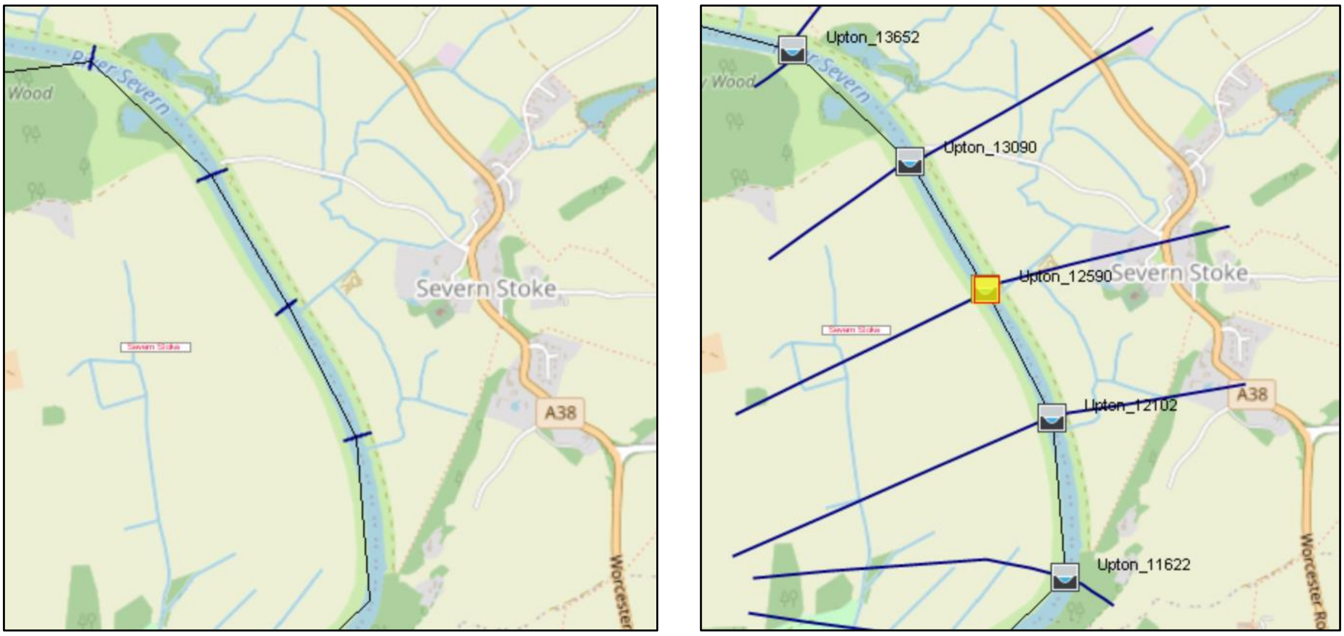


Figure 18. The extents of the Upton_001 (left) and Upton_002 (right)

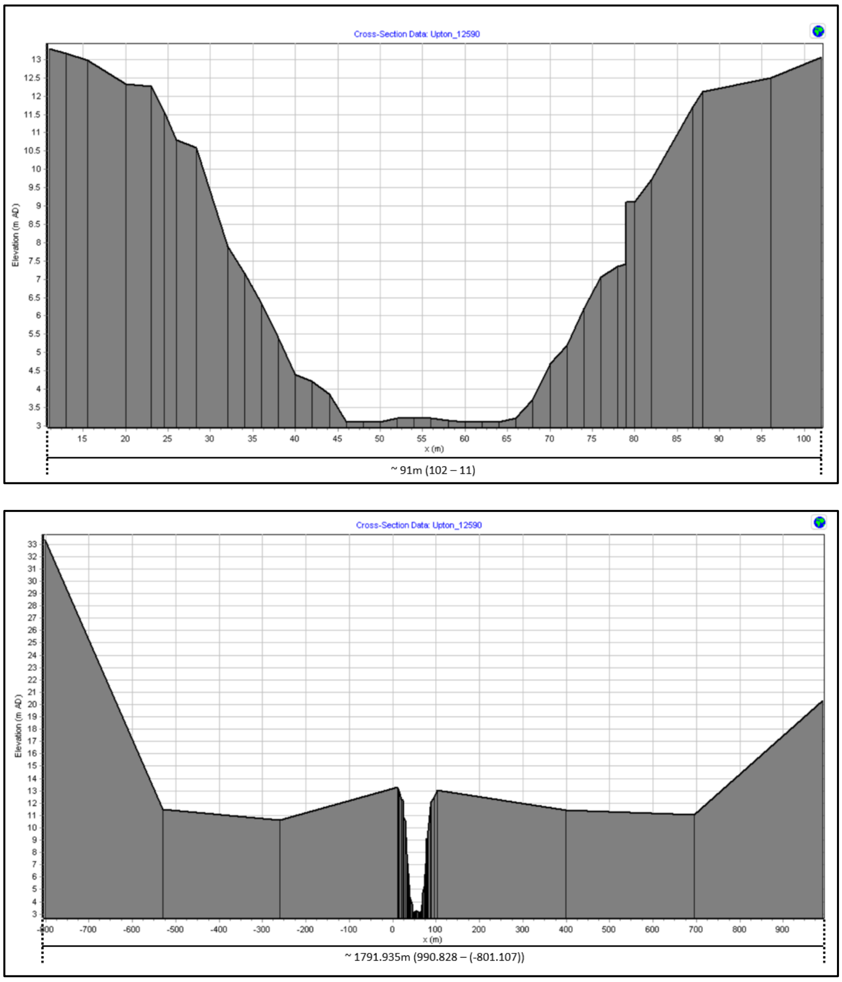


Figure 19. The cross-section of the Upton_12590 in the Upton_001 (up) and Upton_002 (down)

Question 7 (PB7): *Why is the peak outflow from Upton_002 different from the peak outflow from Upton_001 when comparing the plots shown in the simulation progress window?*

The peak outflow from Upton_002 is lower than Upton_001 (Figure 20, 966.50m < 1161.73m). This is because Upton_002 reflects the actual extent of the floodplain so floodwater can spread over it (Figure 18).

