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Team 02: Week 1

HYDROEUROPE

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

WP2: Uncertainty in Advanced Hydrological and Hydraulic Modelling
WP3: Climate Change Impacts on Flash Floods
WP4: Accidental Water Pollution
Case Study : Tervuren-Belgium

Team02: Report Week 1:

Modelling and Analysis of Tervuren Catchment

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Version 1.0 - 22 Feb 2025

Introduction

1. Detailed Steps for Mesh Refinement in HEC-RAS

1.1 Introduction

Refining the computational mesh in HEC-RAS is a crucial step in ensuring accurate flood simulations. The quality of the mesh directly impacts the stability and precision of hydraulic calculations. A well-refined mesh allows for better representation of terrain features, accurate flow paths, and proper interaction between the river channel and floodplain.

This report details the step-by-step process of refining the computational mesh in HEC-RAS, from initial creation to final validation. The process includes defining boundary lines, generating an initial mesh, refining the resolution, correcting irregular cells, and ensuring that the riverbed is accurately represented. The goal is to create a mesh that optimally balances computational efficiency and hydraulic accuracy.

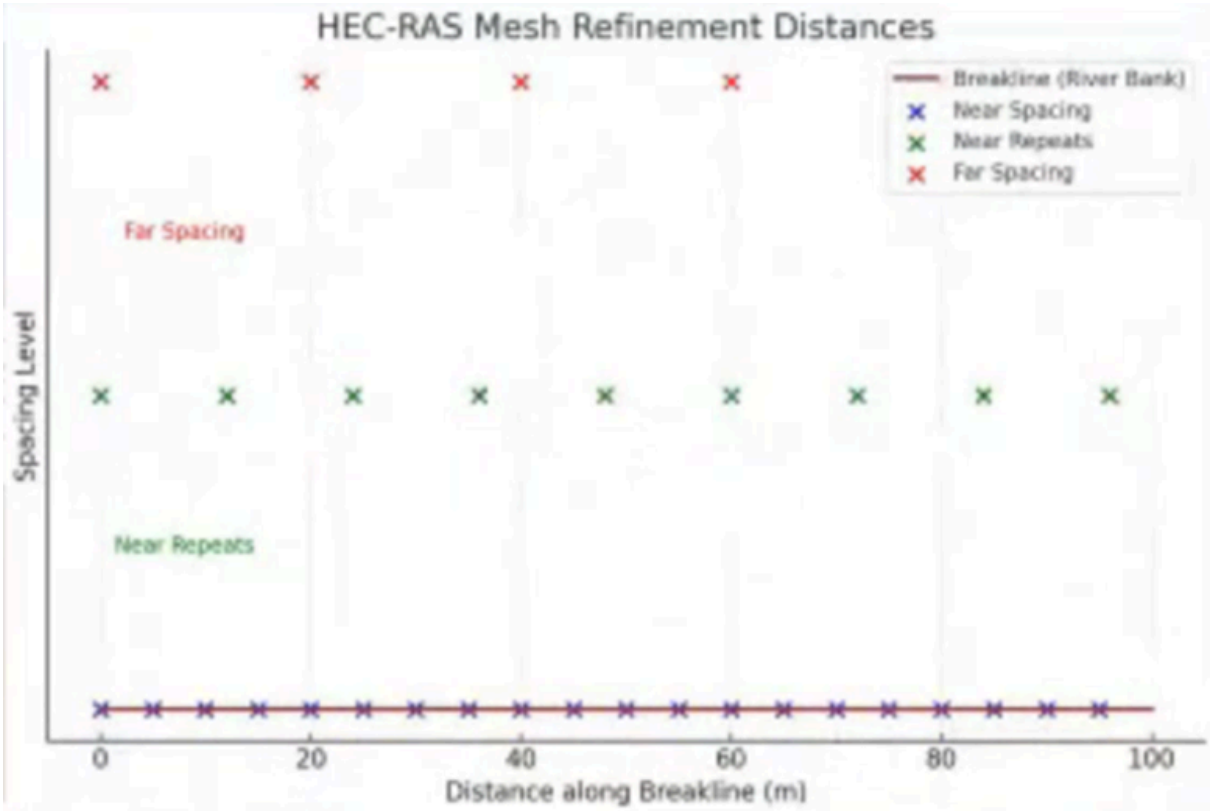


Figure 1 : HEC-RAS Mesh Refinement Distances.

This image represents HEC-RAS Mesh Refinement Distances, which are used in hydraulic modeling to refine the computational mesh along a breakline, such as a riverbank.

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Explanation of the Graph :

- X-Axis (Distance along Breakline in meters) This represents the distance along the breakline (e.g., riverbank) in meters.

- Y-Axis (Spacing Level) This likely represents different spacing levels used for mesh refinement.

Interpretation:

- The blue Xs (near spacing) are clustered close together along the bottom of the graph, meaning that the mesh is highly refined near the breakline.

- The green Xs (near repeats) are positioned at an intermediate level, indicating moderate refinement.

- The red Xs (far spacing) are spaced farther apart, meaning a coarser mesh in these areas.

- The regular intervals along the X-axis suggest that refinement occurs at specific distances along the breakline.

This graph helps visualize how different spacing strategies are applied along a breakline in HEC-RAS to balance accuracy and computational efficiency. The finer mesh is applied near critical areas (such as riverbanks), while coarser spacing is used in less important regions.

1.2 Creating Boundary Lines for Mesh Definition

Before generating the computational mesh, it is necessary to establish boundary lines that define the area where the mesh will be applied. These boundary lines serve as a reference for mesh refinement and help control the distribution of computational cells.

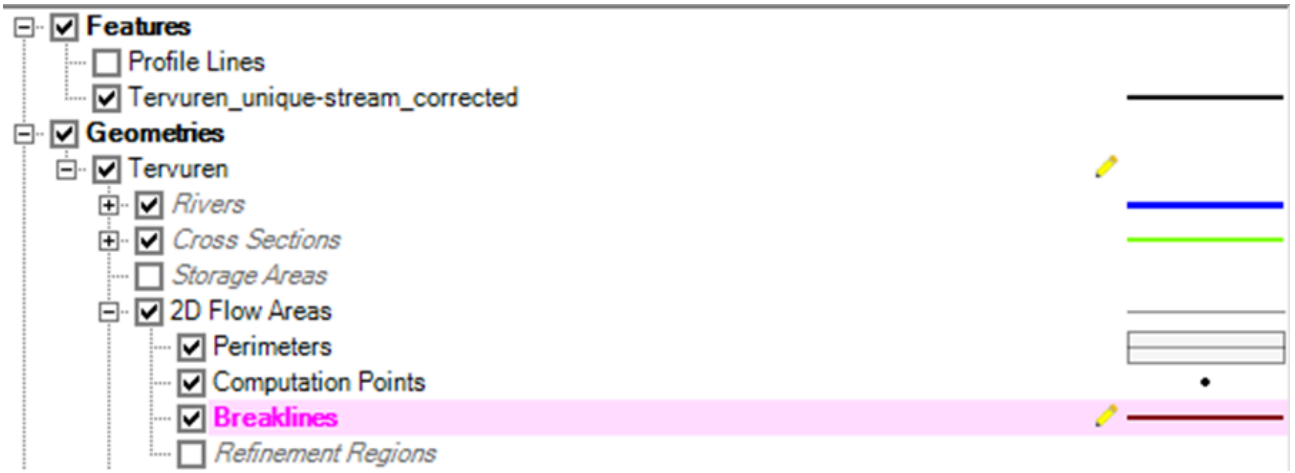


Figure 2: Data Structure of the Tervuren 2D Flow Model in HEC-RAS

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In HEC-RAS, boundary lines are created within the Geometric Data Editor. The user must first define a 2D Flow Area, which represents the entire floodplain and river system where calculations will take place. This is done by drawing a polygon around the study area, ensuring that all relevant sections of the river and floodplain are included.

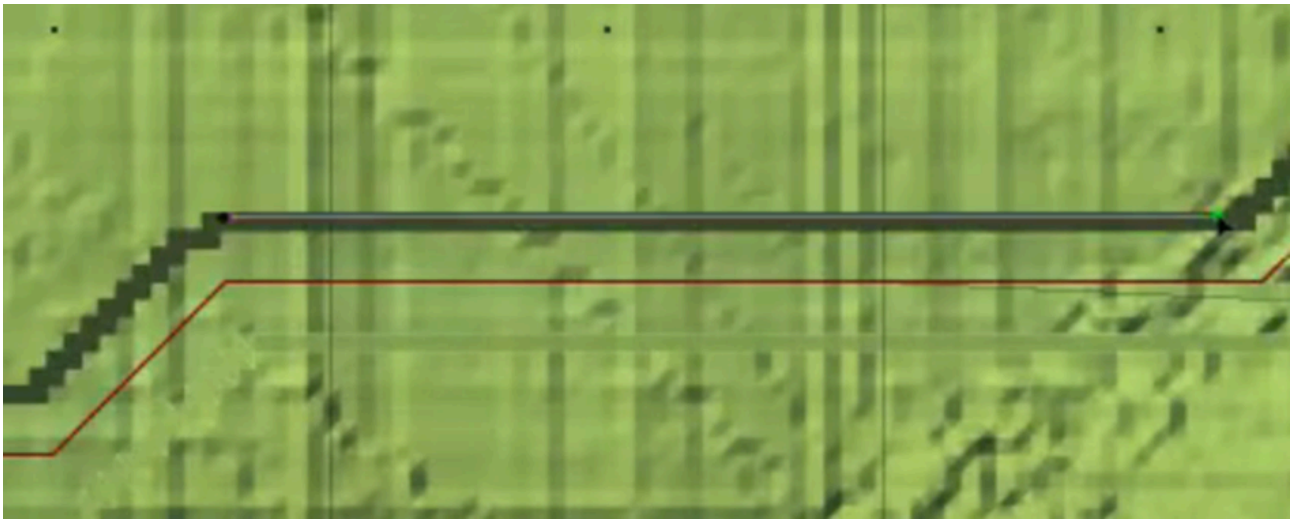


Figure 3: Section of the Drawn Polygon in the Geometric Model

Additionally, boundary condition lines must be established at key locations where water enters or exits the system. These lines define the inflow and outflow boundaries and ensure that the hydraulic model correctly simulates water movement. By properly setting up these boundary lines, the mesh will be more structured and aligned with real-world terrain features.

