Integrated Project

HYDROEUROPE

Erasmus+ Programme Cooperation Partnerships
2022-1-FR01-KA220-HED-000089658
HydroEurope

Climate Change Impacts on Flash Flood

Case Study Tervuren Catchment (Belgium)

Rainfall and Discharge Calculation and Climate Change: 2D Flood Model – LISFLOOD-FP

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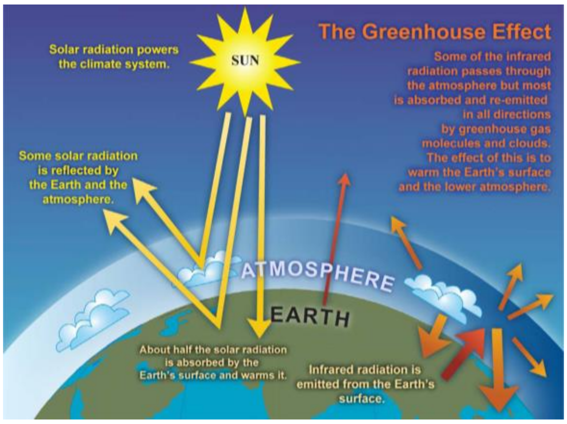
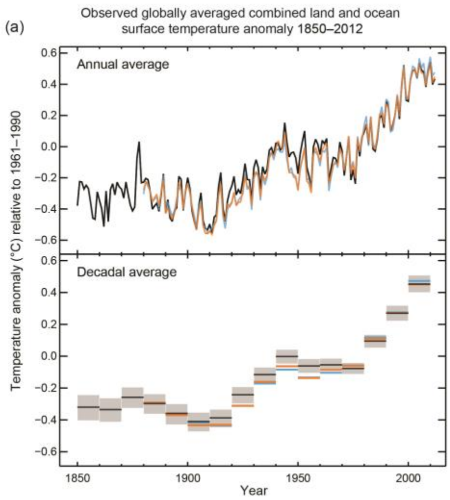
1 Introduction

Climate change is intensifying flash floods by amplifying rainfall extremes and altering precipitation patterns. Warmer temperatures enable the atmosphere to hold more moisture, resulting in sudden, heavy rainfalls that can swiftly overflow rivers and drainage systems. This increment in extreme weather events, combined with shifting storm patterns, makes flash floods increasingly frequent and severe, especially in regions already prone to flooding.

Rainfall and discharge data are essential for understanding climate change impacts on flash floods. Changes in rainfall intensity and patterns can increase flash flood risks, while discharge data reveal how water systems respond to these shifts. Together, they support accurate flood modelling and help anticipate future flood events under changing climate conditions.

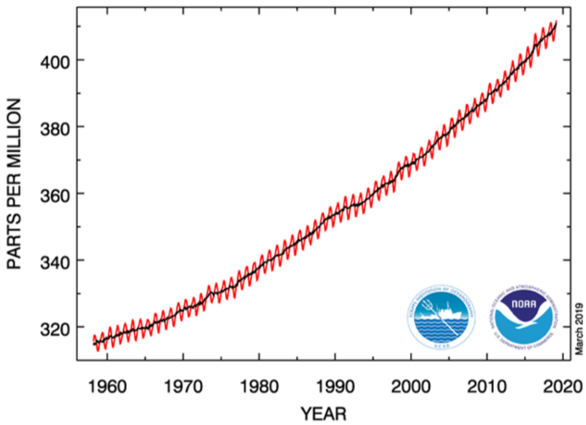
1.1 Rising Greenhouse Gas Emission



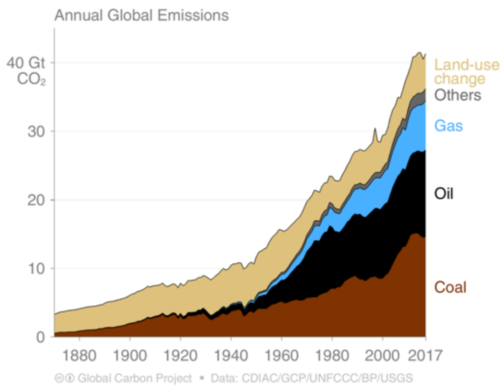


Greenhouse gas (GHG) emissions have steadily increased, raising global temperatures. This warming, now around 1.1°C above pre-industrial levels, leads to higher atmospheric moisture, fueling intense rainfall events that contribute to flash floods.

1.2 Increase of CO_2 concentrations



Concentrations of CO_2 in the atmosphere in the last 60 years



Sources of anthropogenic GHG emissions
(Le Quéré et al., 2018 ESSD)

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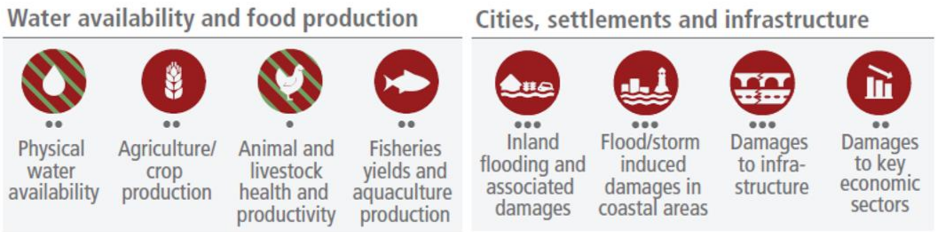
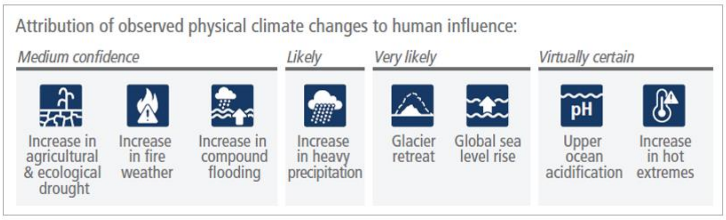
Human activities have significantly increased CO_2 levels since the 1800s, primarily through fossil fuel use, deforestation, and industrial processes. This rise in CO_2 is confirmed by several indicators: higher concentrations in the Northern Hemisphere, specific carbon isotope changes, and an inverse relationship with oxygen levels due to combustion. These shifts disrupt the natural carbon balance, contributing to global warming, which amplifies extreme weather events like flash floods by intensifying rainfall patterns and increasing atmospheric moisture.

1.3 Climate change impacts

Climate change is intensifying water scarcity, agricultural drought, and health risks for livestock, while also reducing fishery yields. Urban areas, especially coastal regions, face heightened risks of flooding, storm-related damages, and infrastructure degradation, which disrupt economic activities.



Widespread and substantial impacts and related losses and damages (IPCC, 2023; AR6)



Impacts are driven by changes in multiple physical climate conditions (IPCC, 2023; AR6)

Evidence links these impacts to human-induced climate change, with varying levels of confidence. There is moderate confidence that climate change is driving more frequent droughts and fire-prone weather, a high likelihood of increased heavy rainfall events, and strong certainty around rising sea levels and more frequent extreme heat. These changes underscore the pressing need for adaptive and mitigative actions to protect both ecological and human systems

1.4 Shared Socioeconomic Pathway (SSPs)

The Shared Socioeconomic Pathways (SSPs) are a set of scenarios used to explore possible futures in climate change research based on different socioeconomic conditions and greenhouse gas emissions. Each pathway presents varying levels of challenges for both adaptation and mitigation. These scenarios help researchers evaluate the potential impacts of socioeconomic developments on climate outcomes.