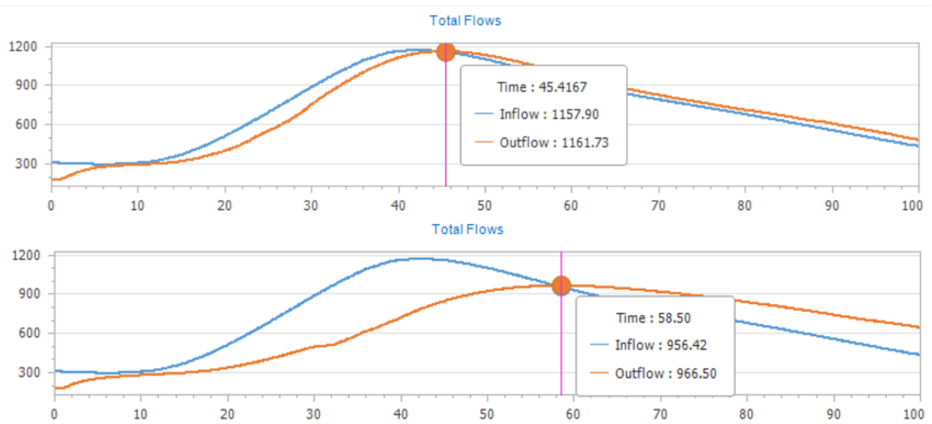


Figure 20. The time-series of the peak outflow from Upton_001 (up) and Upton_002 (down)

Question 8 (PB8): *Did water spill over the top of the embankment during the simulation? How does the elevation of the embankment vary from east to west?*

Figure 21 shows the time-step simulation of floodwater movement. As we can see, floodwater does not spill over the top of the embankment during the simulation. When we look at the cross-section plot of the elevation along the embankment (Figure 22, top-right), there is a certain area with an elevation lower than the average elevation of the floodplain (red-squared). We can infer that there is a hole in the embankment, so floodwater goes through it.

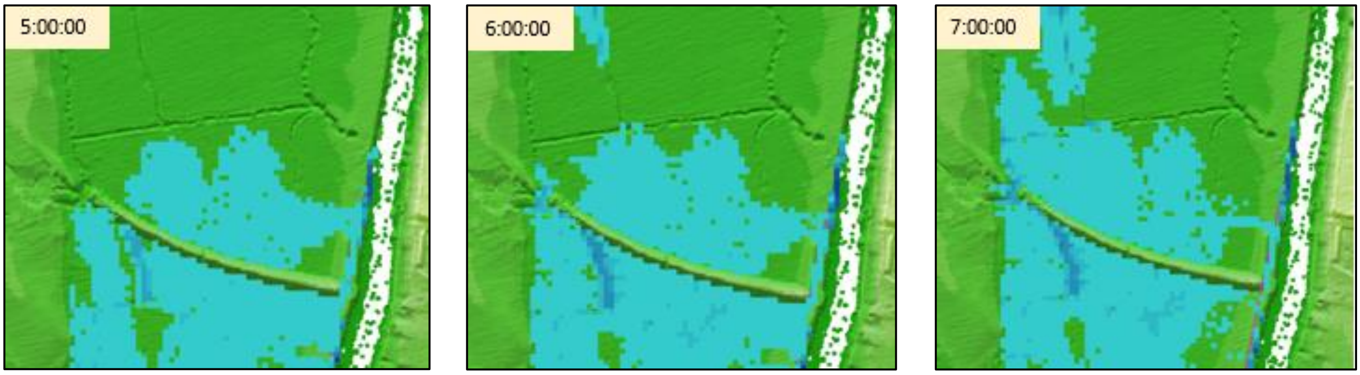


Figure 21. Time step simulation of floodwater movement

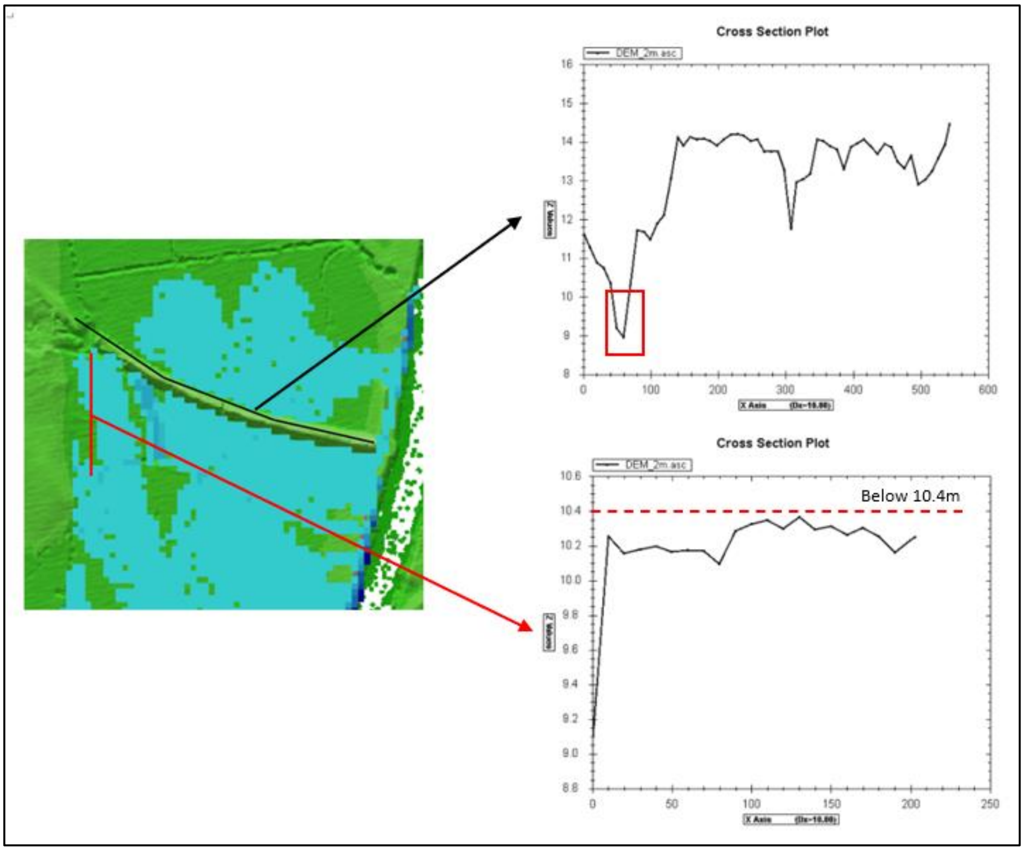


Figure 22. The cross-section elevation of the embankment (top-right) and floodplain (bottom-right)

Question 9 (PB9): *Under the "Domain" tab of the simulation there is a "Roughness Data" box. What Manning's "n" value has been assumed in your simulation? Do you think it is appropriate to use a single value across the whole model?*

Manning's "n" value represents the roughness of the land cover. Setting a single value seems inappropriate because the topographical characteristics and roughness can vary across the region.