1.3 Generating the Initial Computational Mesh

Once the boundary lines are established, the next step is to generate an initial computational mesh. This mesh serves as the foundation for further refinements and adjustments.

In HEC-RAS, the mesh is generated within the 2D Flow Area Editor by defining an initial cell size. A common starting point is 32 feet (approximately 9.75 meters), which provides a basic representation of the terrain. The user must ensure that the mesh fully covers the river channel and floodplain without leaving gaps.

At this stage, it is essential to inspect the mesh quality and verify that the cells align with terrain features. If necessary, adjustments can be made to ensure better coverage of critical areas. This initial mesh is typically coarse but provides the basic structure that will be refined in subsequent steps.

1.4 Refining the Mesh to a Specific Resolution

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Upstream

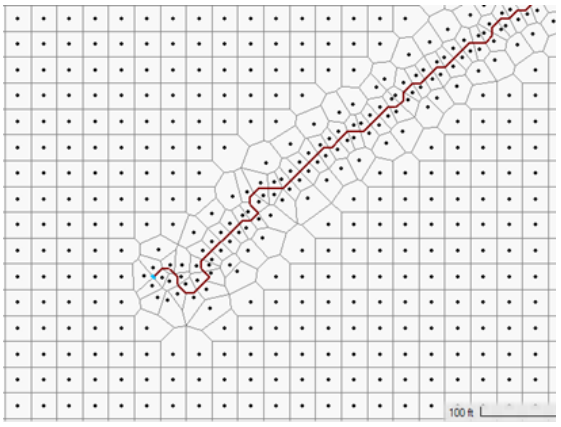


Figure 4:

Downstream

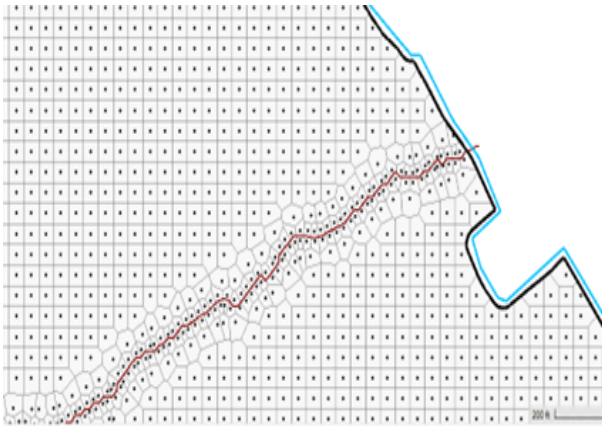


Figure 5:

To improve the accuracy of hydraulic simulations, the mesh resolution must be refined. A smaller cell size allows for better representation of flow characteristics, particularly in areas with complex terrain, high velocity changes, or critical hydraulic structures.

In HEC-RAS, mesh refinement is achieved by adjusting the cell size parameters in the Computational Mesh Refinement Table. For example, a cell size of 16 feet (4.88 meters) can be chosen to improve accuracy in key areas. The refinement table includes:

Column 1 : Target cell size (16 feet).

Column 2 : Bias factor (typically set to 0 for uniform refinement).

Column 3 : For other cell sizes.

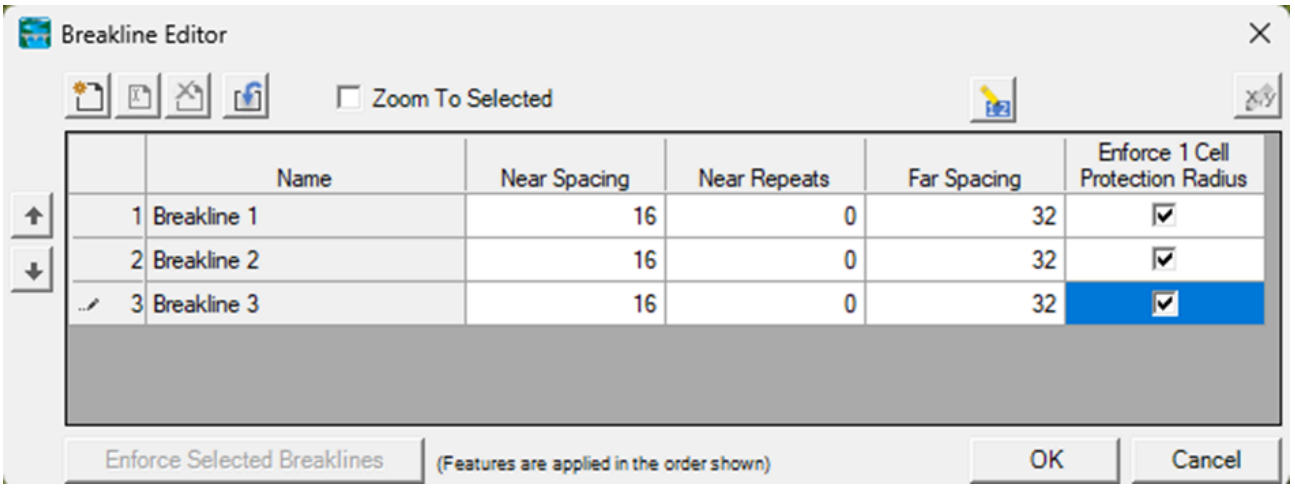


Figure 6:

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After defining these parameters, the mesh is regenerated to apply the new resolution. This step significantly enhances flow distribution accuracy and ensures that the simulation better represents real-world conditions.

1.5 Identifying and Correcting Irregular Mesh Cells

During mesh refinement, certain irregularities may arise, such as cells with too many sides or cells that do not properly conform to the river channel. These irregular cells can negatively impact simulation results and cause numerical instabilities.

To address these issues, HEC-RAS provides a Mesh Quality Check Tool, which highlights problematic cells. The user must carefully inspect the mesh and look for :

- Cells with an excessive number of sides (which can distort calculations).
- Cells that do not align well with terrain contours.

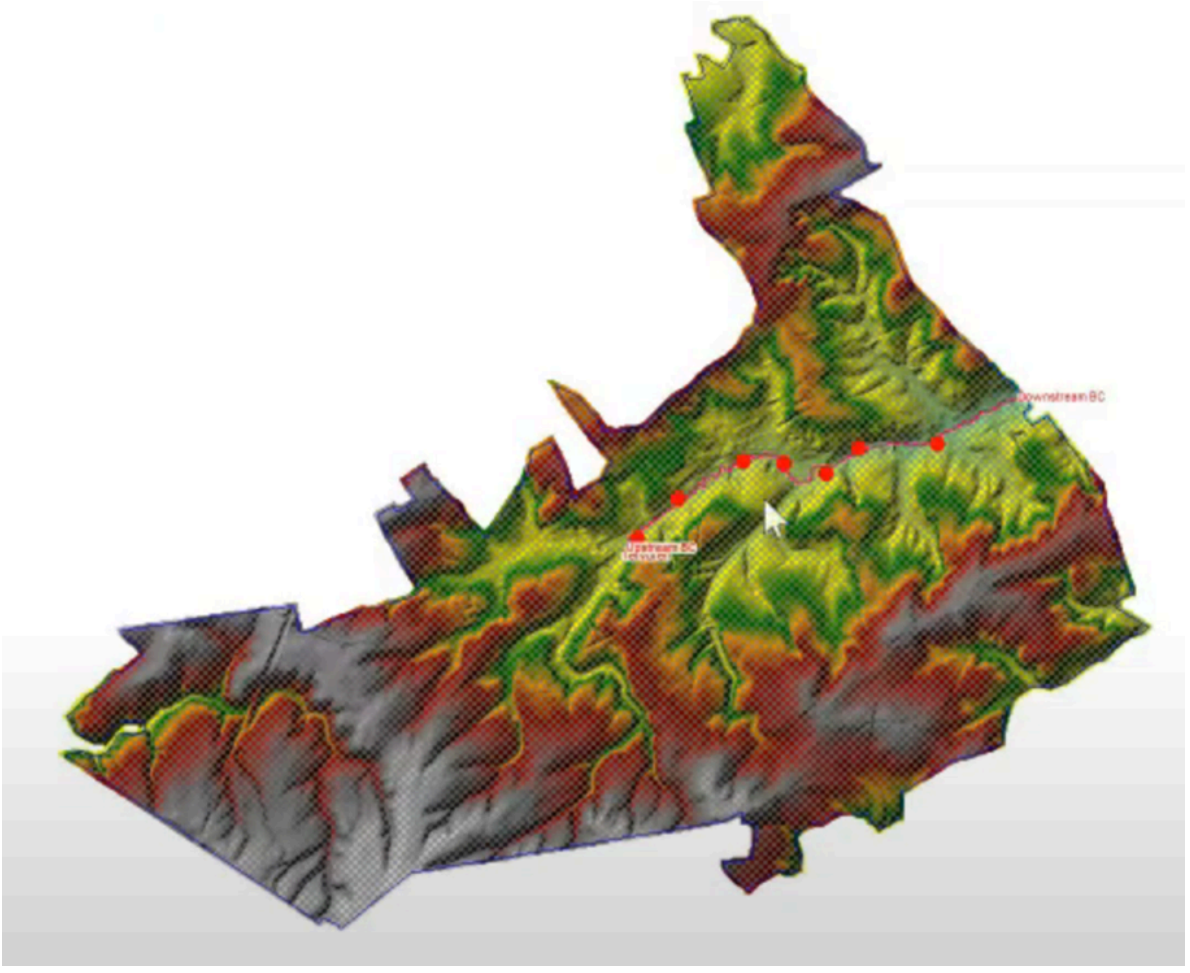


Figure 7:

