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Team 04: Week 2

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WP2: Uncertainty in Advanced Hydrological and Hydraulic Modelling
WP3: Climate Change Impacts on Flash Floods
WP4: Accidental Water Pollution
Case Study: Ouseburn Catchment (United Kingdom)

Team04: Report Week 2:
Modelling and Analysis of Accidental Water Pollution in the Ouseburn Catchment

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1 Accidental Pollution

1.1 Pollution in the Ouseburn River

Accidental pollution of rivers results in severe implications for the surrounding environment and local residents (Zhang et al, 2017). This is a particularly prominent issue in the Ouseburn Catchment due to the close proximity of the Ouseburn River to the popular recreational public green space, Jesmond Dene. As the park is frequented by families with dogs and young children, it is paramount that pollution be kept to a minimum throughout the watercourse to mitigate the adverse health impacts associated with contact of contaminated water.

There are two primary pathways for pollutants to enter the Ouseburn: point source pollution and diffuse pollution.

1.2 Diffuse Pollution

The Ouseburn River is classified as being in 'Moderate ecological status' by the Environment Agency (DEFRA, n.d.). This is due to the high concentration of Phosphate within the river, posing a severe threat to its ecological health (Tyne Catchment Partnership, n.d.). Phosphate has entered the Ouseburn catchment via agricultural runoff stemming from the use of fertilisers in the rural, upstream area of the catchment (around Woolsington gauging station) (Figure 1). This poses a huge risk to organisms living within the river, as high concentrations of phosphate lead to the formation of algal blooms, which block sunlight, causing eutrophication and ultimately leading to anoxia and the subsequent death of the ecosystem (Akinnawo, 2023).

1.3 Point Source Pollution

Initial research by Newcastle University in 2021 found that water quality in the Ouseburn River is variable (Newcastle University, 2023). During a September rain event, it was estimated that between 72 - 77% of bacteria within the river originated from the sewer system located downstream of South Gosforth, classified as combined storm overflow (CSO) discharge (Zan et al, 2023). During storm events and periods of snowmelt, it is within the law for sixteen CSOs to discharge flow directly into the Ouseburn River (Figure 1), which is problematic as 11 CSOs are upstream of the popular recreational space of Jesmond Dene (ibid).

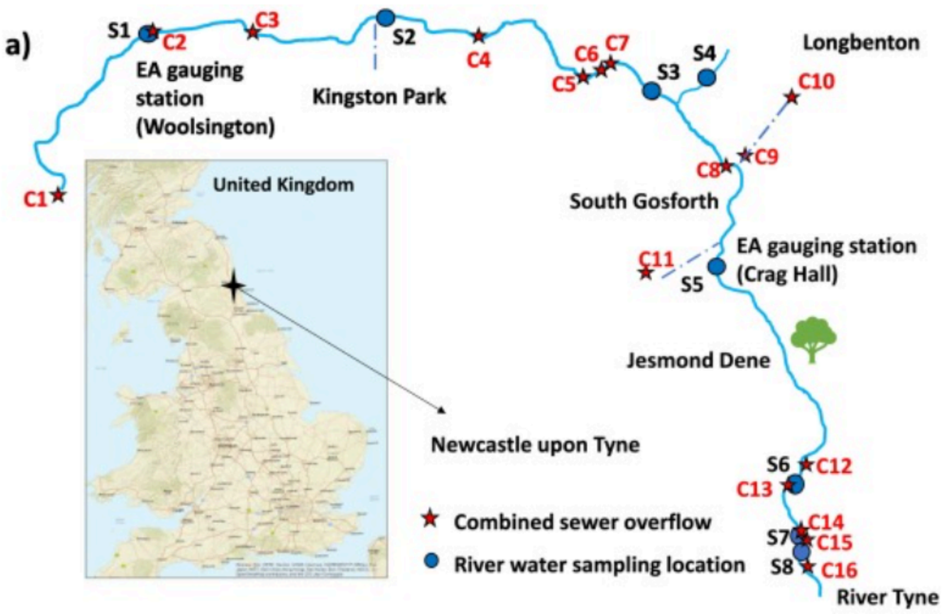

Figure 1: Locations of CSOs and water sampling stations along the Ouseburn River.

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Monitoring of the microbial levels in the Ouseburn River is sporadic, as the site is not classified as bathing water, despite functioning as a popular location during the summer months. Organic matter is a source of energy that promotes bacterial growth (Gupta et al, 2023), indicating the potential for a correlation between sewage discharge into the river and microbial growth. Ouseburn catchment is subject to significant wastewater pollution (microbial contamination and antibiotic resistance). The fecal coliforms (FC) in water are due to the domestic wastewater discharges (Gupta *et al*, 2023). In the Ouseburn river, faecal indicator genes are present with log abundances of (−3.12 ± 0.24) copies/16S rRNA. Some antibiotic resistance genes (ARGs) have also been found with abundances of 2.34 ± 0.19 copies/16S rRNA (Figure 2). The ARGs concede rapidly to bacteria the capacity to resist an antibiotic that would typically kill them.

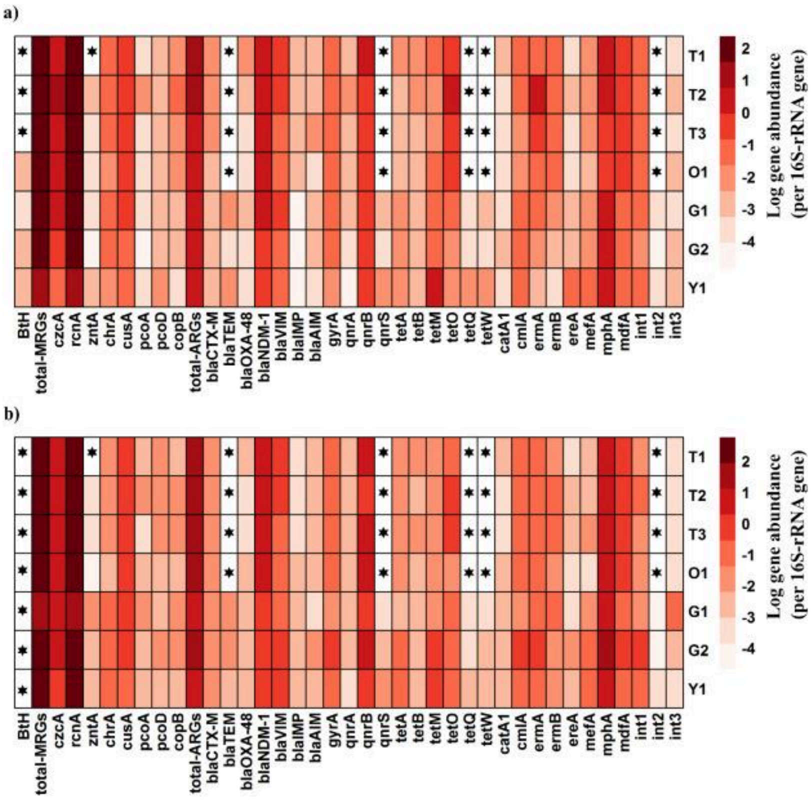

Figure 2: Relative abundance of faecal indicator gene (*BtH*), HMRGs, ARGs, and integrons. a) in water, b) in sediment (Gupta *et al.*, 2023).