Question 10 (PB10): *List some of the potential errors in the input hydrometric data and in the data used to build the 1D and 2D models. Then describe some of the limitations and uncertainties in the flood risk models.*

The input data used for the models is only about terrain elevations and main structures, such as bridges and embankments, with a single Manning's n value (0.045 for the 1D model nodes and 0.1 for the 2D model floodplain). Moreover, it does not include any information about vegetation, boundary conditions or other terrain features. According to Berends (2018), these are the sources of uncertainties in the model. Especially roughness is an important feature to consider because it affects the movement of floodwater in terms of time and space (flow and velocity). Berends (2018) also mentioned that the chosen estimation method for the model could be another source of uncertainties. According to Merz (2009), assumptions of extreme values or extrapolation can lead to uncertainties in the flood risk analysis. Due to the difficulties in measuring extreme cases or lack of data, we make assumptions or use extrapolation for the model, but the result does not guarantee that it reflects reality well.

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Chapter 4.

Practical Climate Hydrology & Irrigation

Question 1 (PB1): *Review the climate graph and comment on the availability of Gondar climate data (i.e. data gaps).*

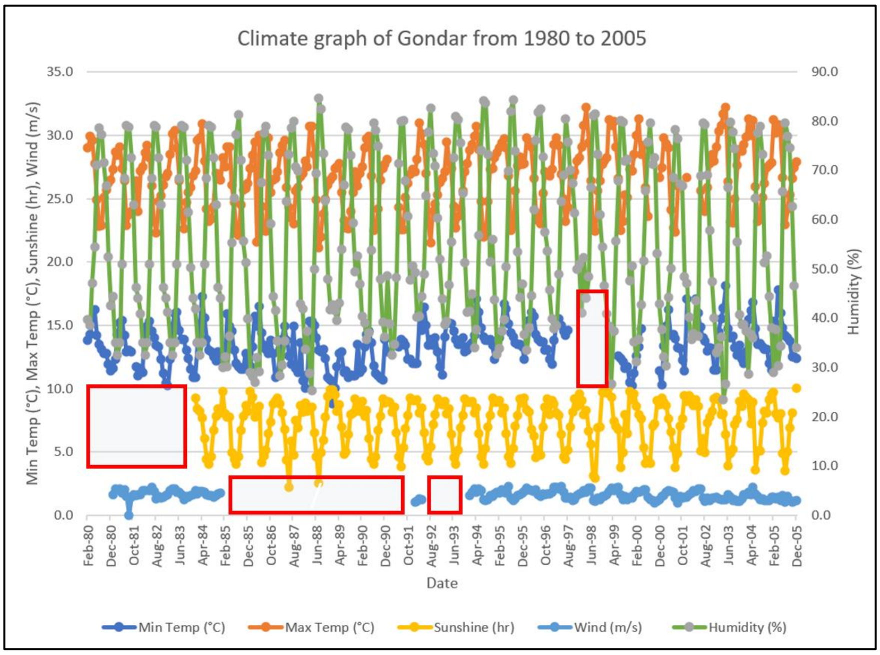


Figure 23. The climate graph of Gondar

Regarding the data availability, we can see blanks for some variables in the graph (Figure 23). The minimum temperature is missing from Aug-97 to Apr-99. And sunshine hours data is missing between Feb-80 and Apr-83. The wind speed data is missing for Feb-80, from Feb-85 to Oct-91, and from Aug-92 to Jun-93. Moreover, the horizontal(x) axis does not include the entire period, not showing the existence of missing values for any periods not in this graph.

Question 2 (PB2): *Describe the seasonal pattern of climate for the year 2005 for Gondar station. (Plot a graph for the climate data for the year 2005).*

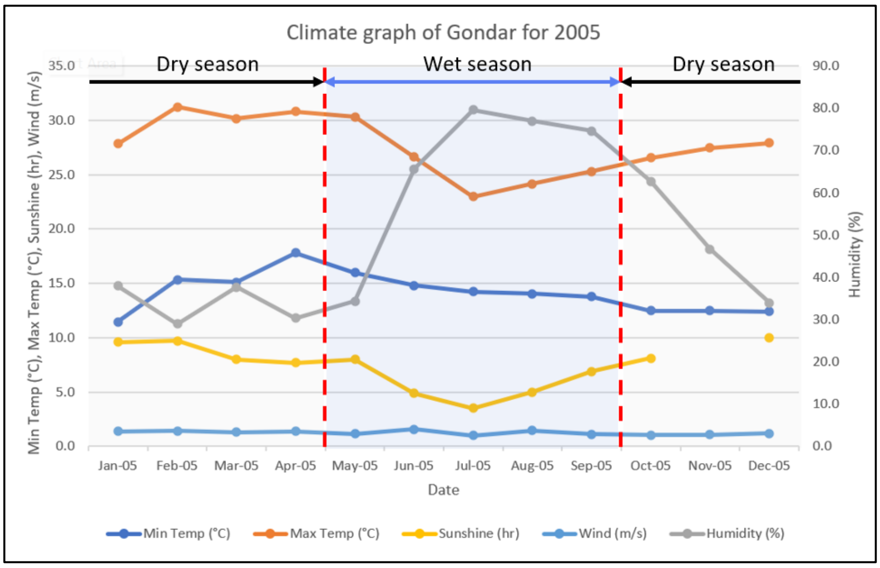


Figure 24. The climate graph of Gondar for 2005

Figure 24 shows the climate graph for the year 2005 for Gondar station. We can discover the seasonal pattern by looking at the climate factors except for wind speed, which stays almost the same (about 2m/s) during the whole period. Based on the pattern, we can split the year into two seasons. The first season is from October to April, which shows relatively long sunshine duration, high maximum temperature, and low humidity (dry season). The second season is from May to September, with high humidity, low maximum temperature, and low sunshine duration (wet season). The most distinguishable seasonal factor is humidity, followed by maximum temperature and sunshine duration. The minimum temperature does not move identically to the seasonal pattern compared to the other seasonal factors. The sunshine duration data is missing for November, but this does not significantly impact determining seasonality.