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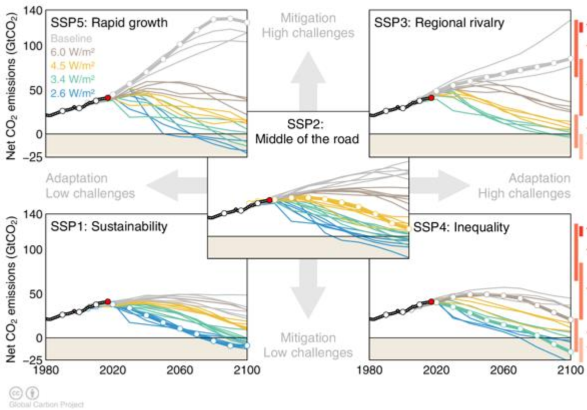
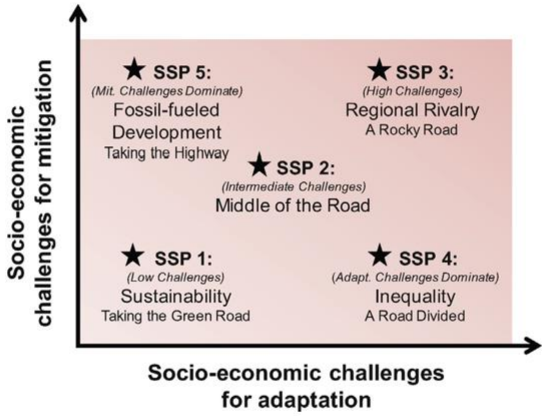
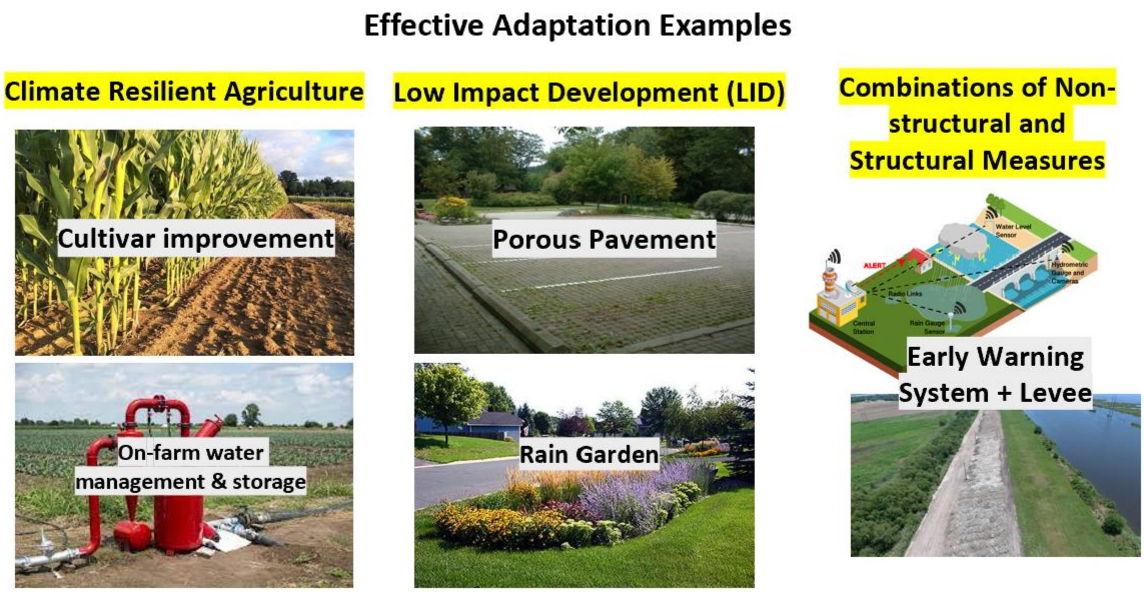


(Le Quéré et al., 2018 ESSD)



(O'Neill et al., 2017 GEC)

1.5 Climate Change Adaptation Measures



Effective climate adaptation strategies implemented across various sectors are yielding multiple benefits. In agriculture, resilience is enhanced through cultivar improvements and on-farm water management, helping maintain productivity amid changing climate conditions. In urban settings, Low Impact Development (LID) practices, such as porous pavements and rain gardens, are employed to manage stormwater and reduce flood risks. Furthermore, combining non-structural approaches, like early warning systems, with structural measures, such as levees, strengthens flood resilience and mitigates disaster impacts. Collectively, these adaptations contribute to building more sustainable and resilient communities

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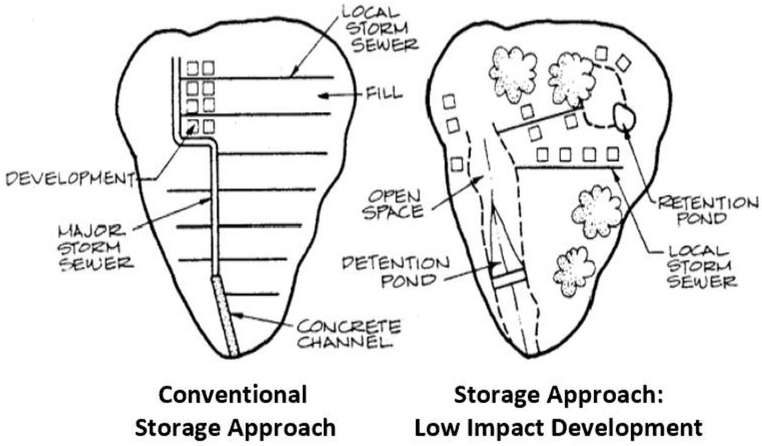
1.6 Low Impact Development (LID)



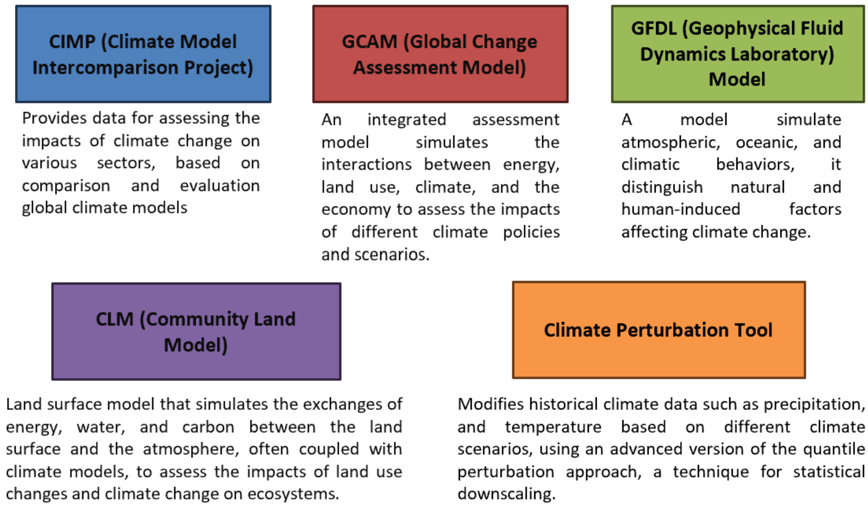
Low Impact Development (LID) is an approach that seeks to restore natural hydrological processes to manage stormwater sustainably. This strategy includes tools like porous pavements, rain gardens, green roofs, infiltration basins, riparian zones, and constructed wetlands. These LID practices offer numerous benefits: they reduce surface flooding by mitigating peak flows, lower lifetime and off-site costs, and provide multifunctional spaces that add environmental and social value.