1.4 Solutions implemented by the authorities

The river has encountered both diffuse and point source pollution for a long time, and the local authorities are aware of that. As an example of what they are trying to implement, we can view the airport case. The de-icing process was putting a lot of ammonia and contributed to reducing the biodiversity in the river (Turnbull and Bevan, 1995). To overcome the problem, the surface runoff water is now collected and analyzed before it goes to the sewer water system. Even if the system is not perfectly efficient, as in 2004 when the airport received a fine of £10,000. In fact, the pollution was so intense that they expected only the strongest species to survive after this event.

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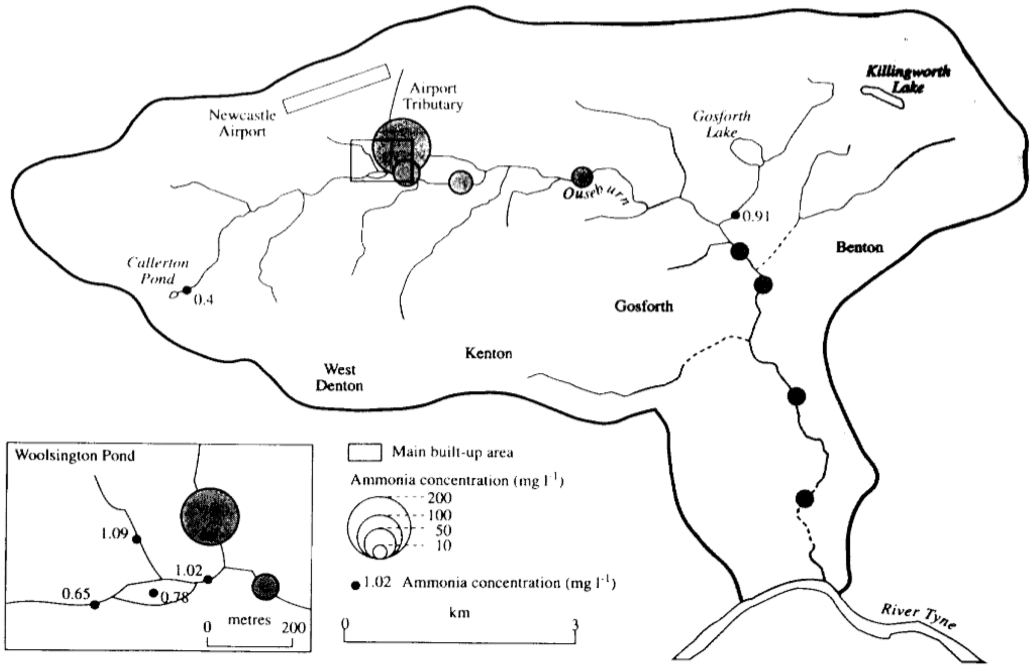

Figure 3: The concentration of ammonia, 26 February 1992 (Turnbull and Bevan, 1995).

Sewer discharge into the Ouseburn River is an acknowledged point source pollutant amongst locals and authority bodies. In 2023, Newcastle University determined that there was significant evidence of pollution within the river (Harris, 2024., Newcastle University, 2023). A campaign from local residents followed these findings, gaining support from local MPs and demanding that Northumbrian Water take immediate action (Harris, 2024). However, whilst the water company has pledged the spending of £14.5 million on storm overflows over the next five years, there has been no government action. Northumbrian Water has since committed £2 million in the Ouseburn Catchment between 2030 - 2035. However, the targets of this funding are unknown (ibid).

2 Objectives

Given the context of the severity of pollution in the Ouseburn Catchment, there is a need for intervention through increased modelling of the potential for pollutant spread under varying climate conditions. This report focuses on ammonium emitted from CSO point sources along the rural section of the Ouseburn River, and thus we aim to:

1) Model the potential coverage of flood water around buildings in the catchment and the consequential spread of waterborne pollutants using HEC-RAS.
2) Model flooding and the coverage of pollutants in the worst-case scenarios under the influence of climate change using CityCAT.
3) Model the reduction in pollution concentrations from permeable pavements.
4) Analyse the associated costs of flood damage and costs of mitigation strategies through suggesting novel solutions.
5) Validate the model results through analysing CityCAT and HEC-RAS outputs.

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3 Modelling

Assessing the worst case scenario involved using baseline conditions for mitigation (existing infrastructure only) and then determining what storm would create the worst flooding outcome (water depth in populated areas). The purpose of this is to assess how an accidental pollutant could spread within the water and highlight the areas that would suffer the highest damage costs (in £'s) and determine the locations for blue-green infrastructure (BGI) intervention.

3.1 Flood Modelling

As per report 2, it has been decided to use CityCAT and HEC-RAS to undertake all modelling. A 1:100-year summer storm event has been used for all modelling purposes.

Using HEC-RAS corresponds to the objectives of the project. It is possible to implement the buildings (Figures 4 and 5) and also the pollution of water. As the catchment is urbanized, construction is an important part of the model. In HEC-RAS, all the locations of buildings have been elevated to create a wall to stop the water and not have results with water inside buildings or on the top of them.