Question 3 (PB3): *Describe the seasonal distribution of default ETo. (Remember the 'wet' season is from May to September and the 'dry season is from October to April).*

The ETo begins to fall down from April until July (7.00 → 4.00), and stays lower than the dry season (Figure 25). Based on the result of question 2 above, low ETo during the wet season seems to be due to the high humidity and low sunshine duration. During the first 3 months of the dry season (from October to December), the ETo still stays low around 5.00, but from January it goes up to the peak of 6.74 in April. It appears to be because of long sunshine duration and low humidity.

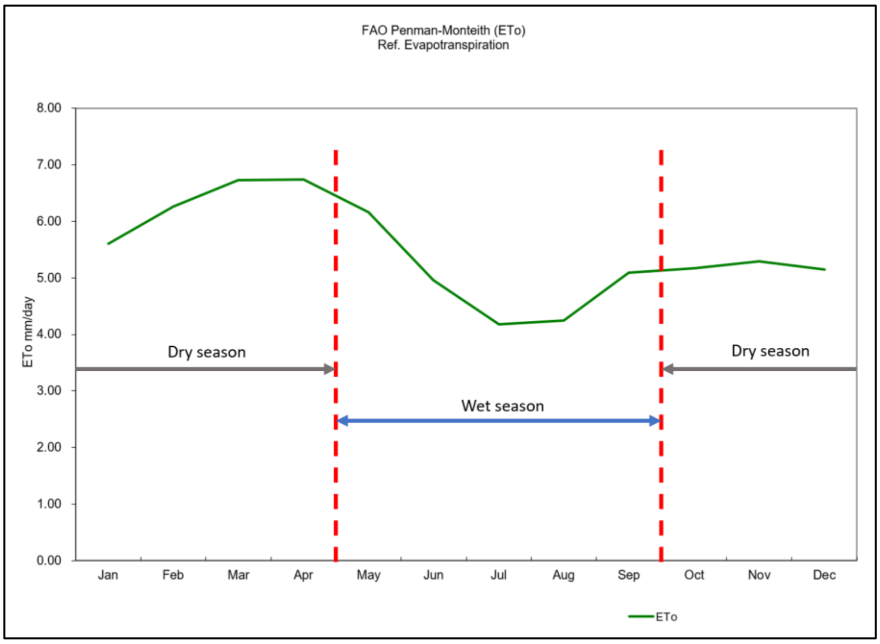


Figure 25. The default ETo graph

Question 4 (PB4): *How sensitive is ETo to changes in, latitude, elevation, wind speed, and humidity? Briefly explain why for each variable.*

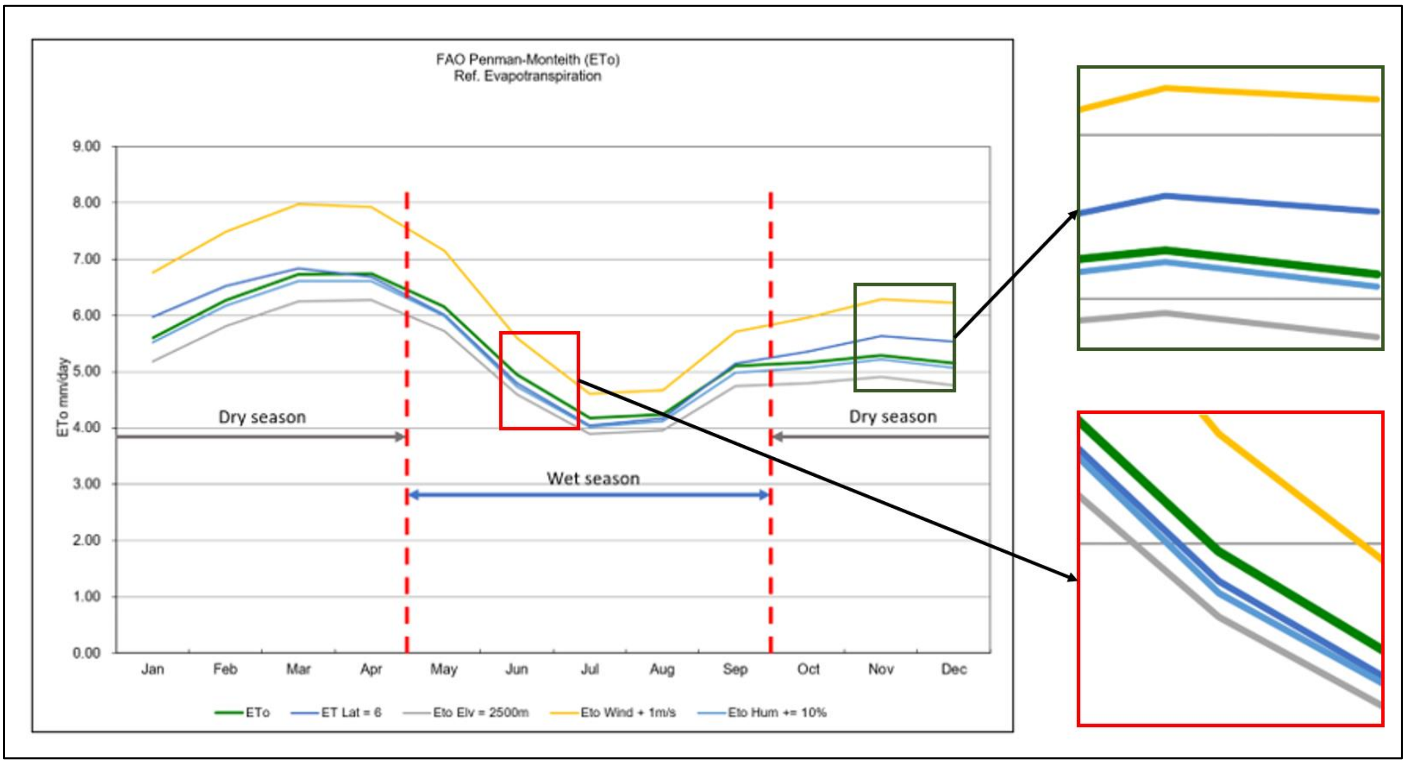


Figure 26. The ETo graph of different climate conditions

In Figure 26, the sensitivity of ETo for each change varies seasonally. First, the sensitivity gets larger in general during the dry season than in the wet season. It may be due to the difference in the climate conditions, such as sunshine duration and humidity. Secondly, the seasonality also changes the relative sensitivity; the changes in the latitude have more impact on ETo than the humidity during the dry season (top-right) and less in the wet season (bottom-right). This appears to be because the change in climate conditions according to the latitude gets larger in the dry season than in the wet season.