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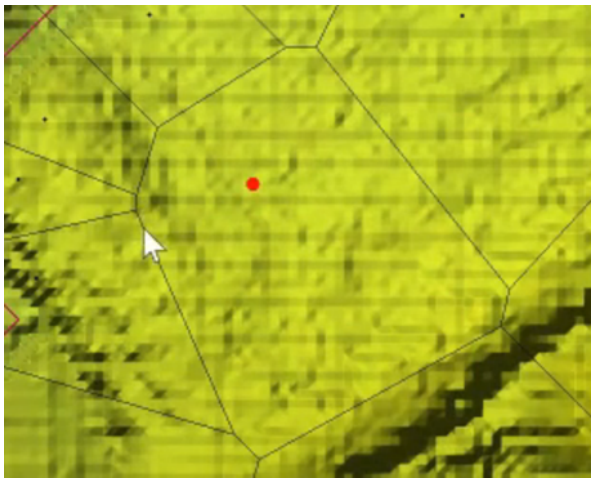


Figure 8:

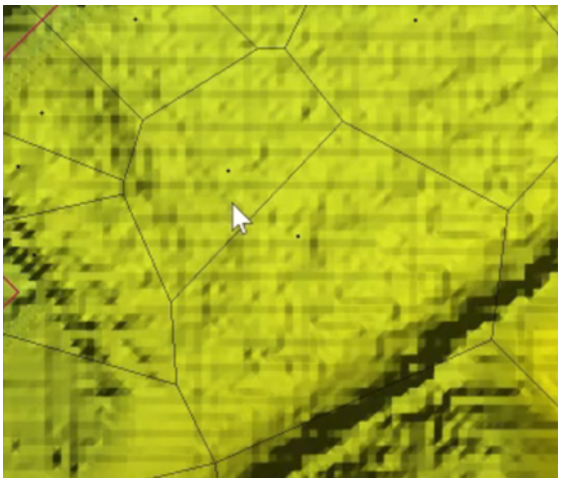


Figure 9:

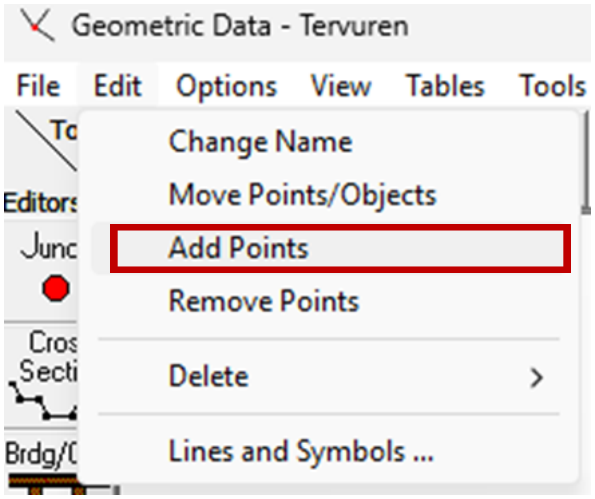


Figure 8:

Corrections are made by manually adjusting cell connectivity. This involves adding additional points to divide large irregular cells into smaller, more structured ones. The user may also move mesh nodes to ensure that the cells properly align with the riverbanks and floodplain boundaries. By refining these irregularities, the overall stability and reliability of the hydraulic model are improved.

1.6 Targeted Mesh Refinement for the Riverbed

To ensure the river channel is properly represented, a localized refinement is applied specifically to the riverbed area. This ensures that variations in depth and width are accurately captured, which is essential for flow simulation.

In HEC-RAS, the user can define a Refinement Region within the Geometric Data Editor. This allows for a finer mesh to be applied exclusively to the riverbed while maintaining a coarser mesh for the surrounding floodplain. Typically, a resolution of 8 feet (2.44 meters) is used in the riverbed to ensure better accuracy.

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A key consideration in this step is ensuring smooth transitions between different mesh resolutions. Sudden changes in cell size can create numerical instabilities, so gradual refinement must be applied. By carefully defining the riverbed mesh, the simulation will more accurately reflect real-world hydraulic conditions.

1.7 Final Verification and Mesh Validation

Before proceeding to full hydraulic simulations, it is crucial to perform a final quality check on the refined mesh.

The validation process includes :

- Checking for remaining irregular cells and ensuring that all problematic areas have been corrected.
- Verifying that mesh resolution is consistent, especially in transition zones between different levels of refinement.
- Running an initial test simulation with basic flow conditions to identify potential issues.
- Saving, closing, and reopening the project to confirm that all refinements have been properly applied.

A well-validated mesh is essential for ensuring stable and reliable hydraulic simulations. This final check helps to avoid unexpected errors or computational issues during flood modeling.

1.8 Conclusion

The refinement of the HEC-RAS computational mesh is a critical step in achieving accurate flood simulation results. By carefully defining boundary lines, refining cell sizes, correcting irregularities, and ensuring proper riverbed representation, the model becomes more robust and reliable.

The key takeaways from this process include:

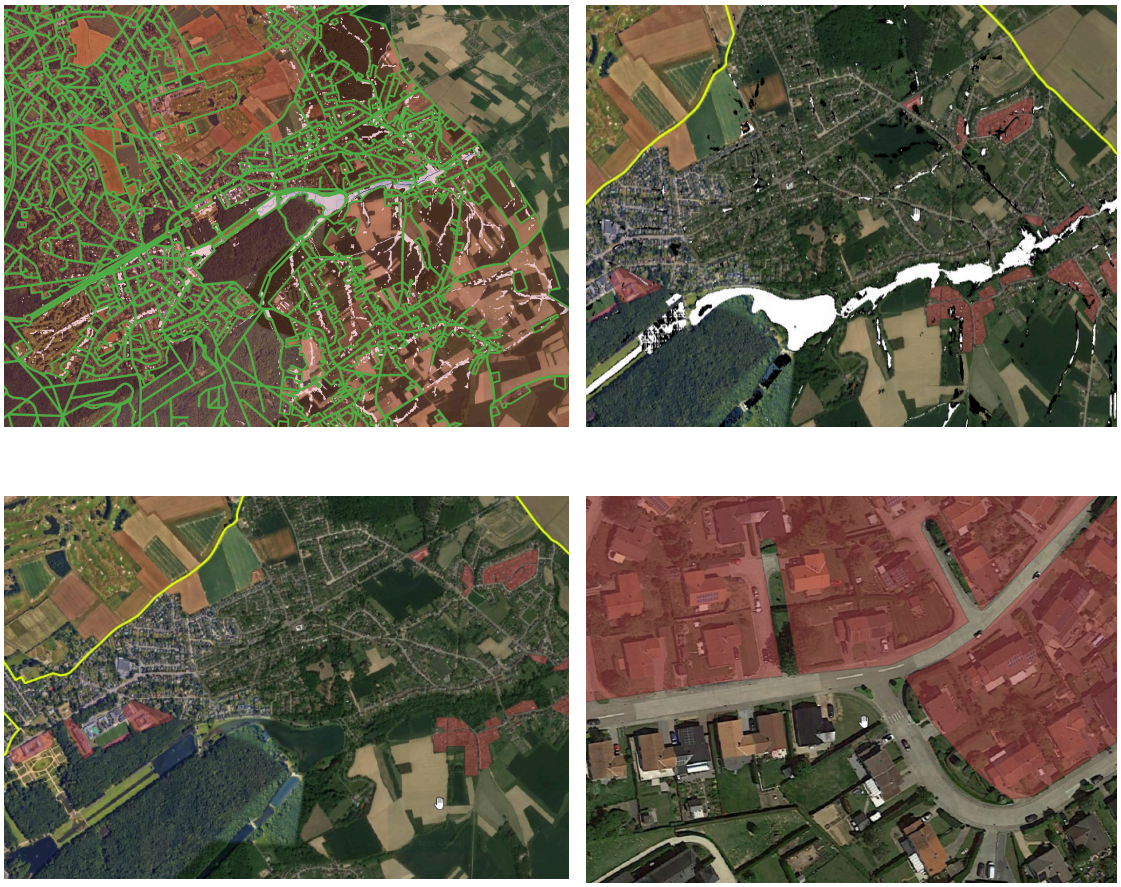
- Proper boundary line definition improves mesh organization and stability.
- Refined mesh resolution enhances flow accuracy in critical areas.
- Correcting irregular cells prevents numerical instability.
- Final validation ensures the mesh is optimized for hydraulic simulations.

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2. Hazards, Vulnerability, and Environmental Risks : Identifying High-Stake Areas

2.1 Introduction

In flood risk assessment, it is essential to determine key areas of interest that are most significantly affected by flooding events. These areas are identified based on specific selection criteria, ensuring that mitigation efforts are focused where they are most needed.



Since population density data is unavailable, the Copernicus satellite data is used to define key locations, such as urban areas, industrial zones, and critical infrastructure. The methodology involves a multi-step selection process, starting with the overlap between flood-prone areas and areas of interest. If too many locations are affected, priority ranking is applied to focus on the 10 most impacted zones. Further filtering considers water depth exceeding 1 foot and a minimum of 10% surface area affected within a given region.

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This report outlines the detailed methodology and selection process used to identify the most critical flood-affected areas.

The identification of flood-affected key areas follows a structured approach based on hydrological data and geospatial analysis. The main criteria are :

1. Identification of the intersection between flood zones and areas of interest (Copernicus satellite data).
2. Selection of the 10 most impacted areas because too many zones are affected.
3. Filtering by water depth, retaining only locations where water levels exceed 1 foot (0.3 meters).
4. Final selection, keeping only areas where at least 10% of their total surface is flooded.