1.7 International Climate Agreements

The Paris Agreement set global commitments to limit warming to well below 2°C, with a target of 1.5°C, by reducing greenhouse gas emissions through nationally determined contributions (NDCs). This agreement represents a historic international effort where all countries have pledged to contribute to climate action.

At COP28 in 2023, key developments included the establishment of a "loss and damage fund" to support countries most affected by climate impacts. Additionally, nations made various commitments to enhance climate resilience, including pledges to improve food systems, promote clean hydrogen, and improve air conditioning efficiency. These initiatives reflect ongoing efforts to address the increasing challenges of climate change.

1.8 Climate Models

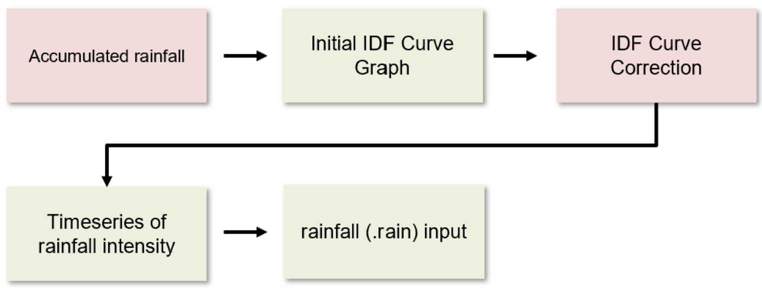


Climate models are essential for understanding and predicting flash floods, as they simulate the complex interactions between atmospheric, land, and oceanic processes under various climate scenarios. By analysing factors like precipitation intensity, land use changes, and temperature increases, models allow scientists to assess potential flood risks. Integrated models examine how economic and energy policies impact climate conditions, influencing flood patterns. The use of these tools also allows to modify historical data to reflect potential future scenarios, helping predict extreme events like flash floods. Together, these models support effective planning and adaptation strategies to mitigate flood impacts in vulnerable regions.

1.9 Rainfall Data

Rainfall patterns, especially intensity, duration, and frequency, are directly influenced by climate change. More intense and irregular precipitation events increase the likelihood of flash floods, overwhelming natural and engineered drainage systems.

Preparation of Rainfall Data



Reliable rainfall data help capture these shifts and are essential for projecting future flash flood risks.

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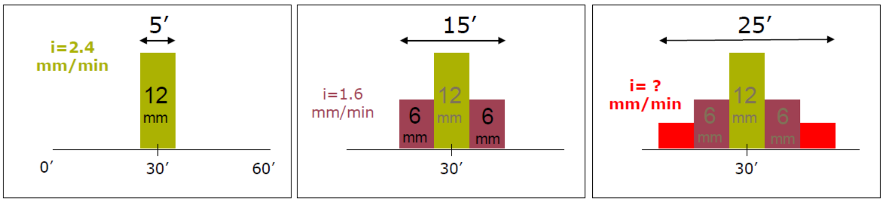
1.10 IDF Curve

IDF (Intensity-Duration-Frequency) curves, which represent the statistical relationship between rainfall intensity, duration, and frequency, are important for climate change analysis as they inform event-based simulations of extreme weather. IDF curves help estimate how often certain rainfall intensities may occur, aiding flood risk assessment and infrastructure design.

IDF →

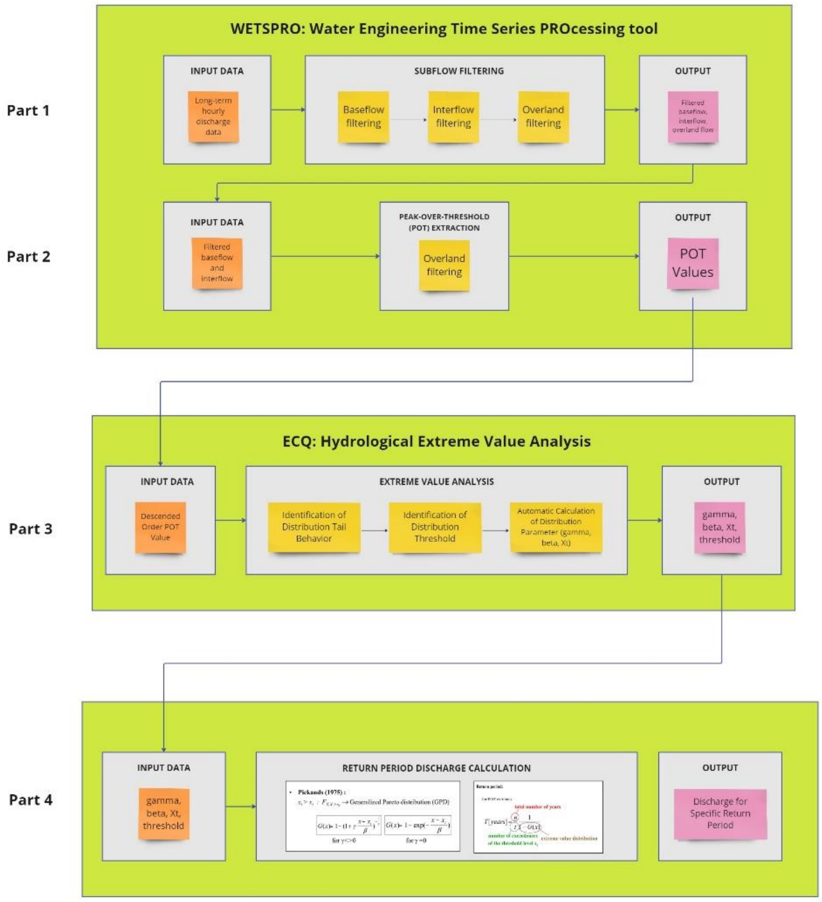
Duration (minutes)	5	15	25	35	45	55	60
I (mm)	12	24	30	35	39	42	44
∆I (mm)	12	12	6	5	4	3	2



However, due to limitations in available data, IDF curves can exhibit asymmetry and bias, which may reduce accuracy. Correcting these biases is essential to improve the precision of climate impact models and make better-informed planning decisions.

1.11 Discharge Calculation

In the context of climate change, accurately calculating discharge is crucial for anticipating extreme events, which are expected to become more frequent and intense.



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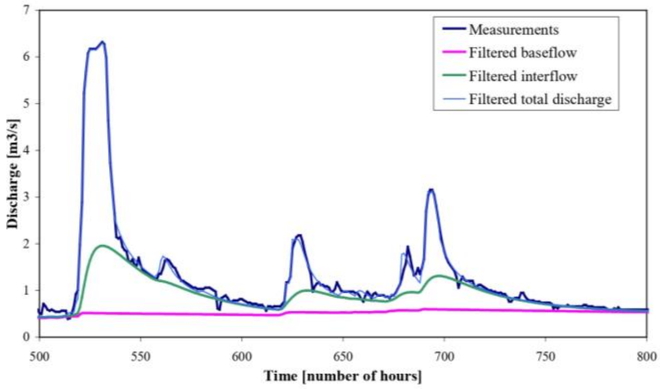
This workflow integrates statistical filtering and extreme value analysis, ensuring that discharge calculations account for high flow variability and extremes, which helps in designing resilient infrastructure and managing water resources.