The ETo is comparatively more sensitive to elevation and wind speed than the other factors. The elevation changes lead to temperature changes, which appear to be an important factor affecting evapotranspiration. However, adding 1m/s to the wind speed makes the biggest changes in ETo, so we can infer that wind speed significantly affects evapotranspiration. However, this analysis needs more testing because the unit and the change amount differ for each factor.

Question 5 (PB5): *Describe the seasonal irrigation demands.*

Table 11

Irrigation scheme	Megech
Area (ha)	5000
Efficiency (%)	50%
Return (%)	20%

Table 12

Cropping pattern	Irrigation area (ha)	Irrigation area (km²)	Area per crop pattern (m²)	% cover
Irrigated	5000	50	50000000	100%

Table 13

rrigation efficiency	
Drip	90%
Sprinkler	80%
Surface	50%

Table 14

No of days	Month	Monthly Effective Precipitation (mm)	Daily ETo (mm)	Monthly ETo (mm)	Net Evap (mm)	Kc profile	CWR (mm)	Irrigation requirements (mm)	Irrigation requirements (m)	Total Irrigation demand (m³)	Irrigation demand (Mm³)	Actual Irrigation Demands (Mm³)	CC Monthly Effective Rainfall (mm)	CC Monthly ETo (mm)
Days	Formula	Peff	ETo (mm)	ETo (mm)	ETo-Peff	Kc	ETo*Kc	CWR-Peff	(CWR-Peff)/1000	(CWR-Peff)/1000 *Area	Demand/ 1000,000			
31	Jan	0.00	5.6	182.31	182.3	1.0	179.6	179.6	0.18	8978742	8.98	16.16	0.00	182.31
28	Feb	0.00	6.3	184.19	184.2	0.9	174.5	174.5	0.17	8726059	8.73	15.71	0.00	184.19
31	Mar	0.00	6.7	219.19	219.2	0.4	80.0	80.0	0.08	4000214	4.00	7.20	0.00	219.19
30	Apr	12.14	6.7	212.28	200.1	0.0	0.0	-12.1	0.00	0.0	0.00	0.00	12.14	212.28
31	May	24.29	6.2	200.56	176.3	0.3	56.2	31.9	0.03	1593489.1	1.59	2.87	24.29	200.56
30	Jun	100.14	5.0	156.08	55.9	0.8	118.6	18.5	0.02	924148.2	0.92	1.66	100.14	156.08
31	Jul	159.13	4.2	135.98	-23.2	0.9	121.4	-37.8	0.00	0.0	0.00	0.00	159.13	135.98
31	Aug	145.74	4.2	138.11	-7.6	1.1	157.5	11.7	0.01	585696.9	0.59	1.05	145.74	138.11
30	Sep	75.51	5.1	160.60	85.1	0.6	96.4	20.8	0.02	1042145.4	1.04	1.88	75.51	160.60
31	Oct	8.92	5.2	168.15	159.2	0.0	0.0	-8.9	0.00	0.0	0.00	0.00	8.92	168.15
30	Nov	3.18	5.3	166.82	163.6	0.5	78.4	75.2	0.08	3761541	3.76	6.77	3.18	166.82
31	Dec	0.00	5.1	167.61	167.6	0.8	134.1	134.1	0.13	6704269	6.70	12.07	0.00	167.61
		529.04	65.6	2091.88	1562.84	0.60	1196.54	667.50	0.73	36316303	36.32	65.4		

Figure 27. The irrigation demand calculation table

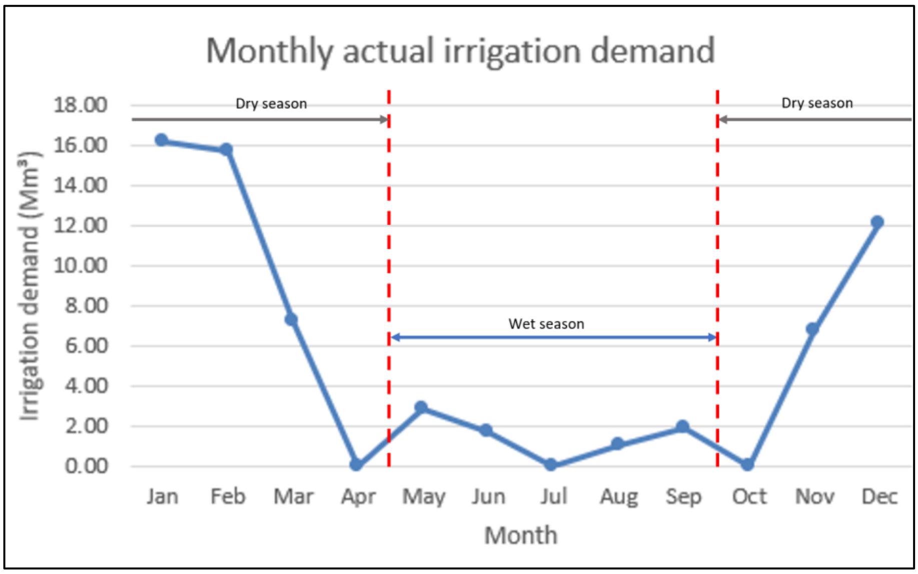


Figure 28. Monthly actual irrigation demand of Megech

Figure 28 shows the monthly actual irrigation demand (climate change reflected) derived from the table in Figure 27. The demand is high in the dry season (Oct–Apr) and low in the wet season (May–Sep). This is mainly because of the high monthly effective precipitation during the wet season and low precipitation in the dry season.

Chapter 5.