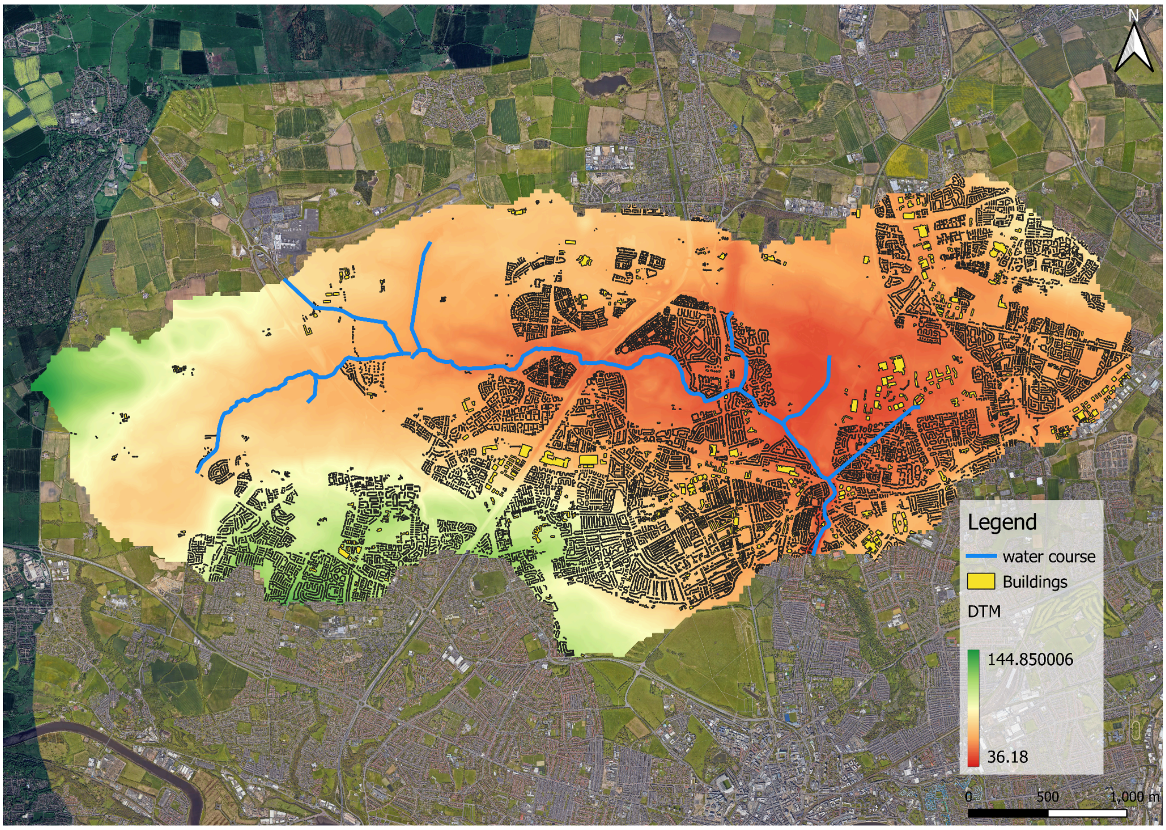

Figure 4: General data and visualisation of the Ouseburn Catchment.

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Figure 5: implementation of the buildings on HEC-RAS, visualisation from QGIS.

Regarding the mesh of the catchment, a 1-meter DTM has been used to create a mesh of 50 meters with a refined zone of 10 meters (Figure 6). To define the 10-meter zone, a first flood map has been generated so we could determine the places where flood problems will mainly occur and refine the mesh there. The 10-meter mesh could not be implemented too close to the outline of the catchment because of computation error on HEC-RAS.

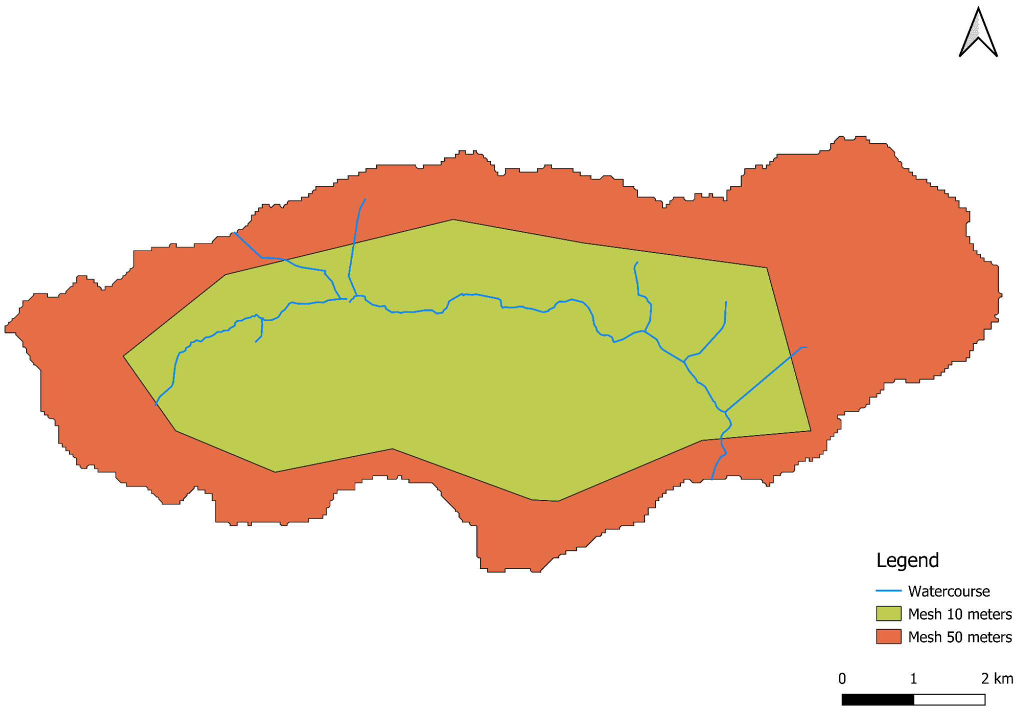

Figure 6: Mesh of the catchment on HEC-RAS.

Storm modeling was also carried out on CityCAT. All simulations model a rainy event lasting 6 hours, taking place in summer.

However, any modeling on City CAT requires the creation of a configuration file, which brings together several parameters that govern the modeling of a rainy event. These parameters mainly concern infiltration, and therefore runoff, of flows. They are used to respond to the Green-Ampt model, which runs on CityCAT. 4 parameters are considered: The hydraulic conductivity K, the Wetting Front Suction Head ψ, the effective Porosity θe, and the effective saturation Se. As the soil becomes finer, moving from sand to clay, the wetting front suction soil ψ increases while the hydraulic conductivity K decreases. Infiltration is therefore modified depending on the type of soil.

USDA Soil Type	Suction (mm)	Hydraulic Conductivity (mm/hr)	Porosity (Fraction)
Clay	316.3	0.3	0.385
Silty Clay	292.2	0.5	0.423
Sandy Clay	239	0.6	0.321
Clay Loam	208.8	1	0.309
Silty Clay Loam	273	1	0.432
Sandy Clay Loam	218.5	1.5	0.33
Silt Loam	166.8	3.4	0.486
Loam	88.9	7.6	0.434
Sandy Loam	110.1	10.9	0.412
Loamy Sand	61.3	29.9	0.401
Sand	49.5	117.8	0.417

Figure 7: Soil types for the Green-Ampt Infiltration Method

Before proposing solutions that would limit the costs of flooding, the objective will therefore be, among other things, to modify the infiltration coefficients depending on the type of soil present on site. Thanks to this, we will be able to know to what extent these parameters impact runoff.

3.2 Pollutant Modelling

The potential spread of ammonium from point sources (from CSO discharge) into the Ouseburn River has been modeled using HEC-RAS and CityCAT. To simulate the worst-case scenario storm, a 1-in-100-year storm by the year 2070 has been used (Annex A). In addition to this, comparisons of different storm profiles have been used to demonstrate and conclude that a back-loaded storm could create additional flooding (Villalobos Herrera, 2024). An intense storm such as this has the potential to spread more ammonium across the Ouseburn Catchment than other, less severe storms.

The impact of CSO discharges upon the Ouseburn catchment has been modelled. E.coli and ammonium are commonly present in domestic sewage discharge (Wąsik, 2017). This and their disparate dispersive properties give us insight into the range of behaviours by other potential pollutants.