By following these steps, the study focuses on the most significant areas, ensuring that flood mitigation efforts are prioritized effectively.

2.2 Understanding Key Concepts : Hazard, Vulnerability, and Risk

2.2.1 Hazard

A hazard refers to the natural or anthropogenic phenomenon that has the potential to cause damage. In flood risk assessment, hazards are typically linked to :

- River flooding due to excessive precipitation.
- Urban flooding caused by inadequate drainage systems.
- Coastal flooding due to storm surges.
- Dam or levee failures, which result in sudden, extreme water release.

2.2.2 Vulnerability

Vulnerability refers to the exposure and sensitivity of a given area to flooding. Certain locations are more vulnerable than others due to :

- High population density (residential neighborhoods, schools, hospitals).
- Industrial presence (chemical plants, refineries, factories).
- Critical infrastructure (power stations, transportation hubs, water treatment plants).

2.2.3 Risk

Flood risk is defined as the combination of hazard probability and vulnerability. High-risk areas are those where significant flooding hazards overlap with high vulnerability locations, leading to potential human, economic, and environmental consequences.

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2.3 Identifying High-Stake Areas : Industrial and Residential Zones

To effectively map and assess flood risks, it is necessary to identify the key locations that could be severely impacted by a flood event. These include factories, industrial sites, commercial zones, and residential communities.



To assess land use in Tervuren, data was obtained from the Copernicus Land Monitoring Service (*https://land.copernicus.eu*), an online platform jointly implemented by the European Environment Agency (EEA), which manages the European component, and the DG Joint Research Centre (JRC) of the European Commission, which oversees the global component. An Urban Atlas/Land Use map was downloaded and imported into QGIS for visualisation. The dataset was then opened, and the relevant attribute column was selected and classified using the layer properties to effectively analyse potential flood-affected areas.

2.3.1. Locating Industrial and Critical Infrastructure Sites

Industrial areas pose a high environmental risk due to the presence of hazardous materials, chemicals, and energy production facilities. Flooding in such areas can result in :

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- Chemical spills into water bodies, leading to contamination.
- Explosion risks due to water exposure in industrial plants.
- Disruption of energy production, affecting large populations.
- Steps for Identifying Industrial Sites in GIS

2.3.2. Identifying Vulnerable Areas

Residential areas are at high risk due to potential human casualties, displacement, and property damage. Vulnerable populations include:

- Urban centers with high-density housing.
- Hospitals and schools, where evacuations are complex.
- Elderly and disabled communities, which require special assistance.
- Steps for Mapping Population Exposure in GIS

Import Population Density Data :

- Add a population density layer (data in .shp or .tif format)
- Intersect with Flood Extent Maps : Use Vector > Geoprocessing > Intersection to identify residential zones exposed to high flood risk.

Visualize and Rank Vulnerable Areas :

Generate a heatmap to prioritize areas needing emergency response planning.

2.4 Environmental Risks and Sensitive Ecosystems

Flooding can cause severe environmental damage, especially in regions containing protected ecosystems, wetlands, and agricultural land.

2.4.1 Water Contamination

Floodwaters can carry toxic pollutants from industrial zones into rivers, lakes, and groundwater systems, leading to :

- Long-term ecosystem damage due to hazardous chemical exposure.
- Waterborne disease outbreaks in affected communities.
- Destruction of agricultural land from contamination.

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2.4.2. Wetlands and Natural Buffers at Risk

Wetlands serve as natural flood buffers but are often at risk due to :

- Alteration of hydrological balance caused by excessive flooding.
- Loss of biodiversity due to sedimentation and pollution.
- Destruction of mangroves and forests, which play a key role in carbon storage and erosion prevention.
- Steps for Assessing Environmental Risk in GIS

Overlay Flood Hazard Maps with Environmental Zones :

- Load the protected area dataset (e.g., wetlands, forests, nature reserves).
- Combine with flood risk layers using Vector > Overlay.
- Assess Damage Potential :
- Identify areas where flooding may cause irreversible environmental damage.
- Prioritize Conservation Strategies : Classify flood-prone ecological zones for protection and restoration efforts.

3. Climate Change Modelling

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3.1 Methodology

3.1.1. Stochastic Rainfall Model - Observed and Baseline Data

A Markov model is a stochastic model that predicts the probability of transition based on the current state. Some of the variables used in this model where precipitation is being modelled include the probability of a wet day (pwet), the probability of a dry day (pdry), which for this model, sum to 1, and the transition matrix, which consists of the probability of a wet day followed by a wet day (pww), a dry day following a wet day (pwd), a wet day following a dry day (pdw) and consecutive dry days (pdd). The rows across the transition matrix for this type of model should sum to 1. Since the model is stochastic, every run will obtain different results.

To firstly construct the stochastic model representative of the catchment area, variables from historical data must be used. Catchment daily rainfall data was provided for catchment Ukkel over 18 years from 2007-2025. Of this data, a 18-year period from 2007 – 2024 was used, this includes the year 2008 that our HEC-RAS model is run over. This rainfall time series was run through a python script designed to abstract the required variables from the observed rainfall data as shown in tables 1,2 and 3, though precise values were used throughout the modelling process to minimise uncertainty, figures have been given to 3 decimal places for clarity in this report. These variables are then used as input data for the model and ensure consistency with historical data.

Table 1: Statistics for observed rainfall data

Mean Wet Daily Rainfall	Mean Daily Rainfall	Mean Annual Rainfall	Max Rainfall Value	Pdry	Pwet
6.954	2.124	775.000	379.8	0.695	0.305

Table 2: Observed data transition matrix

Pww	Pwd	0.513	0.487
Pdw	Pdd	0.214	0.786

Table 3: lambda and inverse lambda values

1/λ	6. 954
λ	0.144

Using the variables abstracted from the observed rainfall, detailed in tables 1,2 and 3, as input values, a baseline Markov model, representative of the historical/current data, was then set up for a 29-year period from 01-01-1981 to 31-12-2010, matching the CMIP6 baseline period and some

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of the ALARO baseline period (1961-1990) the output data from the model is shown in tables 4-6 below.

Table 4: Output statistics for baseline data

Mean Wet Daily Rainfall	Mean Daily Rainfall	Mean Annual Rainfall	Max Rainfall Value	Pdry	Pwet
6.814	2.026	740.029	54.489	0.703	0.297

Table 5: output transition matrix for baseline data

Pww	Pwd	0.501	0.499
Pdw	Pdd	0.211	0.789

Table 6: output baseline lambda and inverse lambda values

1/λ	6. 814
λ	0.147

Comparing the input and output data for the baseline model, very similar but not identical results can be seen, indicating that the baseline model is representative of the historical data. One limitation of a Markov model is its inability to represent peak events – seen by the substantial difference in max rainfall value, due to this, design storms have been modelled differently. A monthly plot of the rainfall can be viewed in the results section. An important factor that is currently not modelled in the baseline rainfall is seasonality, this has been modelled in the future estimates.

3.1.2. CMIP6 and ALARO

CMIP6 holds the most recent future global climate projection data, using the IPCC interactive atlas for the Total Precipitation variable and the max 1-day precipitation, it gives probabilistic projections of percentage of these changes relative to 1981 – 2010 using 33 different models, based on four different emission scenarios. In this report, SSP5-8.5 and SSP2-4.5, the highest and 2nd lowest emission scenarios, have been considered to compare seasonally over the long-term period from 2081-2100, and annually for the long medium- and short-term period. The 50th and 95th percentile projections have been considered over the region, for the two SSPs and the 50th percentile change was available over the approximate coordinates of Tervuren, 50.8258° N, 4.5078° E. The probabilistic projections of percentage change have been used to abstract change factors.

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In addition, another model called ALARO, more representative of Belgium specifically, has been used to compare with CMIP6 projections. Change factors have been abstracted from the probabilistic projections for this model.

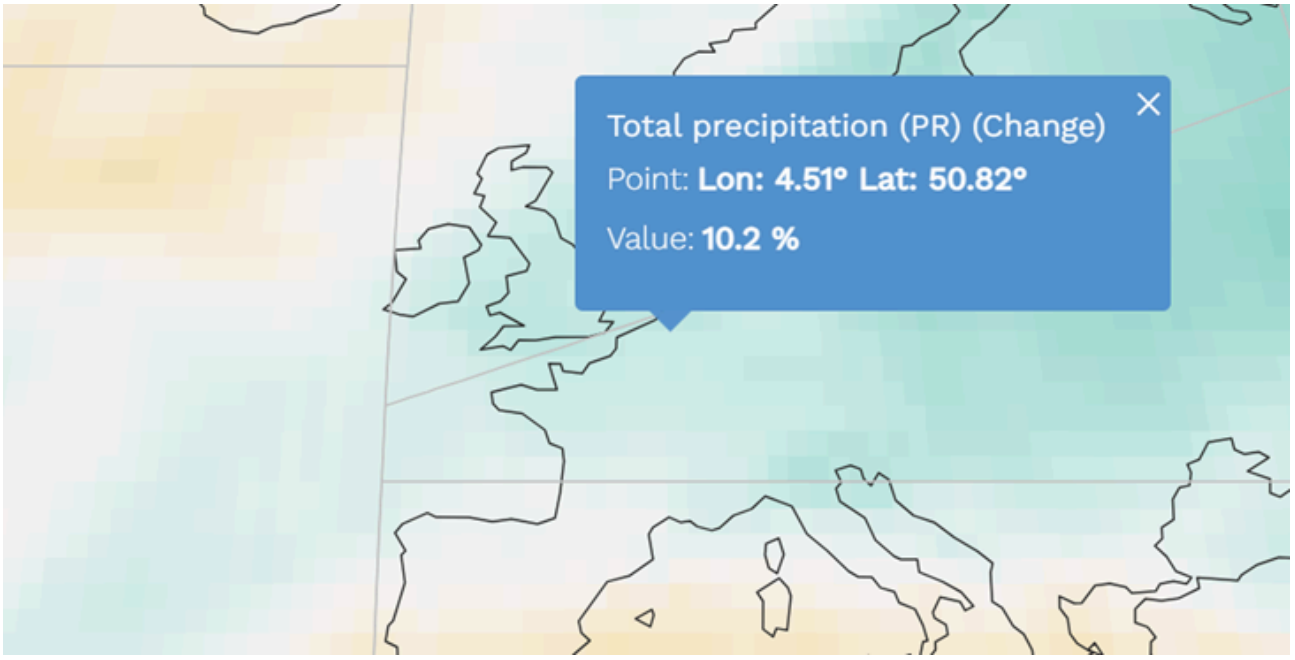


Figure 11: IPCC Projection for December-February (winter) for Tervuren Coordinates