Practical Glacier Hydrology

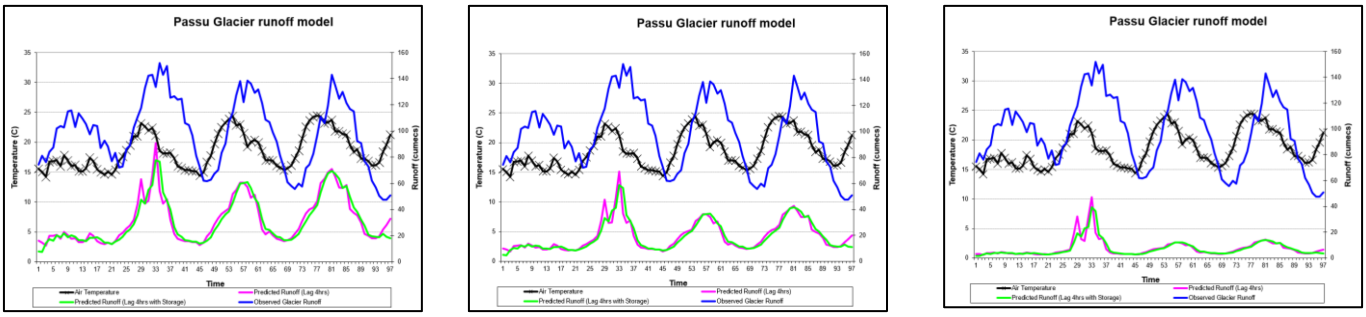
Question 1 (PB1): *For each parameter discuss what effect altering its value has on predicted runoff and explain why.*

a) Table 1 shows the basic setting to test different values of parameters.

Parameter	DDF	Lapse rate	Snowline Elev
Value	0.5:0.5 (Snow:Ice)	0.5 °C per 100m (10.0 °C per elevation zone)	2500m

Table 1. The basic setting for testing different parameters

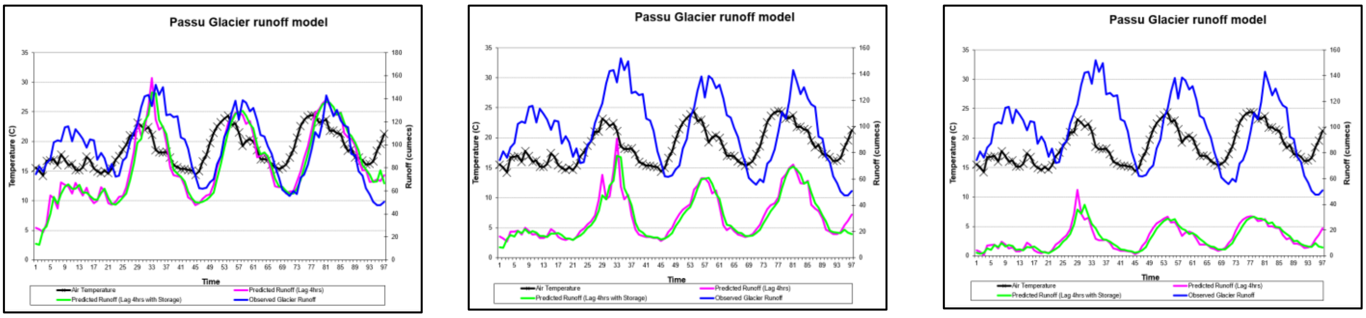
b-1) DDF parameter: Giving higher ratio to Ice makes the predictions lower and flattened.



0.5:0.5 = Snow:Ice   0.3:0.7 = Snow:Ice   0.1:0.9 = Snow:Ice

Figure 29. The graph of the Passu Glacier runoff model with different DDF parameters

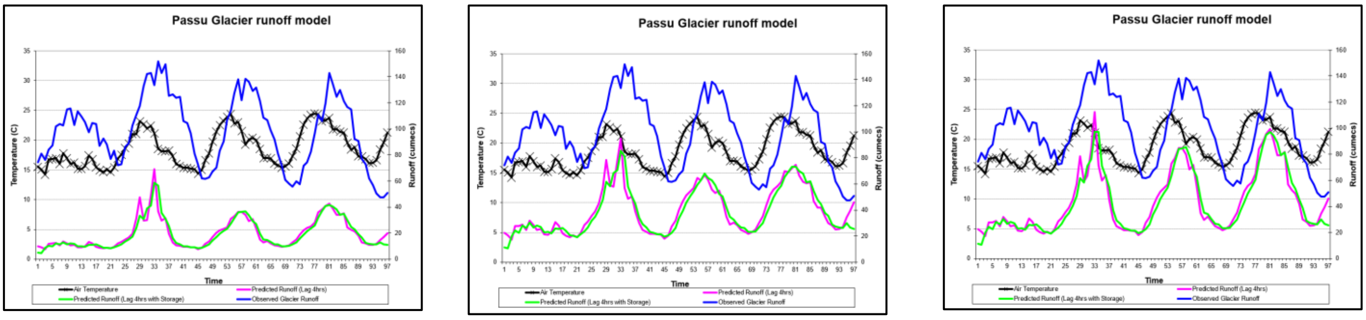
b-2) Lapse rate: The higher lapse rate, the lower predictions.



0.3 ℃ per 100m   0.5 ℃ per 100m   0.7 ℃ per 100m

Figure 30. The graph of the Passu Glacier runoff model with different Lapse rate

b-3) Snowline Elev: By its definition, this parameter only matters when the DDF ratio between snow and ice is different. Figure 31 shows the predictions peak higher when we set the higher value of snowline elevation with the DDF ratio of *snow:ice = 0.3:0.7*.



2500m *5000m* *6000m*

Figure 31. The graph of the Passu Glacier runoff model with different Snowline Elev.

***Question 2 (PB2):** What mix of parameters gave you the best output? Note the parameter values and include these in your write-up with your graph.*