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The CSO discharges were treated as point sources of pollution at specific points within the river to represent the injection of pollutants directly into the watercourse. Subsequently, using the concentrations and diffusion coefficients in Table 1, the transport and concentration change through time was modelled using the advection-diffusion equation (equation xxx) with the "QUICKEST" numerical scheme (Leonard, 1979).

Table 1:

	Advection Diffusion equation to be put here	()

Previous source tracking by Zan in 2023 concluded that existing bacterial communities at points S3, S5, S6, S7,and S8 in the Ouseburn River were significantly impacted by CSO discharge (Zan, 2023), hence the decision to model ammonium pollution from a new point source downstream of CSO 3 (Figure 8).

The location and type of pollutants considered for this report are shown in Figure 8.

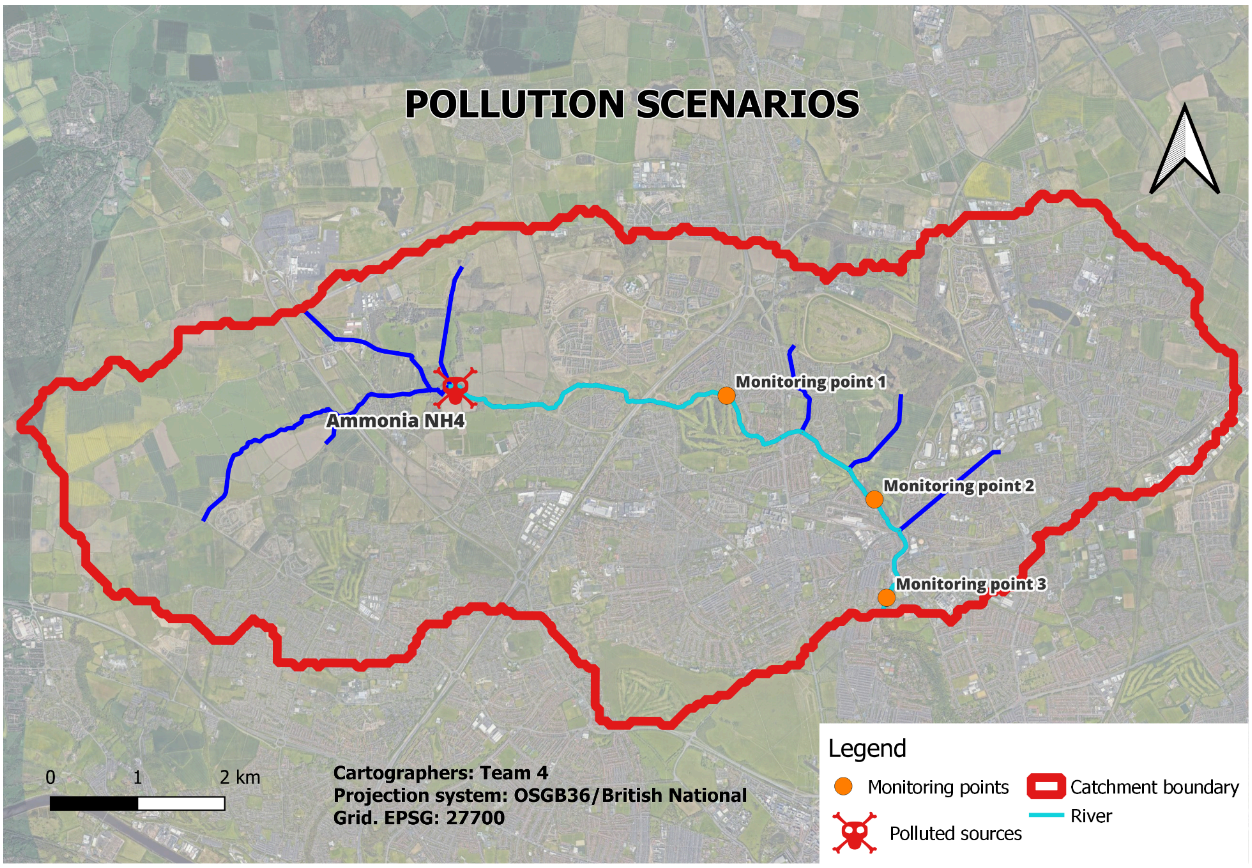

Figure 8: Location of pollutants and their sources on the Ouseburn River.

The main hydraulic characteristics of the pollutants are shown in Table 2.

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Table 2: Properties of the pollutants under investigation.

Pollutant	Ammonium	E.Coli
Diffusive factor (D) (m2/s)	1.86 * 10^-9 (Institute of Medicine (US) Forum on Microbial Threats, 2012)	0.5
Initial concentration (mg/l)	200 (Turnbull and Bevan, 1995)	2.5 x 10^6 (cfu/100mL)

The standard concentration of ammonium in an unpolluted river lies between 0.2 mg/l and 1 mg/l (Environment Agency, 2014). If the concentration is over 2.5 mg/l, ammonium poses a threat to aquatic life (ibid). Currently, ammonium levels in the Ouseburn are categorised as high, and subsequently, biological quality elements such as fish are categorised as poor status (DEFRA, 2022).

For E-coli, the minimum threshold for a water body to be classified as sufficient is for 90% of water samples to contain less than 900 cfus per 100 ml of water (Battarbee et al, 2023).

4 Solutions

4.1 High infiltration

To know the impact of soil type regarding the flooding, the idea is to carry out 2 different models, with two different infiltration data sets. The first data used corresponds to Sandy Loam soil, it is a type of soil generally used for modeling rain events around Newcastle. The data from the second simulation are taken from previous simulations carried out by our team, which were calibrated and validated. We can summarize the following parameters:

Simulation 1: $K = 1{,}090$ cm/h; $\psi = 11.01$ cm; $\theta e = 0.412$; $Se = 0.3$

Simulation 2: $K = 24.423$ cm/h; $\psi = 45.67$ cm; $\theta e = 0.42$; $Se = 0.95$

By comparing the values of the effective saturation Se of the soil, we see that in the first case, the soil is not much waterlogged when the storm occurs, while simulation two models a soil which no longer has almost any absorption capacity.

4.2 Impermeable Surfaces

The main idea to reduce runoff in the Ouseburn catchment is to transform walkways into permeable pavements. From this, we can locate the optimum location for implementation to increase the downward infiltration of rainwater into subsurface flow pathways, reducing the accumulation of surface water and thus decreasing the exposure of the infrastructure within the catchment to a smaller remit.

4.3 Flood Plains

Increasing floodplain storage is also a suitable BGI to implement into the Ouseburn, as it directly intercepts the natural flow pathway into offline storage (Ur Rehman, 2024). An initial study of Newcastle City Centre by Uh Rehman in 2024 concluded that water detention ponds offer a good

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cost - benefit ratio due to their capacity to mitigate storms of a higher return period than other BGI solutions, such as permeable paving and green roofs (ibid). For the Ouseburn Catchment, 10 lowered floodplains have been proposed (Figure 8).