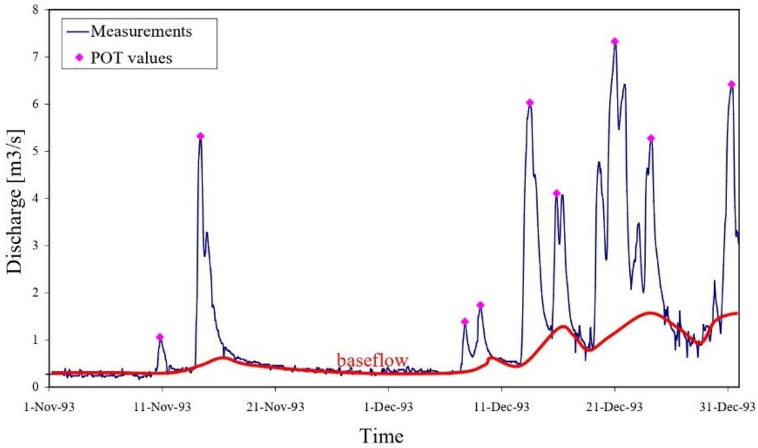
1.12 Sub-flow filtering

Using the WETSPRO tool, long-term hourly discharge data undergoes sub flow filtering to separate baseflow and interflow, with further overland flow filtering to produce filtered discharge components. By isolating baseflow and interflow, which represent the more stable, it helps filter out normal discharge events and prepare the data for identifying only the extreme events.



1.13 POT Selection

The filtered baseflow and interflow data are processed through a Peak-Over-Threshold (POT) extraction, isolating high flow events. It allows the analysis to focus specifically on extreme discharge events, providing a more accurate basis for calculating the probability of severe flood events.



1.14 Extreme Value Analysis

Using the ECQ tool for hydrological extreme value analysis, the POT values are analysed to identify distribution tail behaviour and threshold, leading to the calculation of distribution parameters, providing the necessary inputs to calculate discharge values for specific return periods, predicting the likelihood of extreme discharge events.

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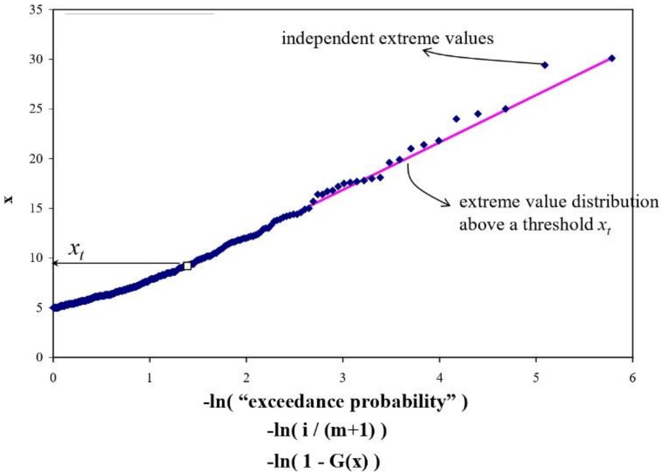
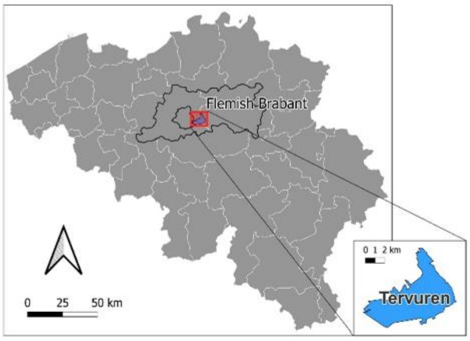
in the quantile plot:



2 Case Study: Tervuren Catchment



Study Area of Tervuren, Belgium

- The study area of this project is Tervuren Municipality, Belgium
- A large area in Tervuren is at risk of urban fluvial and pluvial floods (HNL, 2023; Flemish Government, 2023)
- Climate change is expected to increase precipitation extreme which potentially exacerbate urban pluvial flooding in Tervuren

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3 Step by step tutorial

3.1 Introduction

This exercise is the last part of LISFLOOD input data preparation series which will present the workflow to prepare rainfall data file (.rain). Design storm which will be used as model data input is based on corrected curve of Intensity-Duration-Frequency (IDF) Curve in Ukkle Station. Additionally, the river discharge time series (time-varying boundary condition) will be calculated. To analyse 100-years return period flood, hydrological sub-flow filtering and extreme value analysis will be carried out using WETSPRO and ECQ to obtain 100-years design discharge. WETSPRO is a time-series tool developed by Willems (2008) that allows separation of rainfall-runoff discharge into the overland flow, interflow, and baseflow based on linear reservoir modelling concept. ECQ, developed by Willems, et al. (2007), describes the probability of the occurrence of extreme events based on extreme value.

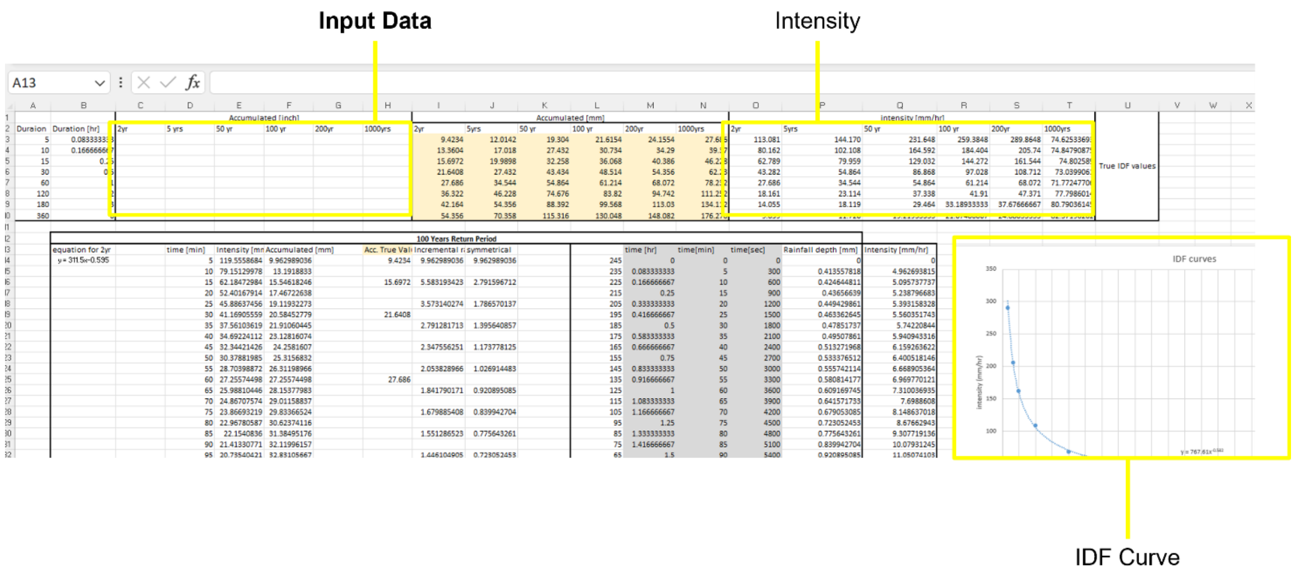
This tutorial will also include the use of The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), a modeling framework that assesses the impacts of climate change consistently across various sectors, including biodiversity, health, water, agriculture, energy, and coastal infrastructure.

3.2 Rainfall Data

The 'Corrected IDF Curve.xlxs' spreadsheet is provided to facilitate the construction of corrected IDF curve for different return periods. Estimated accumulated precipitation in mm for 5, 10, 15, 30, 60, 120, 180, 360 minutes duration, which will be used as data input for this calculation, is available in 'Tervuren Rainfall Input.xlxs'.

Step 1: Input Data, Intensity Calculation, IDF Curve Plotting

To begin with, input the estimated precipitation frequency in the designated part in the 'Corrected IDF Curve.xlxs'. While the spreadsheet allows calculation of design storm for different return periods, it is possible to only provide and calculate design storm of one desired return period. After the data is input, rainfall intensity for each duration [mm/hr] for each return period will be calculated and IDF curves will be plotted.