Examples of the change factors abstracted can be shown in tables 9 and 10, which show the change factors for the seasonal rainfall model and the design storm respectively, calculated using the following equation:

$$Change\ Factor = 1 + (\frac{precipitation\ rate\ anomaly}{100})$$

Table 9: change factors per season and percentile SSP5-8.5 Long Term (2081-2100) Using CMIP6 for use in the Markov model

SSP5-8.5 Long Term	Spring	Summer	Autumn	Winter
Area PR 50th	1.096	0.745	1.014	1.195
Area PR 95th	1.235	0.966	1.086	1.378
Tervuren Coordinates PR	1.026	0.698	0.995	1.215
Area Max1day 50th	1.201	0.993	1.191	1.287
AreaMax1day	1.291	1.124	1.270	1.430

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95th				
Tervuren Coordinates Max1day	1.184	1.032	1.196	1.235

Table 10: change factors per estimate period and percentile ALARO for use in the design storm calculations.

ALARO Annual	2030	2050	2085	2100
95th Percentile	1.164	1.223	1.327	1.372
Summer 5yr return period	1.131	1.178	1.262	1.298
Summer 10yr return period	1.127	1.174	1.257	1.292
Summer 15yr return period	1.125	1.172	1.253	1.288
Summer 30yr return period	1.131	1.181	1.267	1.304
Winter 5yr return period	1.207	1.283	1.415	1.472
Winter 10yr return period	1.207	1.283	1.415	1.472
Winter 15yr return period	1.208	1.284	1.417	1.474
Winter 30yr return period	1.208	1.285	1.418	1.476

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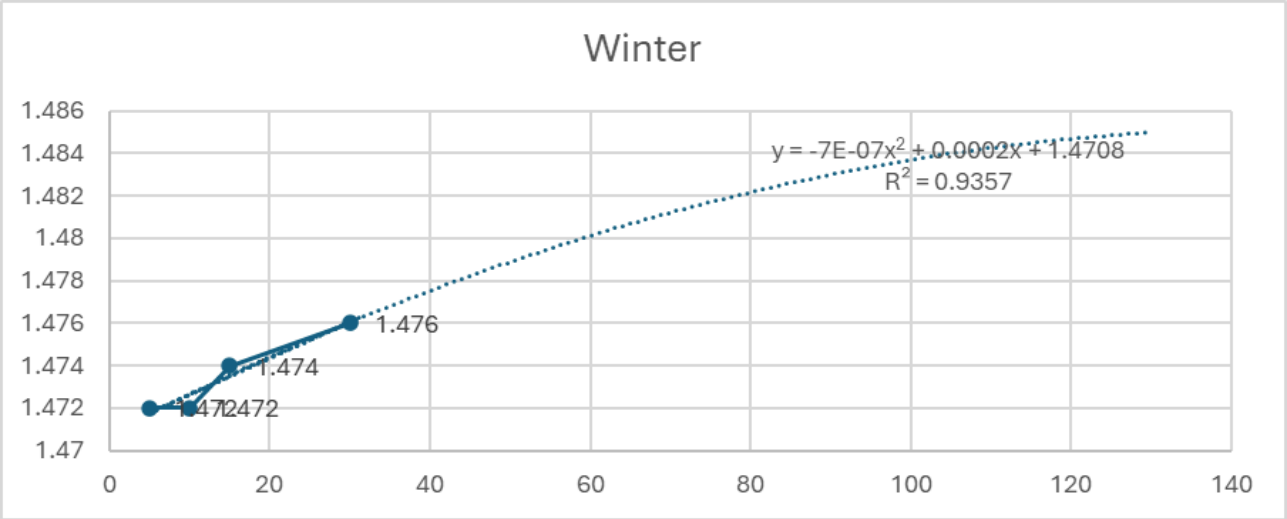


Figure 12: Winter 2100 extrapolation change factor

To create artificial rainfall representative of the future rainfall, and to create design storms, the delta change method has been used, where change factors have been multiplied by the current mean wet daily rainfall for each season. The delta change approach has some limitations, just changing the mean is not fully representative of how climate extremes change and keeps biases in historical simulations in future simulations this should be taken into consideration when using these predictions.

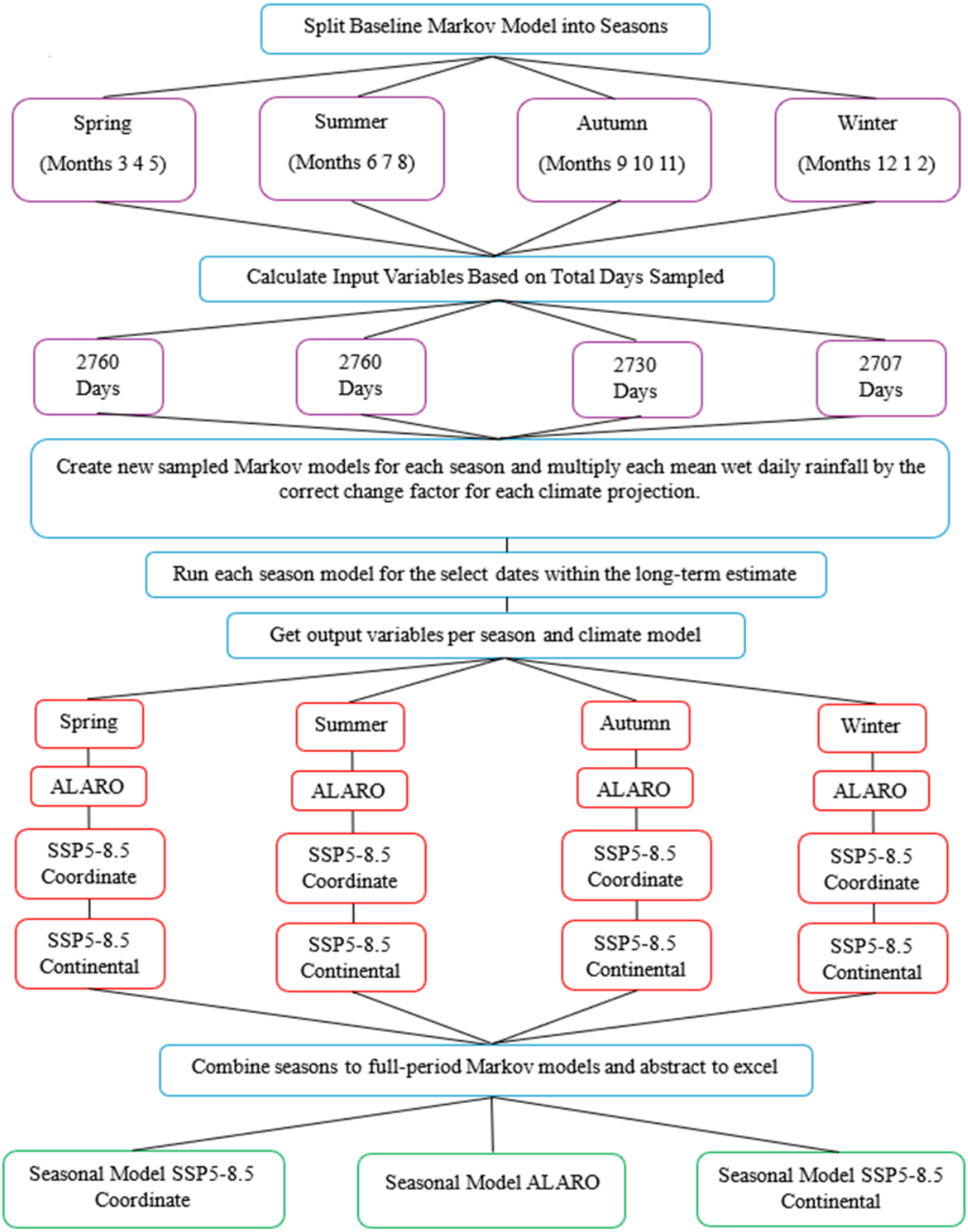
For the design storms a 50-year period was modelled to obtain the change factors for 2030, 2050 and 2100, polynomial trendlines were extrapolated using excel. An example is shown in figure 2 for the winter 2100 change factors, the equation determining the 2100 50-year return period change factor is shown below.

$$-7x10^{-7}x^2 + 0.0002x + 1.4708 = 1.47905$$

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3.1.3. Seasonality in Future Rainfall

The following schematic describes the process taken to implement seasonality into the future Markov models, this was done using python.



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This process was run for the SSP5-8.5 and ALARO models, derived change factors were applied to mean wet daily rainfall, which in turn affects both the lambda value, and the pdry and pwet values through the following equations:

$$mean\ wet\ daily\ rainfall = \frac{1}{\lambda} \qquad pdry = \frac{mean\ daily\ rainfall}{mean\ wet\ daily\ rainfall}$$

$$pwet = 1 - pdry$$

3.2 Future Rainfall Results

To explore variability in projections and uncertainty between the models, figures x shows the observed average daily rainfall per month for Observed rainfall over the 19 years, CMIP6 95th percentile area SSP8.5 2081-2100 (long-term), CMIP6 Tervuren coordinate 2081-2100 (long-term), and ALARO 95th percentile 2100 (long-term). Showcasing both the wide range of uncertainties associated with certain models and the change in rainfall associated with each model for the long-term estimate.