Using QGIS, locations of such installments were selected within the catchment boundary due to the abundance of available green space surrounding the river, minimising the associated costs of transforming the land. Initial designs were created in the software package LSS and designed to existing ground levels. Following this, the bottom of the floodplain was designed to be 3 m below the lowest region, and embankments were designed with a gradient of 1:3. The surrounding topography caused an issue. As the terrain varies in each location (~5 m in places), the designed floodplains should have a constant elevation at the top and bottom of the plain to prevent over-topping. Due to the time restrictions, it was not possible to redesign the surrounding region of each plain as each area or choose other regions for installation.

Figure 9: Proposed locations of new floodplain storage.

4.4 Pollutant Mitigation

From the pollution analysis, the route and concentration of the contaminated water can be determined. Two potential sources of pollution have been assumed to allow for analysis. From this, it will be possible to determine a number of important mitigation features. One of these is time. From the source of the pollutant, it will be possible to determine the amount of time it will take to reach an urban location. This will allow emergency services to determine a response time in the event of an incident.

Another mitigation from this analysis is the determination of locations to store emergency spill kits, response equipment and any other materials that may be useful to aid responses. This will allow emergency services to plan routes to access the area to provide aid.

Due to the methodology implemented, it is possible to determine the concentration of the contamination during the event. From this, a suitable amount of material can be provided at either

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the response location or at various emergency service locations within the catchment. Further to this, the time for the water to reach a "safe level" can be calculated.

From the methods outlined, we can produce a number of potential issues and pre-plan responses to the situation.

5 Results

5.1 Initial Results

The first thing to do was to implement flood only on the HEC-RAS model. With the results from previous weeks, two parts have been done: the current situation (with a 10-year and a 100-year return period of rainfall event) and the climate change situation (with the 100-year return period for a summer storm rainfall event).

The main parameters studied are the maximum depth and velocity over the Ouseburn catchment. For the 10-year current storm (Figure 9 and Figure 10), the maps show that an area is particularly affected by the floods. There are not many buildings in the area, so that is a great element for the protection of the population and the minimising the cost of damages.

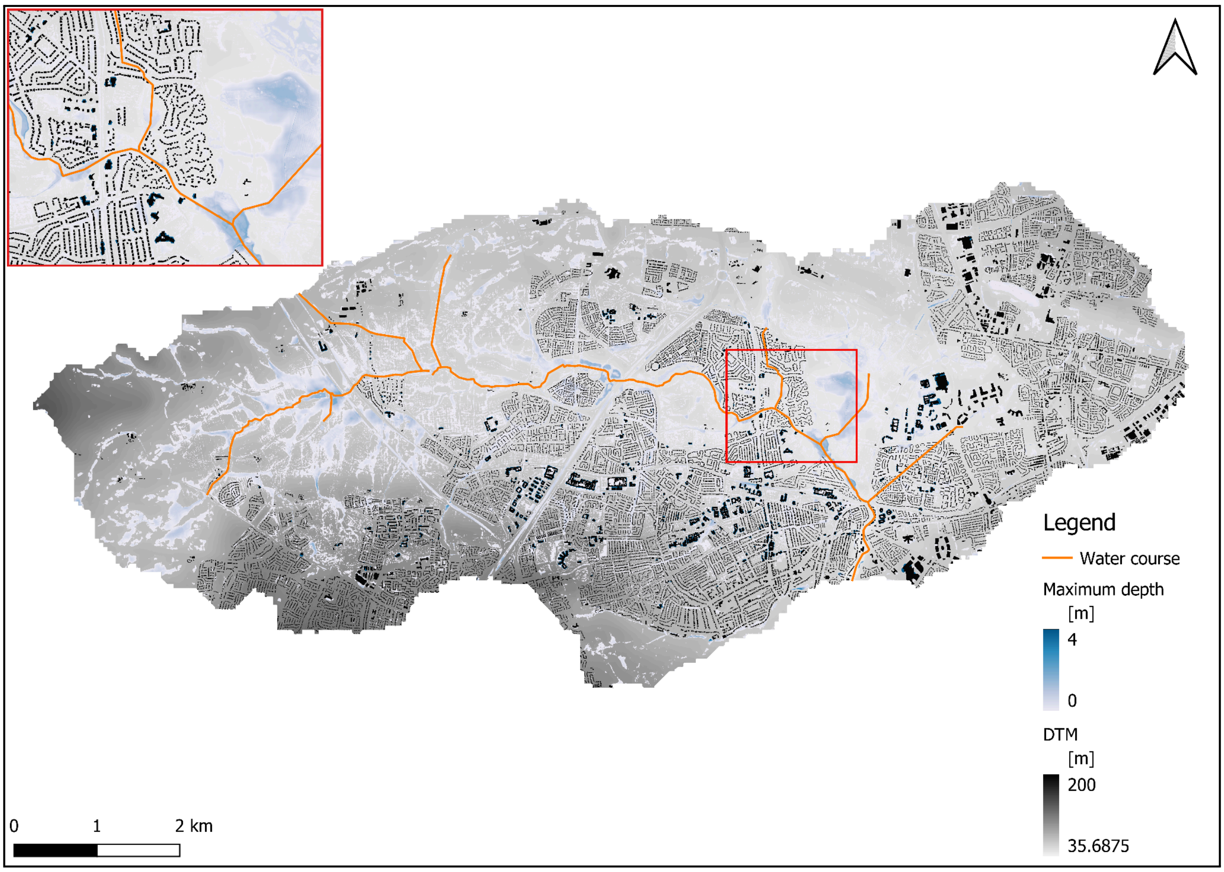

Figure 10: maximum depth for the current 10-year return period rainfall on HEC-RAS.