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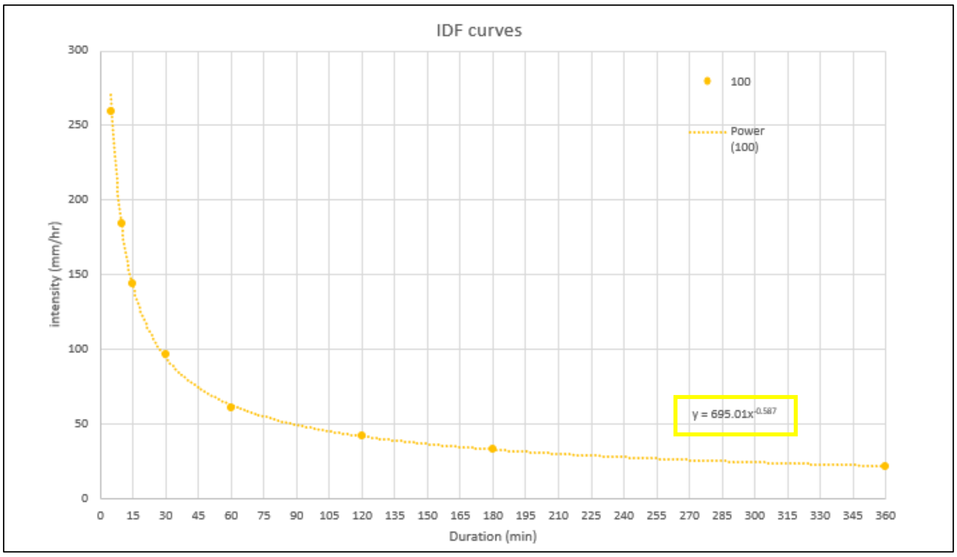
Step 2: Design Storm Calculation

Display the equation based on 'power' trendline of IDF Curve plot and use the formula to calculate intensity for each time step (for example 5 minutes).



In the example below, the formula is used to calculate 5-mins time step rainfall on cell E4:E62. Based on this data, corrected intensity will be calculated from 5-minutes time step rainfall depth based on reconstructed symmetrical IDF curve. Corrected rainfall intensity is the output of this calculation which will be used in the rainfall data file (.rain).

E14 =695.01*(D14^-0.587)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
0	360	6							54.356	70.358	115.316	130.048	148.082	176.276	9.059	11.726	19.21933333
1																	
2									100 Years Return Period								
3		equation for 2yr		time [min]	ntensity [mn	Accumulated [mm]		Acc. True Valı	Incremental r	symmetrical			time [hr]	time[min]	time[sec]	Rainfall depth [mm]	Intensity [mm/hr]
4		y = 695.01x-0.587		5	270.2064 84	22.51720153		9.4234	22.51720153	22.51720153		245	0	0	0	0	0
5				10	79.15129 78	13.1918833						235	0.083333333	5	300	0.413557818	4.962693815
6				15	62.18472 84	15.54618246		15.6972	-6.971019071	-3.485509536		225	0.166666667	10	600	0.424644811	5.095737737
7				20	52.40167 14	17.46722638						215	0.25	15	900	0.43656639	5.238796683
8				25	45.88637 56	19.11932273			3.573140274	1.786570137		205	0.333333333	20	1200	0.449429861	5.393158328
9				30	41.16905 59	20.58452779		21.6408				195	0.416666667	25	1500	0.463362645	5.560351743
0				35	37.56103 19	21.91060445			2.791281713	1.395640857		185	0.5	30	1800	0.47851737	5.74220844
1				40	34.69224 12	23.12816074						175	0.583333333	35	2100	0.49507861	5.940943316
2				45	32.34421 26	24.2581607			2.347556251	1.173778125		165	0.666666667	40	2400	0.513271968	6.159263622
3				50	30.37881 85	25.3156832						155	0.75	45	2700	0.533376512	6.400518146
4				55	28.70398 72	26.31198966			2.053828966	1.026914483		145	0.833333333	50	3000	0.555742114	6.668905364
5				60	27.25574 98	27.25574498		27.686				135	0.916666667	55	3300	0.580814177	6.969770121
6				65	25.98810 46	28.15377983			1.841790171	0.920895085		125	1	60	3600	0.609169745	7.310036935
7				70	24.86707 74	29.01158837						115	1.083333333	65	3900	0.641571733	7.6988608
8				75	23.86693 19	29.83366524			1.679885408	0.839942704		105	1.166666667	70	4200	0.679053085	8.148637018
9				80	22.96780 87	30.62374116						95	1.25	75	4500	0.723052453	8.67662943
0				85	22.1540 36	31.38495176			1.551286523	0.775643261		85	1.333333333	80	4800	0.775643261	9.307719136
1				90	21.41330 71	32.11996157						75	1.416666667	85	5100	0.839942704	10.07931245
2				95	20.73540 21	32.83105667			1.446104905	0.723052453		65	1.5	90	5400	0.920895085	11.05074103
3				100	20.11212 23	33.52021539						55	1.583333333	95	5700	1.026914483	12.3229738
4				105	19.53666 48	34.18916284			1.35810617	0.679053085		45	1.666666667	100	6000	1.173778125	14.08533751
5				110	19.00331 58	34.83941372						35	1.75	105	6300	1.395640857	16.74769028
6				115	18.50729 25	35.47230631			1.283143467	0.641571733		25	1.833333333	110	6600	1.786570137	21.43884164
7				120	18.04451 83	36.08902967		36.322				15	1.916666667	115	6900	-3.485509536	-41.82611443
8				125	17.61150 98	36.6906458			1.218339489	0.609169745		5	2	120	7200	22.51720153	270.2064184
9				130	17.20528 46	37.27810766						15	2.083333333	125	7500	-3.485509536	-41.82611443
0				135	16.82323 96	37.85227415			1.161628354	0.580814177		25	2.166666667	130	7800	1.786570137	21.43884164
1				140	16.46310 61	38.41392243						35	2.25	135	8100	1.395640857	16.74769028
2				145	16.1229 45	38.96375838			1.111484227	0.555742114		45	2.333333333	140	8400	1.173778125	14.08533751

intensity (5-mins time steps)

Output: corrected intensity

The format of the rainfall data file in shown in the figure below and the explanation of every line is described in Table 1.