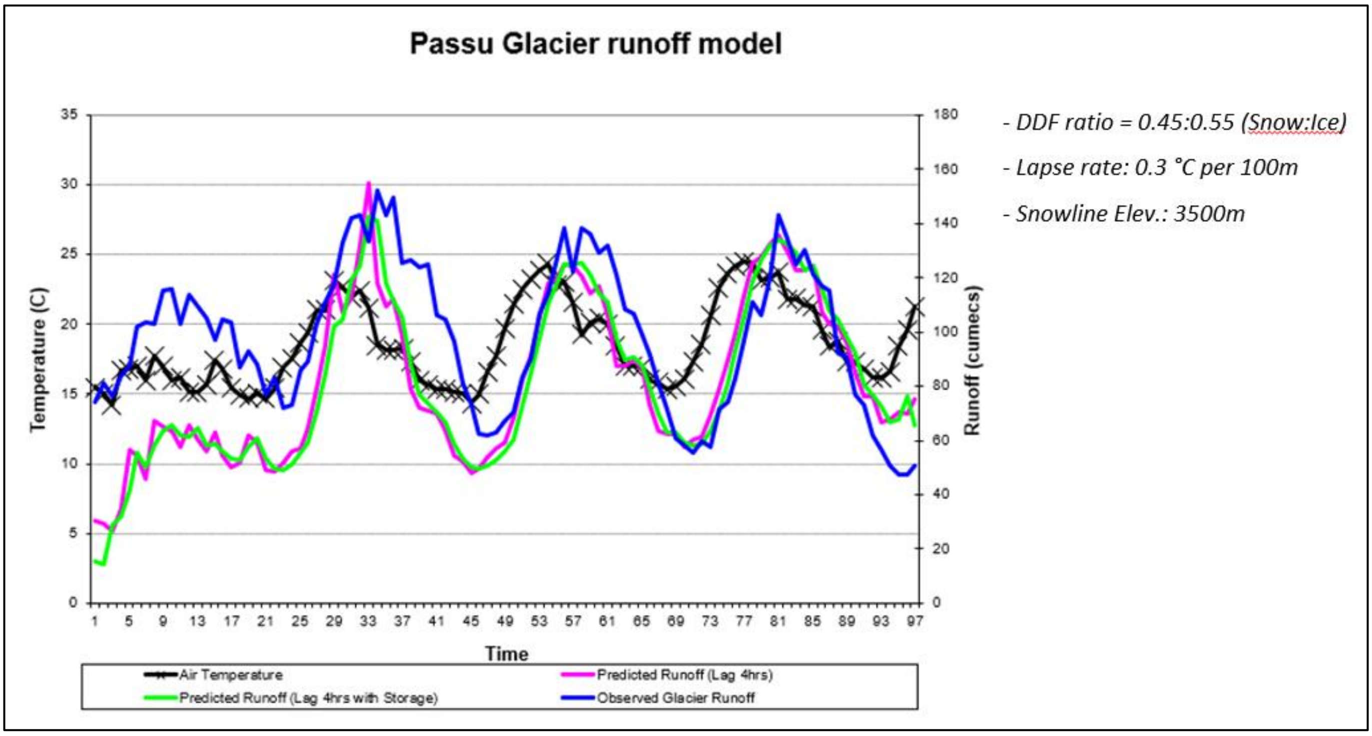


Figure 32. The graph of predicted values and observations of Passu Glacier runoff model

Figure 32 shows the result of the prediction model by changing the DDF ratio from 0.5:0.5 to 0.45:0.55, lapse rate from 0.4°C to 0.3°C per 100m, and snowline elevation from 2500m to 3500m.

Question 3 (PB3): *What effect does setting a 'conduit-dominated' drainage system beneath a glacier have on predicted runoff? With suitable storage coefficients in place, adjust the other model parameters in 'Model' to try and obtain the best fit between observed and predicted runoff.*

Setting a 'conduit-dominated' subglacial drainage affects the model by separating the flow into quick and slow. This effect appears on the graph as the green line (4hrs delay+subglacial drainage) shifts slightly to the right making a gap from the pink line (4hrs delay only). Figure 33 below shows the best result, where the green line fits the best to the observations (blue line).

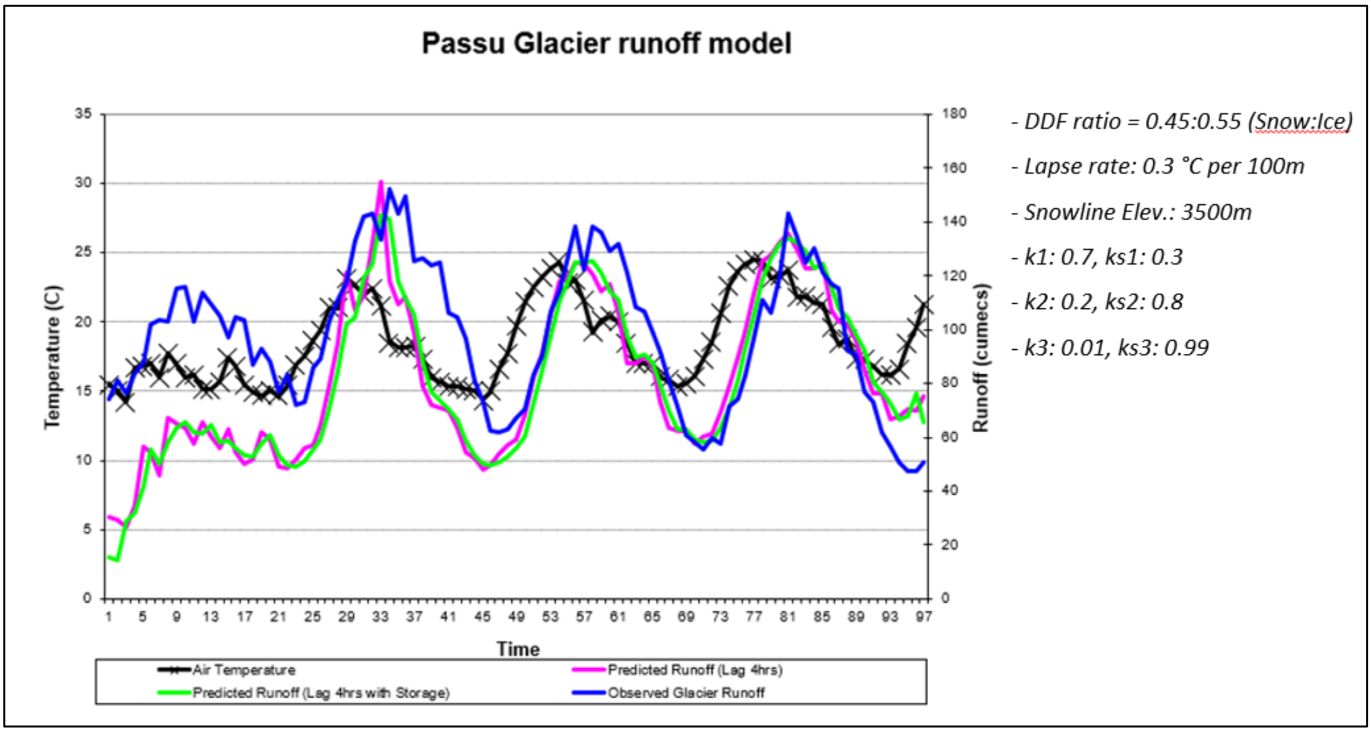


Figure 33. The best fit prediction line (green) with subglacial drainage effect

Question 4 (PB4): *What effect does this change in lag time have on portal river flow compared to original river flows with only 4 hrs transit time?*

Increasing the lag time delays the runoff and vice versa. This effect appears on the graph as the green line shifts to the right, increasing the gap from the pink line (Figure 34).