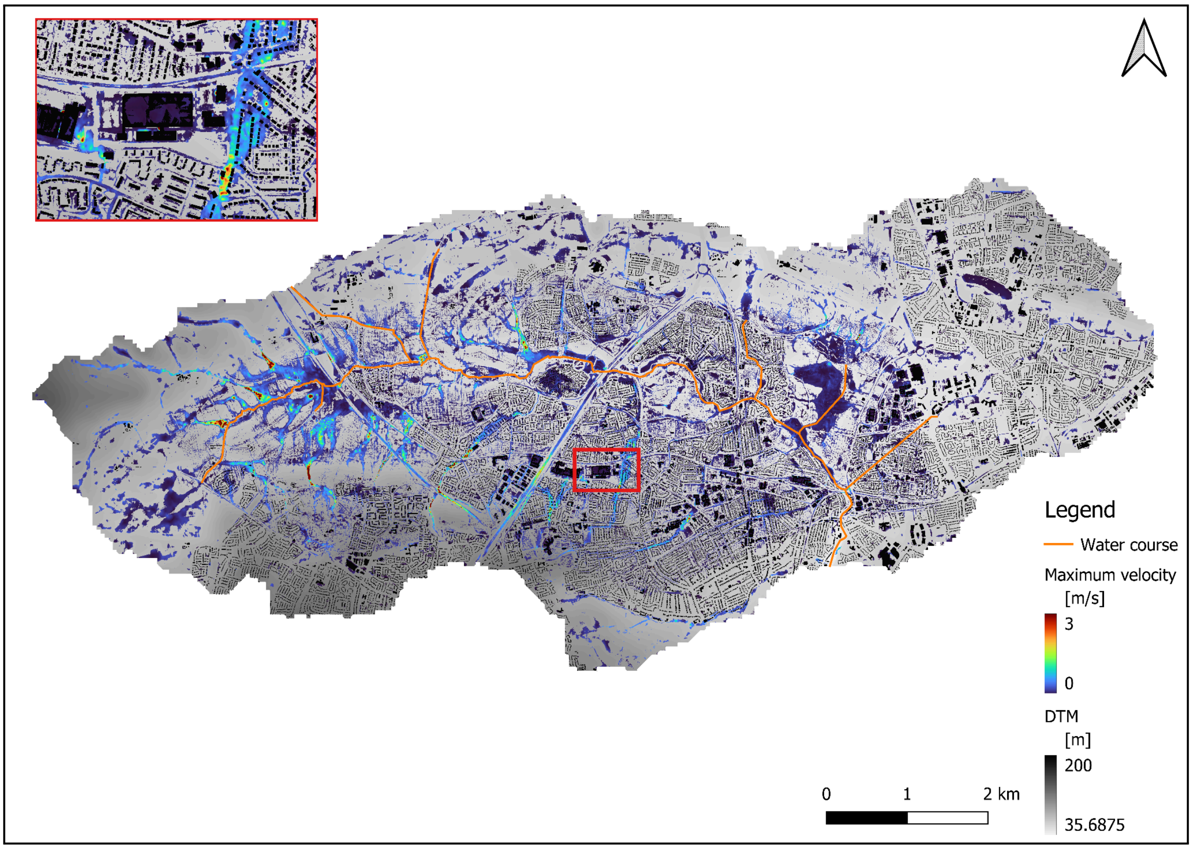

Figure 11: maximum velocity for the current 10 years return period rainfall on HEC-RAS.

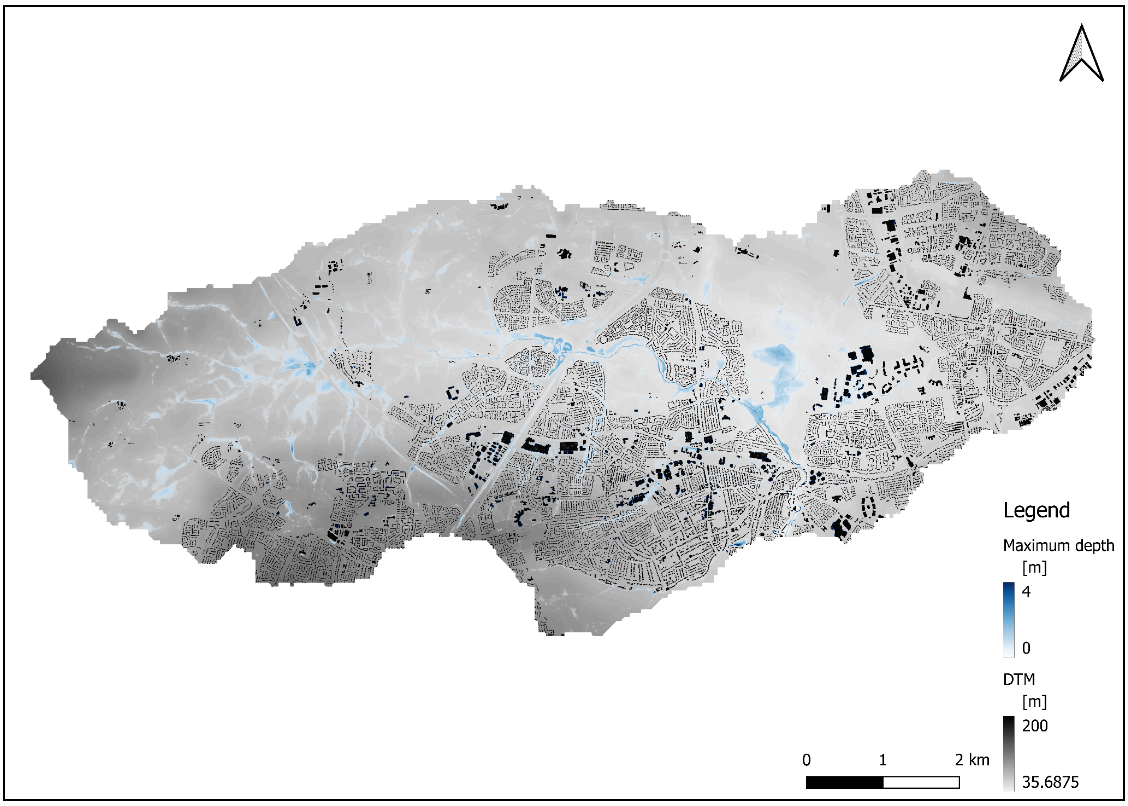

Figure 12: maximum depth for the current 100 years return period rainfall on HEC-RAS.

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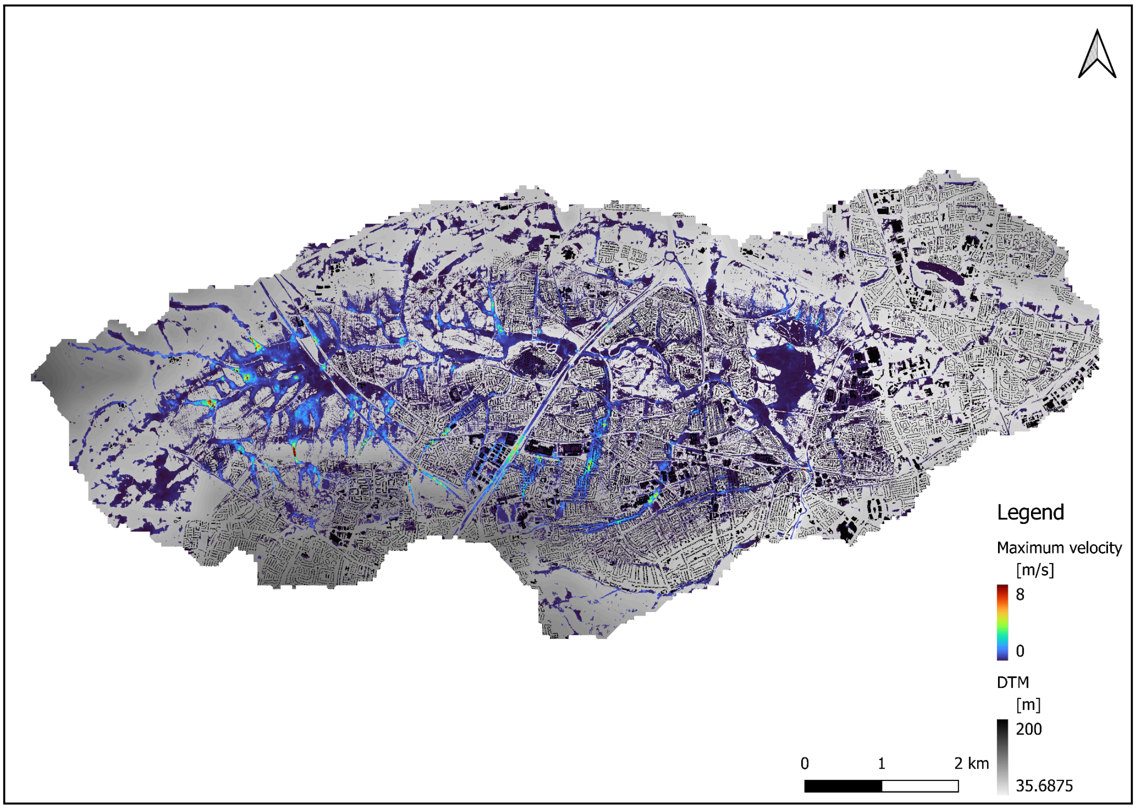