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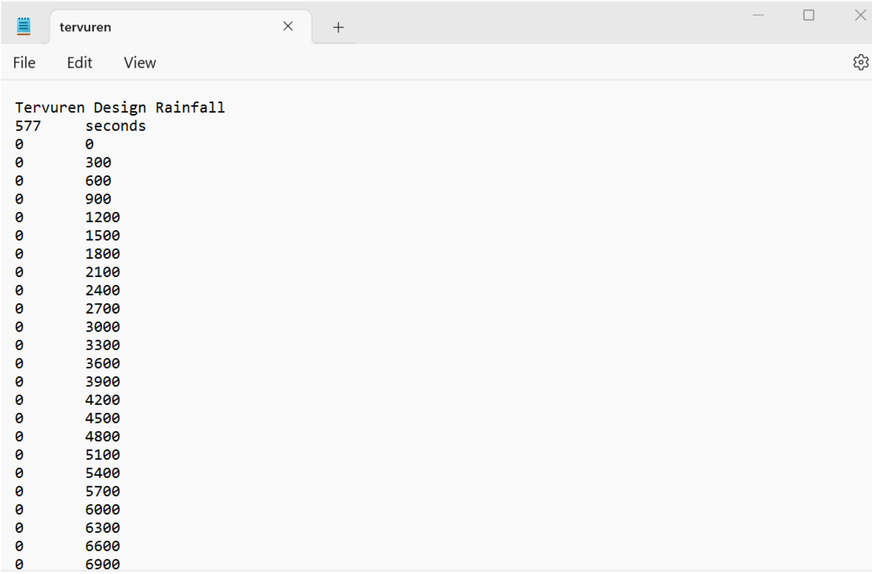


```
Tervuren Design Rainfall
577     seconds
0       0
0       300
0       600
0       900
0       1200
0       1500
0       1800
0       2100
0       2400
0       2700
0       3000
0       3300
0       3600
0       3900
0       4200
0       4500
0       4800
0       5100
0       5400
0       5700
0       6000
0       6300
0       6600
0       6900
```

Table 1 Rainfall File Description

Line	Description
1	Command line
2	Number of time points at which boundary information is given followed by a keyword for the time units used (either 'days', 'hours' or 'seconds').
3	Value Time

Line 5 to the end of the time series follow the same format as line 3.

3.3 Extreme Event Discharge

a. WETSPRO

Step 1: Sub-flow Filtering

Sub-flow filtering and POT selection will be carried out using WETSPRO (WETSPRO.xlsm). To begin with input hourly discharge data in the input section. The separation began with baseflow separation, followed by interflow and overland flow at last. To carry out the separation, k and w were calibrated to fit the slope of sub-flow in the overall discharge. The calibration should start with 'recession constant [number of time step]' ('w-parameter [-]' set as 1), followed by w-parameter calibration. Set the remaining filter parameters as default, meanwhile, for visual analysis adjust 'distance lines graph [number of time steps]' and 'first time step lines' in Graphical parameters. Afterward, click 'execute baseline' to execute baseline filtering and check the result on 'Chart results' → 'Filter result – BF'.

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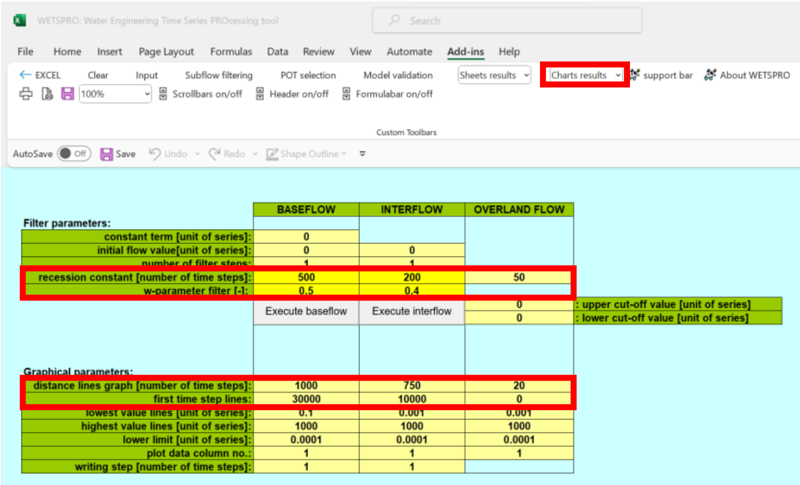

	BASEFLOW	INTERFLOW	OVERLAND FLOW
constant term [unit of series]:	0		
initial flow value[unit of series]:	0	0	
number of filter steps:	1	1	
recession constant [number of time steps]:	500	200	50
w-parameter filter [-]:	0.5	0.4	
upper cut-off value [unit of series]			0
lower cut-off value [unit of series]			0
distance lines graph [number of time steps]:	1000	750	20
first time step lines:	30000	10000	0
lowest value lines [unit of series]:	0.1	0.001	0.001
highest value lines [unit of series]:	1000	1000	1000
lower limit [unit of series]:	0.0001	0.0001	0.0001
plot data column no.:	1	1	1
writing step [number of time steps]:	1	1	

Figure 1 examply discharge time series with the resulted filtered baseline along with slope recession constant. Baseline slope in time series measurement, usually found after a long dry period (blue line), should be fitted with slope recession constant for baseflow (green line) to identify filtered baseflow (pink line). The same line-fitting procedure is applied for interflow and overland flow. The final result of discharge filtering is shown in 'Chart results' → 'Filter results'.

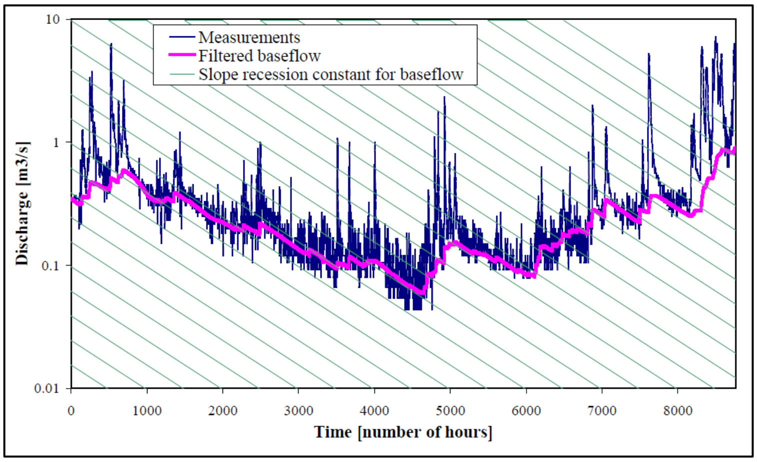

Figure 1 Baseflow filtering based on recession constant (Source: Statistics for Water Engineering / Stochastic hydrology Lecture Material)

Step 2: POT Selection

In this exercise POT selection will be carried out using method 2 available in WETSPRO. Using this method, peak discharge is classified as POT if it exceeds the minimum peak height and is considered independent. Two successive discharges are considered independent if the maximum difference ratio between the sub-flows approaches the baseflow value (baseline + interflow).

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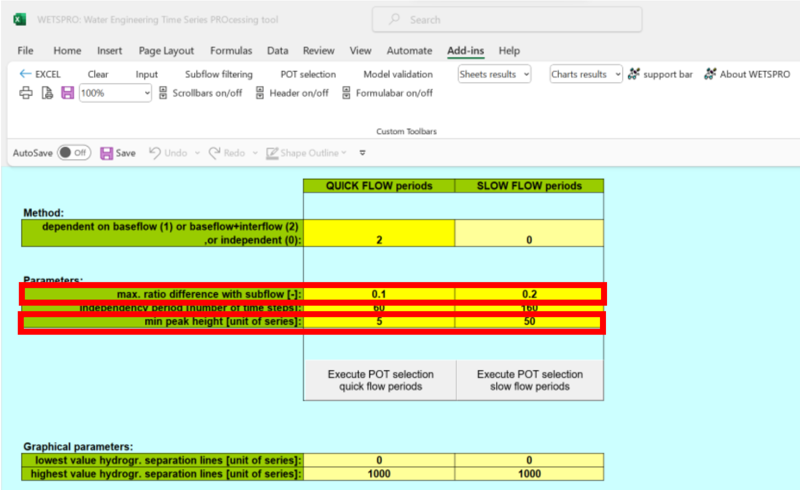

Calibrate and determine 'min. peak height [unit of series]' and 'max. ratio difference with subflow [-]' by the level of strictness in defining the POT values. The result of POT extraction is available on 'Sheet results' → 'POTResults', and will be used in the further process. Meanwhile, the visualization is available on 'Chart results' → 'POT Selection'.