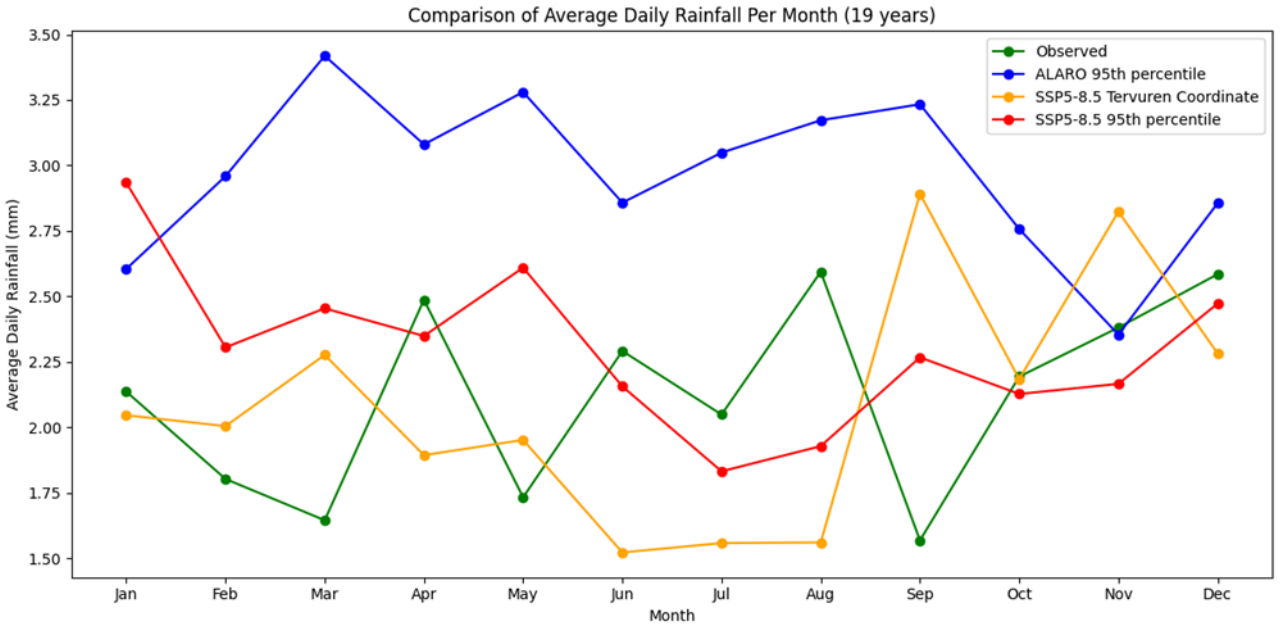


Figure 13: Comparison of average daily rainfall per month for each model scenario

The ALARO model in the 95th percentile change over long-term analysis predicts the highest rainfall, for this reason we will use ALARO for the design storms as it will allow us to model the most extreme events.

3.3 Design Storm Rainfall Results

Applying the 50-year return period change factor for 2030, 2050 and 2100 to the 24h period rainfall data in HEC-RAS allowed us to model a design storm for a short, medium and long-term scenario.

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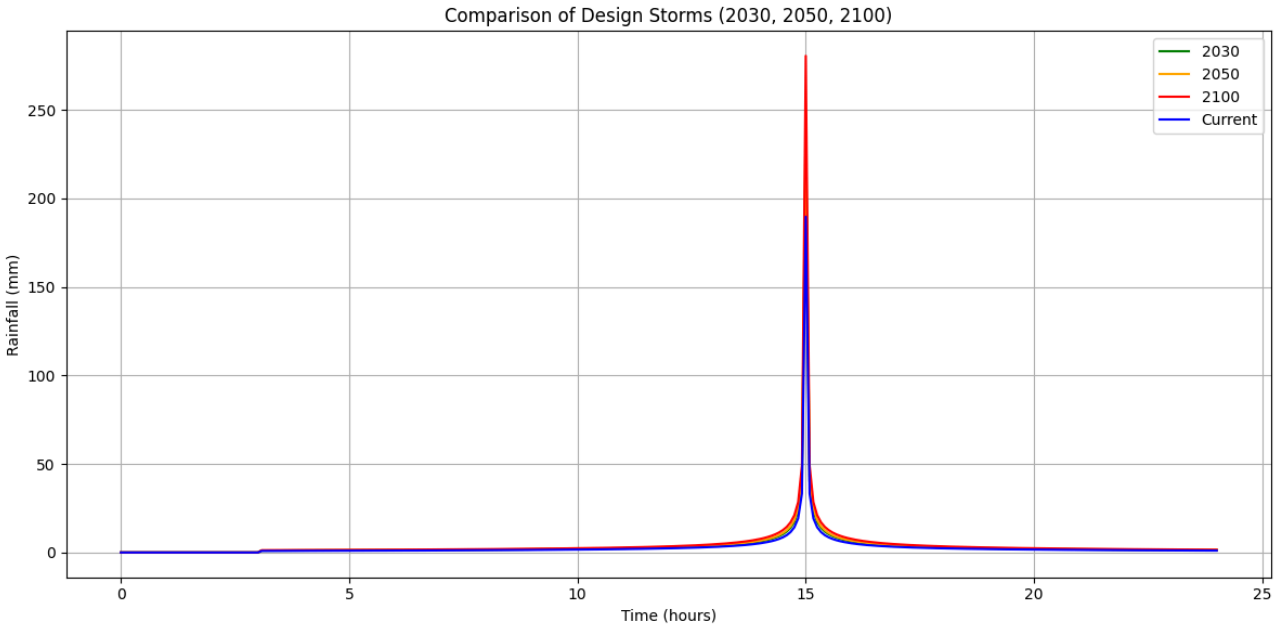


Figure 14: Design Storm Comparison

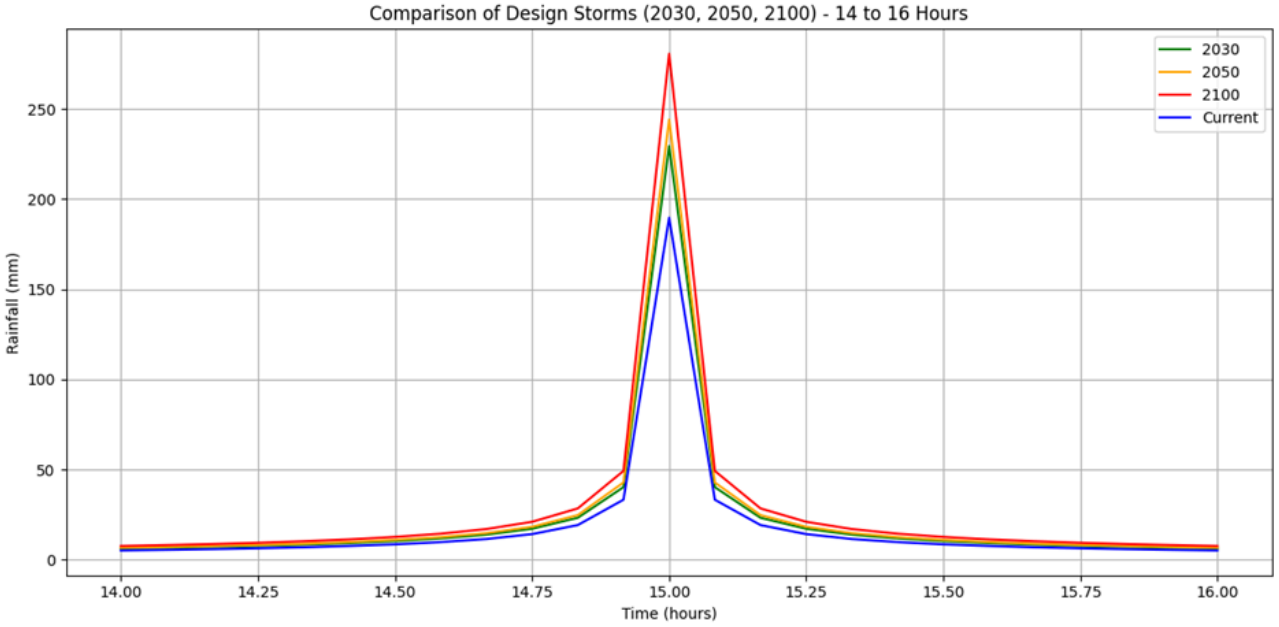


Figure 15: Comparison of design storms between hour 14 and 16

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4. Flood Prevention Methods and Mitigation Strategies

Following the flood simulation and risk assessment conducted in our study area, we identified the most vulnerable regions prone to flooding. To mitigate the impact of extreme weather events and enhance flood resilience, several flood prevention methods will be considered based on the area's hydrological, topographical, and environmental characteristics. These methods aim to reduce surface runoff, enhance water infiltration, and improve floodwater storage and redirection.

The selection and implementation of each method will be tailored to the specific conditions of the study area, ensuring a sustainable and effective flood management strategy. Below is a detailed description of the key flood prevention techniques that will be evaluated and integrated based on our analysis.

as shown on the table, we have classified 20 high-risk areas according to the ratio of flooded surface area. Areas where more than 10% of the total surface is covered by floodwaters are considered highly vulnerable. These areas have been marked under the "Condition (above 10%)" column as "YES."

To mitigate flood risks, we will analyze each area's characteristics and apply the most suitable flood prevention strategies. These strategies will be selected based on factors such as flood depth, surface area, flood direction, type of properties and land use conditions to ensure effective flood management and resilience.