8

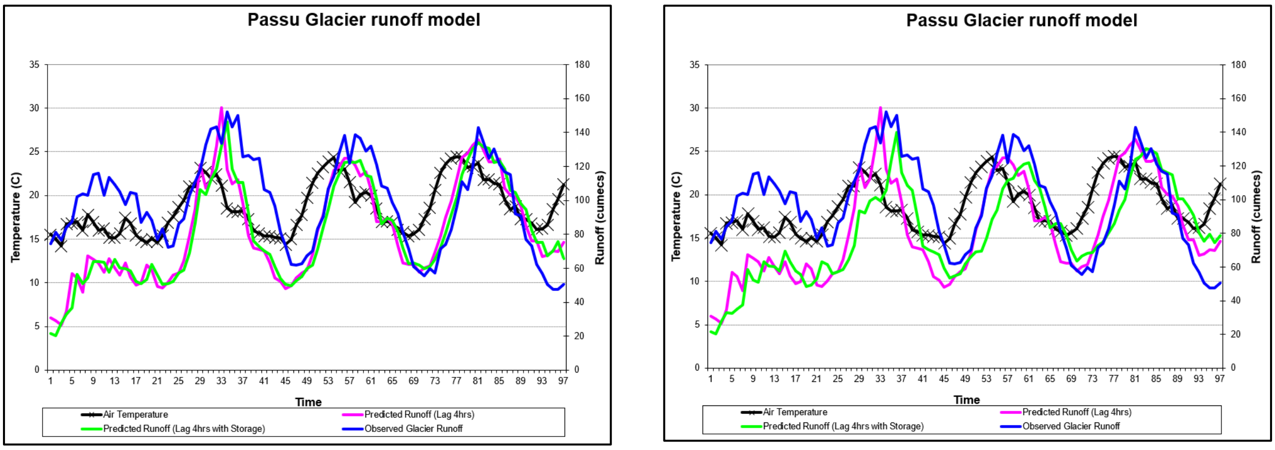


Figure 34. The effect of increasing the lag time (from left to right)

Question 5 (PB5): *Assuming our model is accurately describing and predicting runoff, what might the observed runoff response to this rainfall event tell us about the morphology of the sub-glacial glacier hydrological system beneath Passu Glacier in July 1997? Ensure that you also copy the resultant rainfall graph and include a fully annotated version in your writeup.*

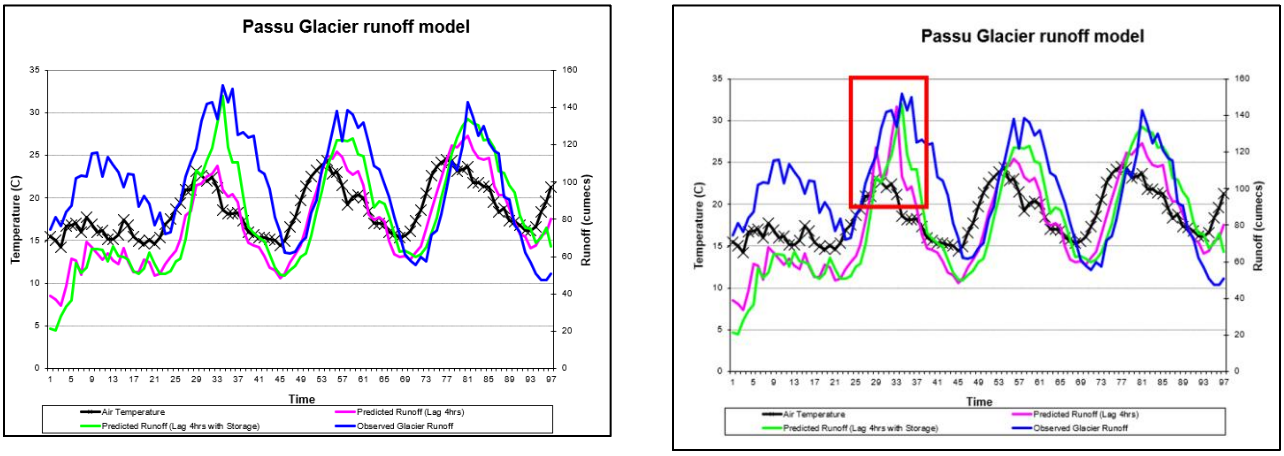


Figure 35. The effect of including the rainfall event from 12-16:00 on 11 July 1997

As shown in Figure 35, the rainfall event only changes the purple line, not the green line. The difference between these two lines is whether they reflect the storage effect or not. So, we can conclude that rainfall does not affect the slow subglacial flow. Also, we can infer that there was no passage to the sub-glacier network from the surface during that period.

Question 6 (PB6): *Explain what glaciological and meteorological data/information would improve the model.*

The model can be improved by using humidity, wind speed and direction, and atmospheric radiation data, important factors for degree day models (Davies, 2020). Also, we can think about the seasonal variation of the model parameters. For example, Thayyen (2018) showed how the lapse rate changes with the seasons.

This model uses two degree day factor parameters for “Snow” and “Ice”, considering the difference in the albedo of the two surface types. However, depending on the degree of melting or purity of the surface, albedo can appear much different, as shown in Table 2 from Bendle (2020). Therefore, this model may be further improved if more specific surface type data is obtained and used.

Surface	**Albedo**
Dry snow	0.80-0.97
Melting snow	0.66-0.88
Firn	0.43-0.69
Clean ice	0.34-0.51
Slightly dirty ice	0.26-0.33
Dirty ice	0.15-0.25
Debris-covered ice	0.10-0.15

Table 2. Albedo values with different surface types (Bendle, 2020)

REFERENCES

- Bendle (2020). *The role of debris cover on glacier ablation*. Available at: https://www.antarcticglaciers.org/wp-content/plugins/antarcticglaciers-pdf/download.php?p=9621 (Accessed: 30 April 2023).
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- Thayyen, R. and Dimri, A. (2018). 'Slope Environmental Lapse Rate (SELR) of temperature in the monsoon regime of the western Himalaya'*, Frontiers in environmental science,* 6 (2018), pp. 1-20. [Online]. Available at: https://www.frontiersin.org/articles/10.3389/fenvs.2018.00042/full (Accessed: 30 April 2023).