Figure 13: maximum velocity for the current 100 years return period rainfall on HEC-RAS.

Based on the previous week's work, the climate change flood maps have been generated with HEC-RAS. The summer storm is the major event, and it is the worst scenario and so useful for the comparison of the two models (CityCAT and HEC-RAS). The 100-year return period has been used to follow the objective of obtaining results for the worst case. The water depth (Figure 13) shows that there is more than 5 meters of water around the buildings. In fact, the water is stopped by the walls and can not go to the ground because of the impermeable pavement. Regarding the velocity (Figure 14), the maximum on the catchment is 7 m/s, mainly around buildings and on the west side of the catchment where the slope is higher, so the velocity is important. The impact on the population is important because if the buildings are too small, they will be buried, or the inhabitants will not be able to leave the houses, which could create panic. The cost of this type of storm will also not be negligible because of the damages to the construction.

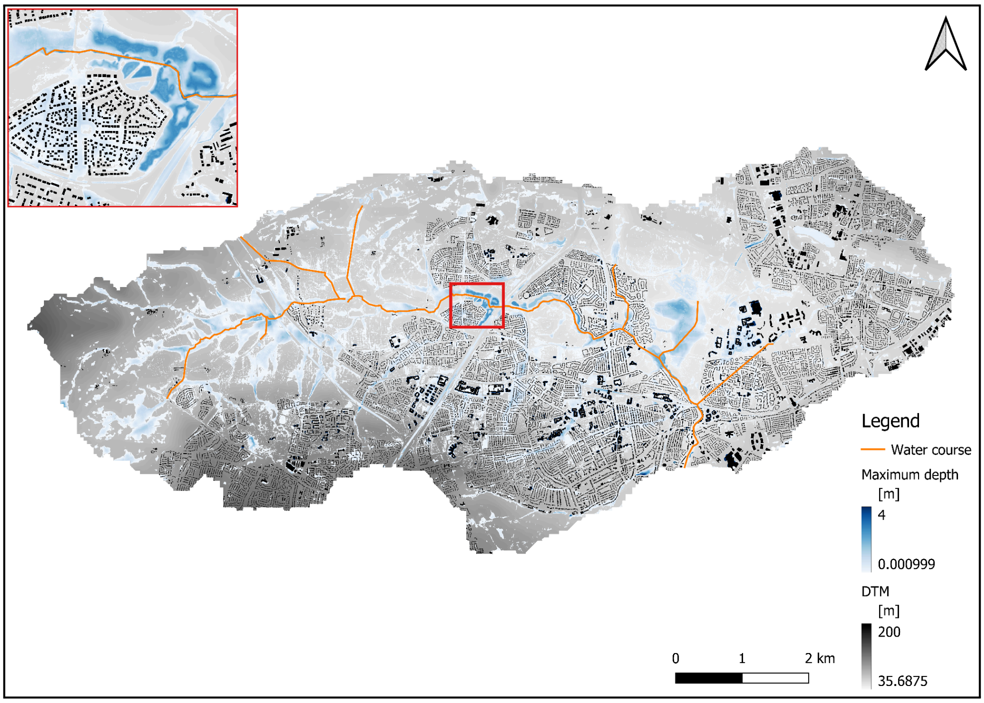

Figure 14: Maximum depth for a 100-year return period summer storm (future) on HEC-RAS.

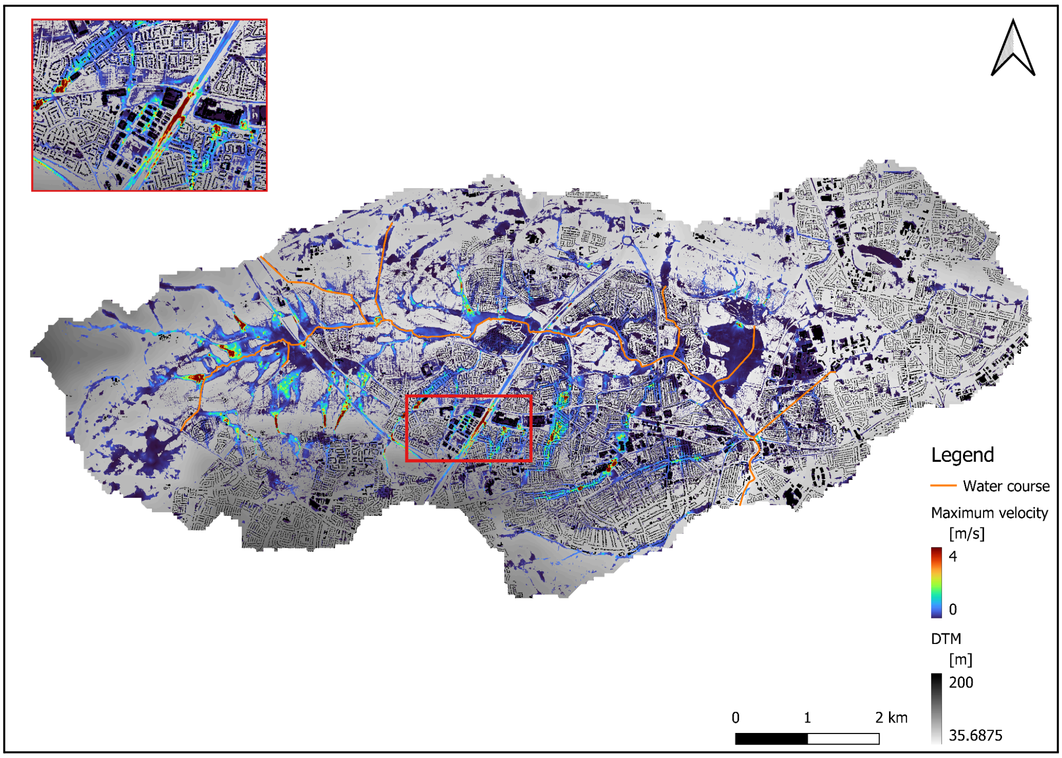

Figure 15: maximum velocity for a 100-year return period summer storm (future) on HEC-RAS.