Table 11: Locations of Implemented Solutions

Zone Code	Zone ID	Surface Area (m²)	Maximum Flooded Area (m²)	Ratio	Condition (above 10%)	H_max (feet)	H_max (m)	Solution
16	347	37954.0777	1827.40016	4.81476635	NO	4.29376	1.30867418	
17	358	64470.6707	3340.33074	5.18116331	NO	4.16238	1.26863151	
4	70	29638.6175	2158.45578	7.28257915	NO	4.95992	1.51170984	
6	149	87456.1629	6653.16329	7.60742648	NO	13.7862	4.20182871	
9	218	28448.7291	2733.77743	9.60948878	NO	6.93283	2.11302347	
20	553	91274.1408	9202.09041	10.0818154	YES	6.53914	1.99303261	porous pavement

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2	25	29537.2221	3435.96033	11.6326455	YES	4.3839	1.33614752	rain gardens / suggesting / infiltration pond
11	221	12831.7503	1663.16021	12.9612888	YES	2.39656	0.73043584	vegetation floor on parking / green roof / porous pavement
7	155	10784.0899	1445.29102	13.4020676	YES	3.88104	1.18288327	infiltration bassin / pavement
5	146	43244.614	6500.36358	15.0316143	YES	5.12854	1.56310271	pavement / rain gardens / storage area
10	219	5821.35785	1008.81072	17.3294744	YES	3.28755	1.00199634	pavement / berm / pierre solution
13	224	33118.3234	6235.67184	18.8284647	YES	6.89682	2.10204816	no
8	205	7955.51824	1507.22539	18.9456594	YES	14.9762	4.56452301	no
12	222	8278.21456	1571.83878	18.9876545	YES	3.01196	0.91800061	pavement / deep chanel / bassin north West
3	43	14015.2622	3140.30791	22.4063444	YES	4.99368	1.52199939	pavement and green roof
18	364	10799.7476	2425.76239	22.4612879	YES	15.3121	4.66690034	Pierre suggestion asnd ask nahad
15	285	38955.3354	9460.05399	24.2843603	YES	4.22745	1.28846388	rain gardens
14	268	18220.2919	4715.18741	25.8787699	YES	5.69029	1.73431576	green roof
1	22	17294.5422	4671.51044	27.0114722	YES	2.54091	0.77443158	Culvert
19	427	5459.55982	2222.63953	40.7109658	YES	4.46243	1.36008229	berm / rain garden

4.1 Porous Pavement

Porous pavement, also known as permeable pavement, is a specialized surface material designed to allow water to infiltrate through the pavement layers into the underlying soil. Unlike conventional impermeable surfaces, porous pavement reduces the volume of surface runoff and enhances groundwater recharge.

Application in Flood Prevention:

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- Facilitates the absorption of rainwater, reducing runoff and minimizing urban flooding.
- Prevents water pooling on roads, sidewalks, and parking lots.
- Reduces the load on drainage infrastructure, improving overall stormwater management.

After reviewing the conditions of the identified locations, porous pavement has been selected as the most suitable flood mitigation strategy for some areas in the zones. ID codes: 553, 146, 219, and 43. The analysis indicated that these areas experience high surface runoff due to the presence of impervious surfaces, making stormwater infiltration a challenge. Implementing porous pavement in these locations will enhance water absorption, reduce runoff, and alleviate localized flooding. This solution was determined to be the most effective based on site-specific conditions, ensuring improved stormwater management and long-term flood resilience.



Figure 16 : applying porous pavement for area id code- 553

4.2 Rain Gardens

Rain gardens are landscaped depressions that capture and temporarily store stormwater runoff, allowing it to gradually infiltrate into the soil. These gardens are designed with high-absorption vegetation and soil layers that enhance natural water retention.

Application in Flood Prevention:

- Reduces stormwater runoff by enhancing infiltration and delaying water movement.
- Helps filter pollutants from runoff, improving water quality in natural waterways.
- Provides aesthetic and ecological benefits, supporting biodiversity in urban areas.

For example, we will apply the rain gardens strategy for this area code id 25,146,285 and 427.

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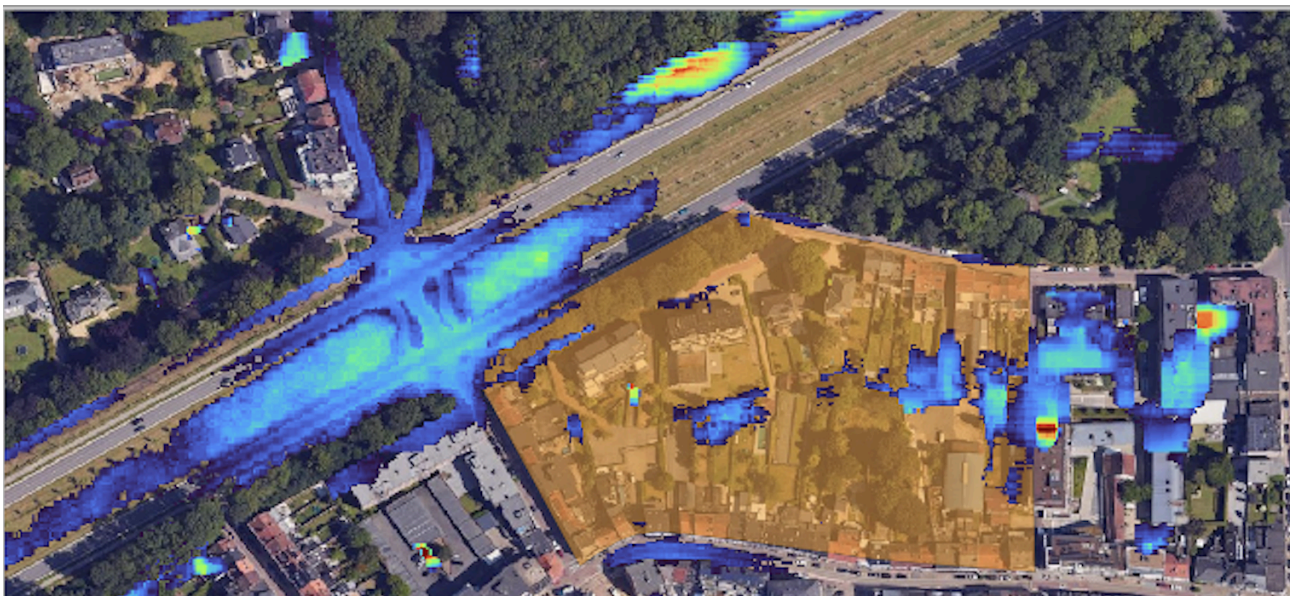


Figure 17 : applying rain gardens for area id code-25.

4.3 Vegetation Cover and Green Roofs

Vegetation cover and green roofs are effective nature-based solutions for managing stormwater and mitigating flood risks in urban environments. Green roofs incorporate vegetation layers on building rooftops to absorb rainfall and reduce runoff, while vegetation cover across landscapes increases soil permeability.

Application in Flood Prevention:

- Intercepts rainfall, reducing direct runoff and lowering flood peaks.
- Enhances evapotranspiration, which reduces excess water accumulation.
- Improves soil stabilization, minimizing erosion and sediment transport.

and we applied this strategy for some places in areas code : 268,43 and 221.

4.4 Infiltration Basins

Infiltration basins are engineered depressions that temporarily store stormwater and promote gradual infiltration into the subsurface. These basins are particularly effective in areas with high runoff volumes and permeable soils.

Application in Flood Prevention:

- Reduces the speed and volume of surface runoff, preventing flash floods.
- Enhances groundwater recharge, reducing dependency on artificial drainage systems.
- Serves as a controlled flood storage mechanism, mitigating flood risks in critical areas.

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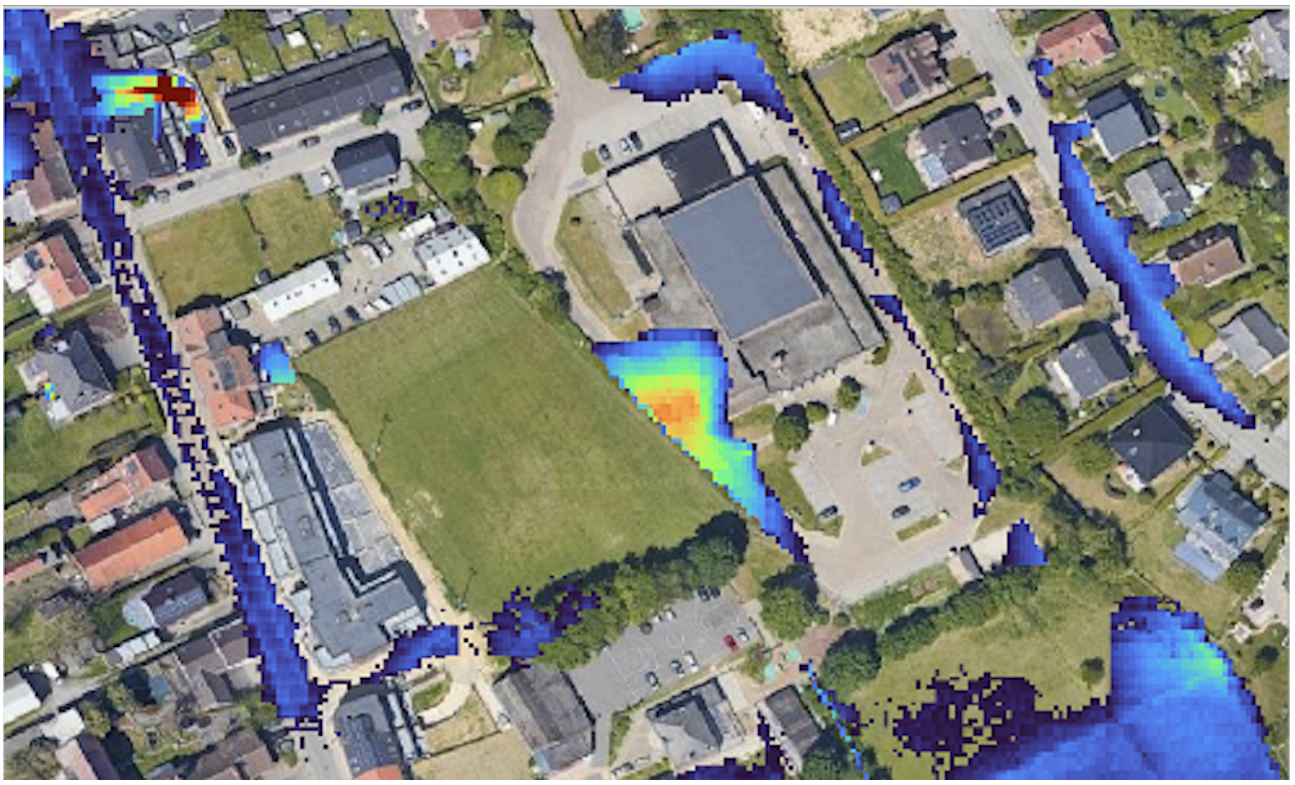


Figure 18: applying infiltration basins method for area id code- 155.