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b. Extreme Value Analysis

Step 1: ECQ

To analyse extreme value based on descending sorted data of POT extraction, use ECQ: Hydrological Extreme Value Analysis (ECQ.xls). Once the data is input in the 'input' section, examine the tail shape of the distribution, and determine the distribution type of the data. Once the distribution type is identified, distribution fitting and slope calculation for normal tail (heavy tail) was carried out based on QQ Plot (Pareto QQ Plot). The distribution type should be indicated in the ECQ calibration result; 1 for normal tail and 2 for heavy tail. Before the fitting, the threshold point should be identified and input in ECQ by the user. In the case of normal tail (heavy), the optimal threshold value is the point with the lowest MSE in the slope exponential QQ plot (exponential Pareto QQ Plot), which distinguishes the stable and unstable ranges as depicted in Figure 2. Based on these calculations, gamma, beta and Xt can be found. In the case of flood occurrence, the process in ECQ is different.

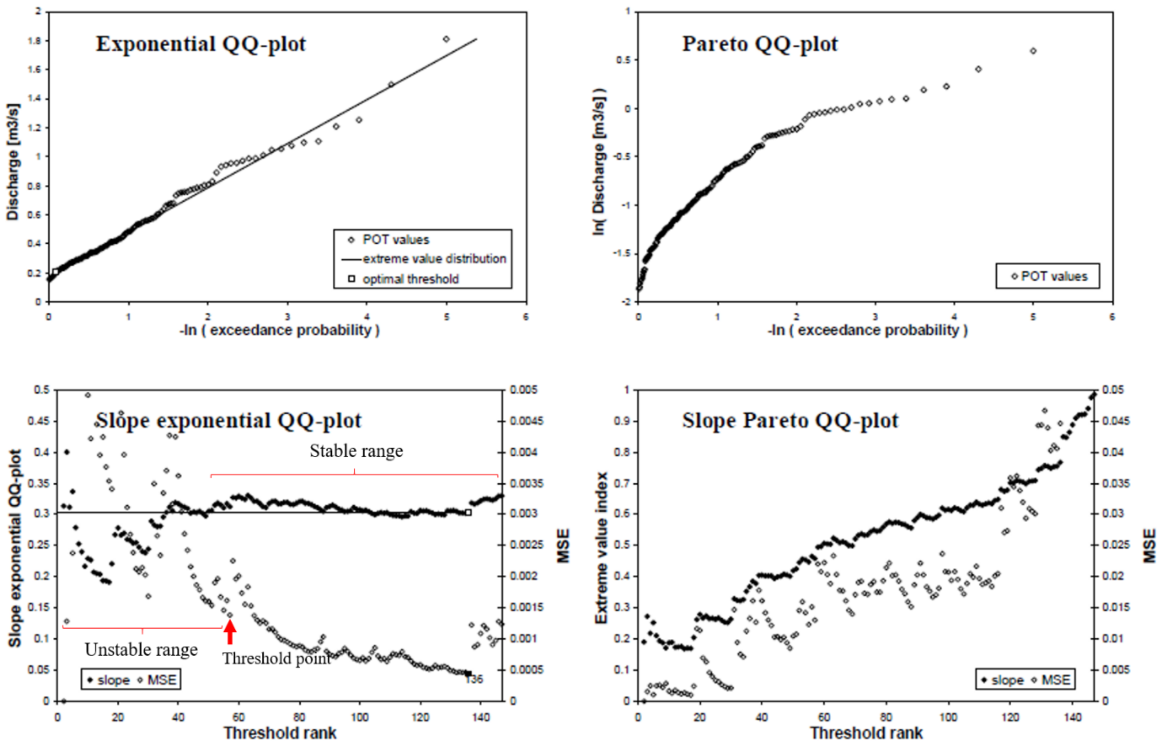


Figure 2 Example of QQ-plots for a normal tail case (Source: Statistics for Water Engineering / Stochastic hydrology Lecture Material)

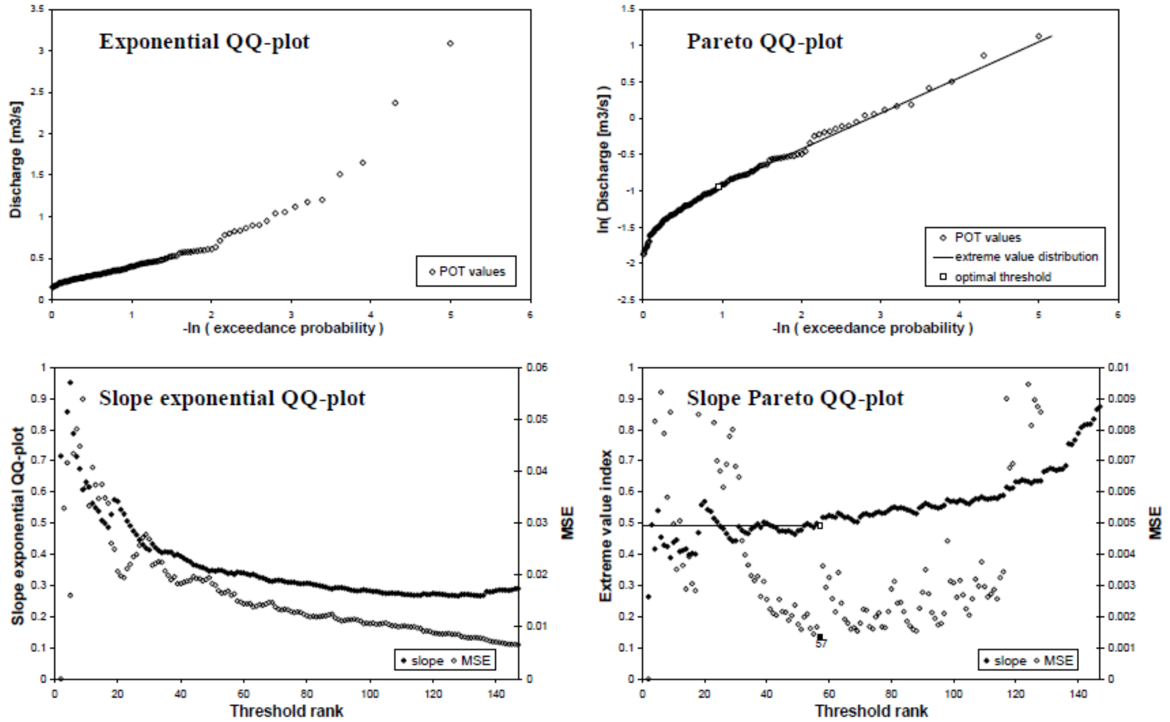
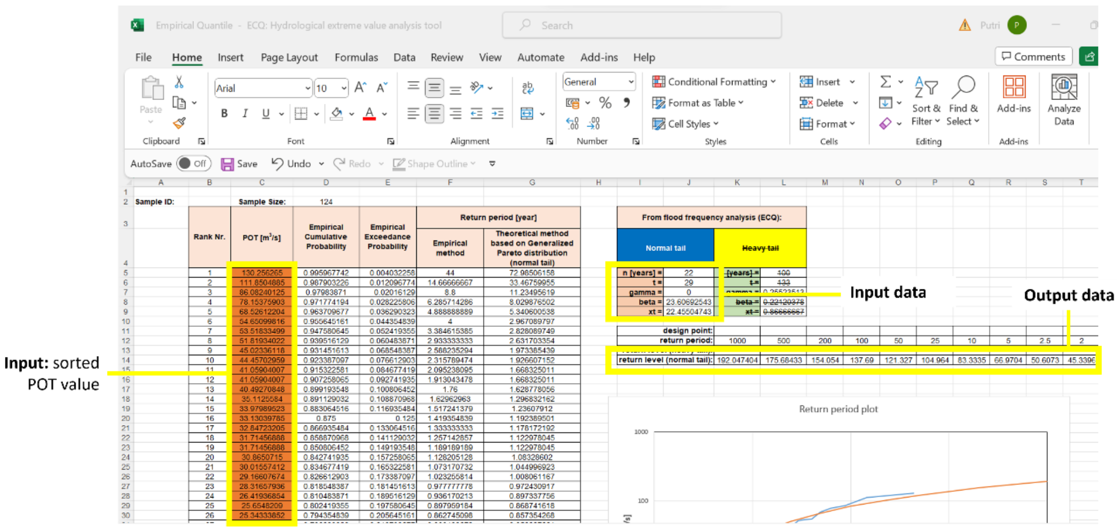