4.5 Storage Areas (Retention and Detention Basins)

Storage areas, such as retention and detention basins, are essential flood mitigation structures that temporarily or permanently hold stormwater to control runoff volumes.

- Retention basins are designed to store water permanently, functioning as artificial lakes or wetlands.
- Detention basins temporarily hold floodwaters and release them gradually over time, preventing sudden flood surges.

Application in Flood Prevention:

- Controls peak discharge rates by storing excess floodwaters.
- Reduces downstream flooding risks by regulating outflow.
- Provides additional environmental benefits by creating wetland ecosystems.

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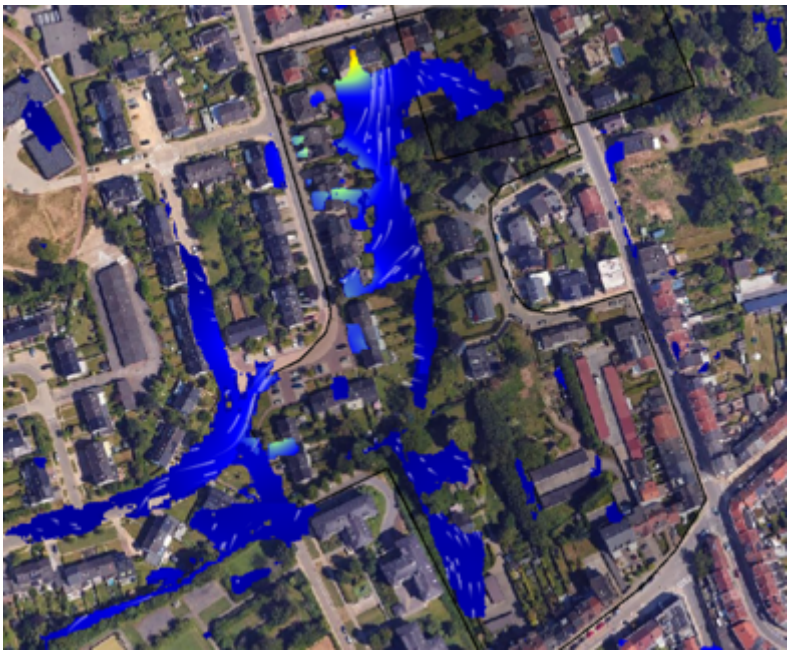


Figure : applying storage area strategy for area id code-146.

4.6 Culverts

Culverts are underground or surface water conveyance structures that allow water to flow under roads, embankments, or railway lines. Properly designed culverts help redirect stormwater flows efficiently, reducing flood risk in areas prone to water accumulation.

Application in Flood Prevention:

- Facilitates the smooth passage of floodwaters, preventing localized flooding.
- Reduces the risk of infrastructure damage by preventing water buildup under roads and bridges.
- Supports drainage system efficiency, ensuring unimpeded water flow.

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Figure 20: applying Culvert strategy for area id code-22.

4.7 Berms

Berms are raised earthen barriers that help divert or contain floodwaters, reducing the impact of extreme rainfall events. These structures can be natural or man-made and are often used to protect critical infrastructure and residential zones from flooding.

Application in Flood Prevention:

- Redirects floodwaters away from at-risk areas, reducing property damage.
- Serves as a protective buffer for industrial and residential zones.
- Can be integrated with vegetation cover to enhance flood absorption and erosion control.

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Figure 21: applying Culvert strategy for area id code- 427.

4.8 Implementation of Our Solutions in the Model

To integrate our solutions into the model, we will modify both the elevation layer and the land cover layer to accurately represent the retention basins and their impact on the environment. These modifications will ensure that the changes are correctly applied at the designated locations and will be reflected in the hydrodynamic simulations.

4.8.1. Modifications to the Elevation Layer

Adjust the Digital Elevation Model (DEM) to account for the excavation of retention basins. This involves lowering the terrain in specific areas where the basins will be placed. Ensure that the depth and shape of the basins match the designed retention volume. This may require using GIS tools or terrain editing software. Verify smooth transitions between the modified and original terrain to prevent unrealistic slopes or depressions that could affect water flow behavior. Update the terrain raster in HEC-RAS to reflect these elevation changes before running simulations.

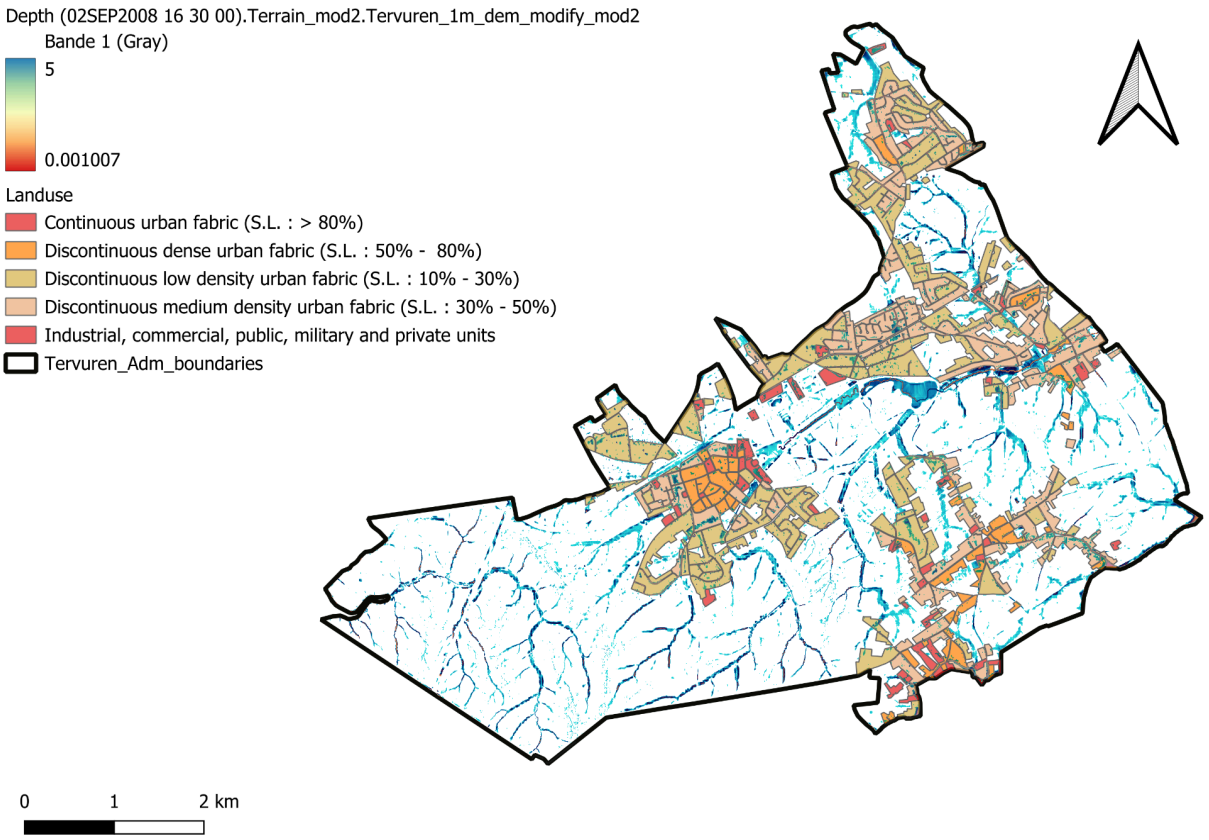
4.8.2. Modifications to the Land Cover Layer

To effectively implement our modifications in the model, we will create new land cover classes, allowing us to dynamically adjust key hydrological and hydraulic parameters. By introducing these new classifications, we will gain the flexibility to modify three critical factors: Curve Number (CN), Manning's roughness coefficient, and infiltration properties. The Curve Number (CN) will be adjusted to refine runoff estimations based on the updated land use, ensuring that the hydrological model accurately represents water retention and flow dynamics. Manning's roughness

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coefficients will be recalibrated in the hydraulic model to account for changes in surface resistance, particularly in areas where retention basins alter the flow regime. Additionally, infiltration properties will be modified to reflect the impact of new land cover types on soil permeability and water absorption capacity. These modifications will be systematically integrated into HEC-RAS, ensuring that flood simulations incorporate the effects of retention basins on both surface and subsurface water movement. Once the new classes and associated parameter adjustments are fully implemented, we will conduct thorough validation checks to confirm the model's consistency and reliability. This approach not only enhances the accuracy of our flood simulations but also provides a structured and scalable method for evaluating the hydrological and hydraulic impacts of retention basins in the study area.

5. Results and Analysis.



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