Figure 3 Example of QQ-plots for a heavy tail case (Source: Statistics for Water Engineering / Stochastic hydrology Lecture Material)

Step 2: Return Period Discharge Calculation

The 'Empirical Quantile.xlxs' spreadsheet is provided to facilitate the calculation of return period discharge based on the Generalized Pareto Distribution (GPD) Formula by Pickands (1975). The required input data for the calculation includes the duration of discharge data ('n[years]'), threshold ('t'), gamma, beta, and xt. The last 4 parameters are derived from the extreme value analysis conducted in the previous step using ECQ. Insert the input data into the designated sections, as illustrated in the figure below. Input the sorted POT value into the corresponding section in the figure to plot and examine the calculation against actual data.



The result of the calculation is available in 'return period (normal tail)' row, as shown by figure above.

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c. Time-Varying Boundary Condition File

The return level of discharge is assumed to be the peak value in the time-varying discharge for the 100-years return period flood. To obtain the full time series, identify the peak value in the original discharge time series and select the antecedent and subsequent values based on the desired duration of the time series. Once the full time-series of 100-years return period discharge is obtained, input the data to time-varying boundary condition file (.bdy). More detail information on the items of each line in the .bdy files is explained in Table 2.

Table 2 Time-Varying Boundary Condition File Description

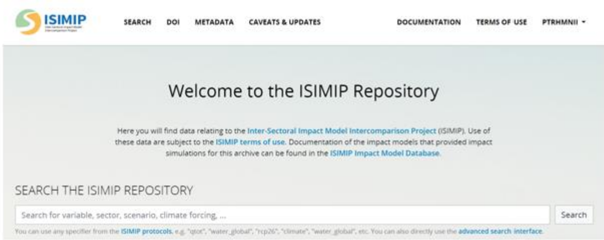
Line	Description
1	Command line
2	Boundary identifier (this should be consistent with notation supplied in the.bci file).
3	Number of time points at which boundary information is given followed by a keyword for the time units used (either 'days', 'hours' or 'seconds').
4	Value Time

Line 5 to the end of the time series follow the same format as line 4.

3.4 ISIMIP Platform

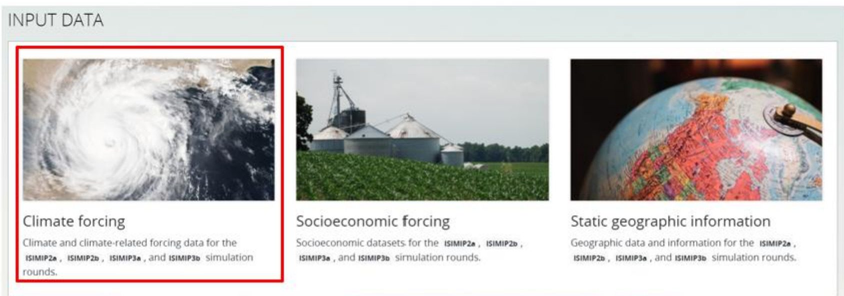
ISIMIP models the impacts of climate change in a way which is consistent across sectors (currently 15 sectors including fire, groundwater and peat). To make comparison between different climate change possible. The goal of ISIMIP is to mirror CMIP for the impact modelling community

Step 1: ISIMIP Data Download



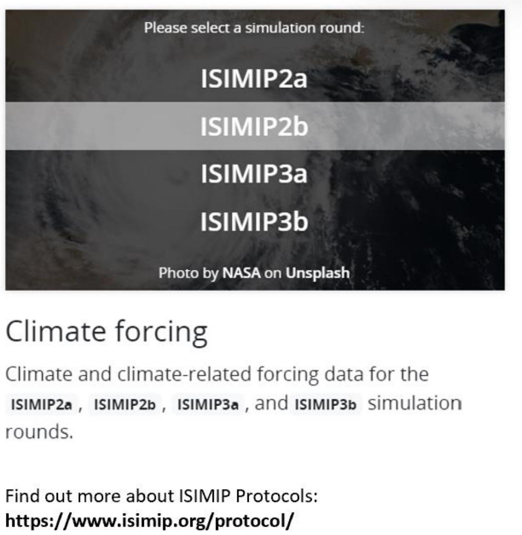
To access ISIP regional data, sign up to the data portal:
https://data.isimip.org/

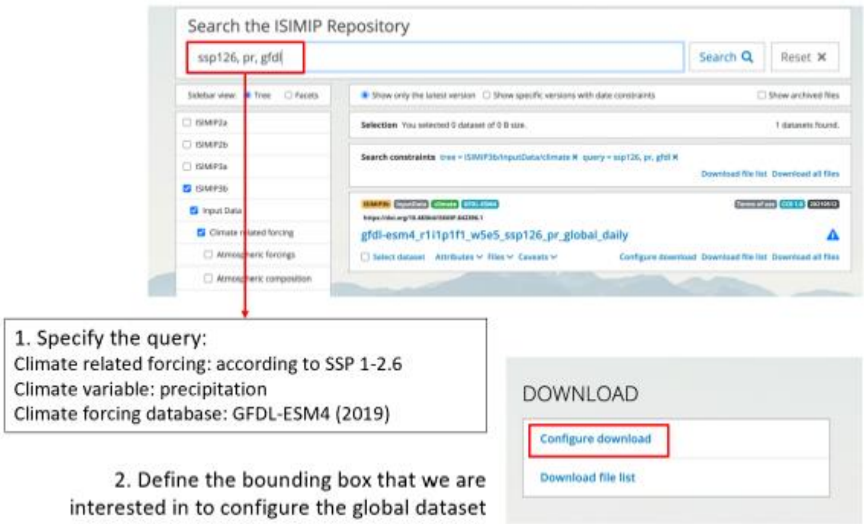
Access climate forcing input data to download the meteorological data:



Step 2: ISIMIP Data Retrieval

ISIMIP provide different protocols with unique focuses, in this case, we are using ISIMIP3B. ISIMIP3B is GCM-based quantification of impacts at different levels of climate change.





ISIMIP retrieval script consist of several parts:

1. Understanding NetCDF data.
2. Plotting 2D map for specific time.
3. Clipping data for specific region (countries, specific area from provided shapefile).
4. Converting data to time series for specific point.

Step 3: Task

1. Climate Change Scenario Flood
2. Extract 2100 precipitation timeseries from ISIMIP
3. Compare future precipitation timeseries with current time series (access precipitation data observed in Uccle, Belgium in https://www.waterinfo.be/)
4. Identify multiplication factor of precipitation increased due to climate change to model flood with climate change scenario

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