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Figure 16: maximum velocity for a 100-year return period summer storm (future) on HEC-RAS, urban area.

The Ouseburn catchment is particularly urbanized as seen since the beginning of the project. Figure 16 demonstrates really well how the buildings are impacted by the flood. The construction and waterproofing of soils accelerate the flows by creating a channeling effect. A Venturi effect can be observed, which improves the damage to infrastructures and people.

Figure 17 shows the maximum water depth under the effect of a back-loaded winter storm in the return period of 100 years. However, to obtain the flow velocity from CityCat, we conducted some post-processing and then performed a flow analysis. We assume the Ouseburn River width is 4 meters, and the value is constant along the river.

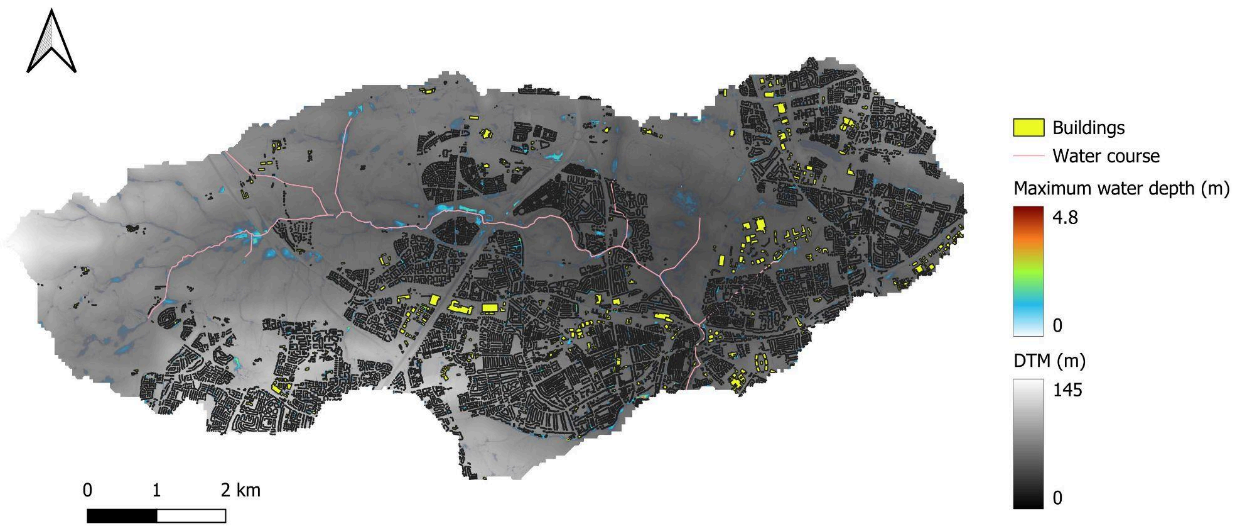

Figure 17: Maximum depth for a 100-year return period winter storm (future) on CityCat.

From the CityCAT outputs, we analyze the mean velocity variation in different time steps corresponding to 100-year return period rainstorms. In this report, we focus on a part of the Ouseburn River and divide it into seven segments to demonstrate the impact of flow on the movement of pollutants. The change in the mean velocity of each river segment in different scenarios is shown below in Figures 19, 20, and 21.

With a historical 100-year return period, the most intense velocity in some river segments are Segments 1 and 4 since Segment 1 is affected by three effluent flows and Segment 4 is affected by two extra effluents. The peak velocity in Segments 1 and 2 reaches over 0.4 m/s and 0.35 m/s, respectively, then drops back to about 0.3 m/s. Meanwhile, other river segments vary from 0 to 0.1 m/s.

The location of the segments is shown in Figure 18, and the distances of the sections are shown in Table 3.

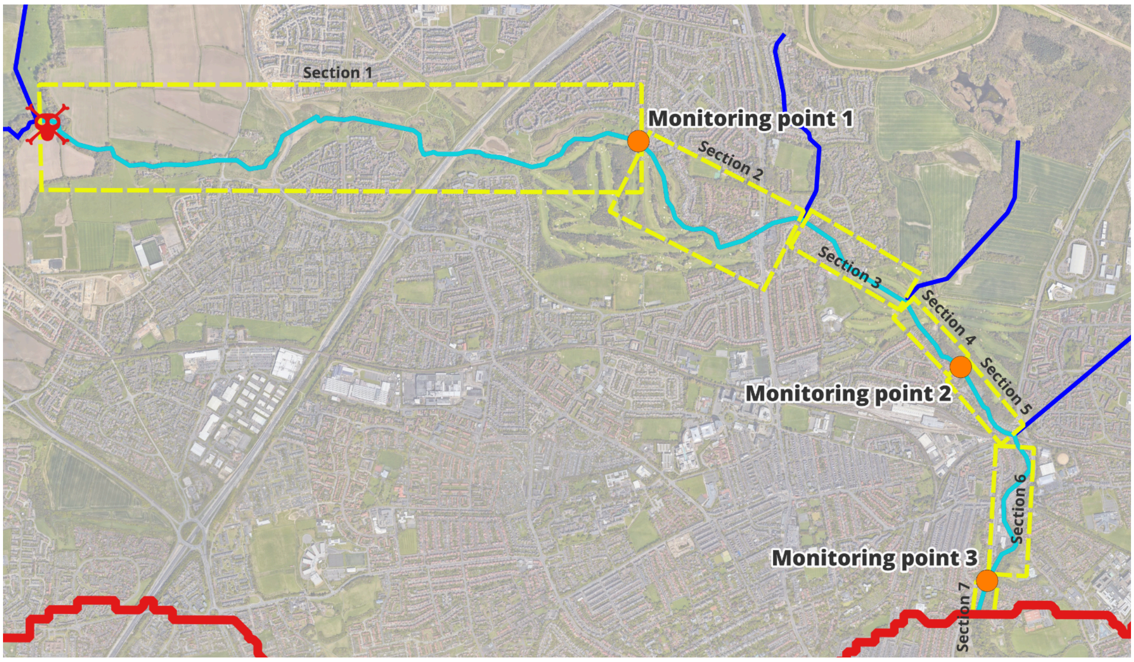

Figure 18: Location of the segments or sections in the Ouseburn River.

Table 3: Distances per segment to evaluate the pollution accident in the Ouseburn river.

Segment	Distance (m)
1	3600
2	1250
3	710
4	450
5	480
6	920
7	180

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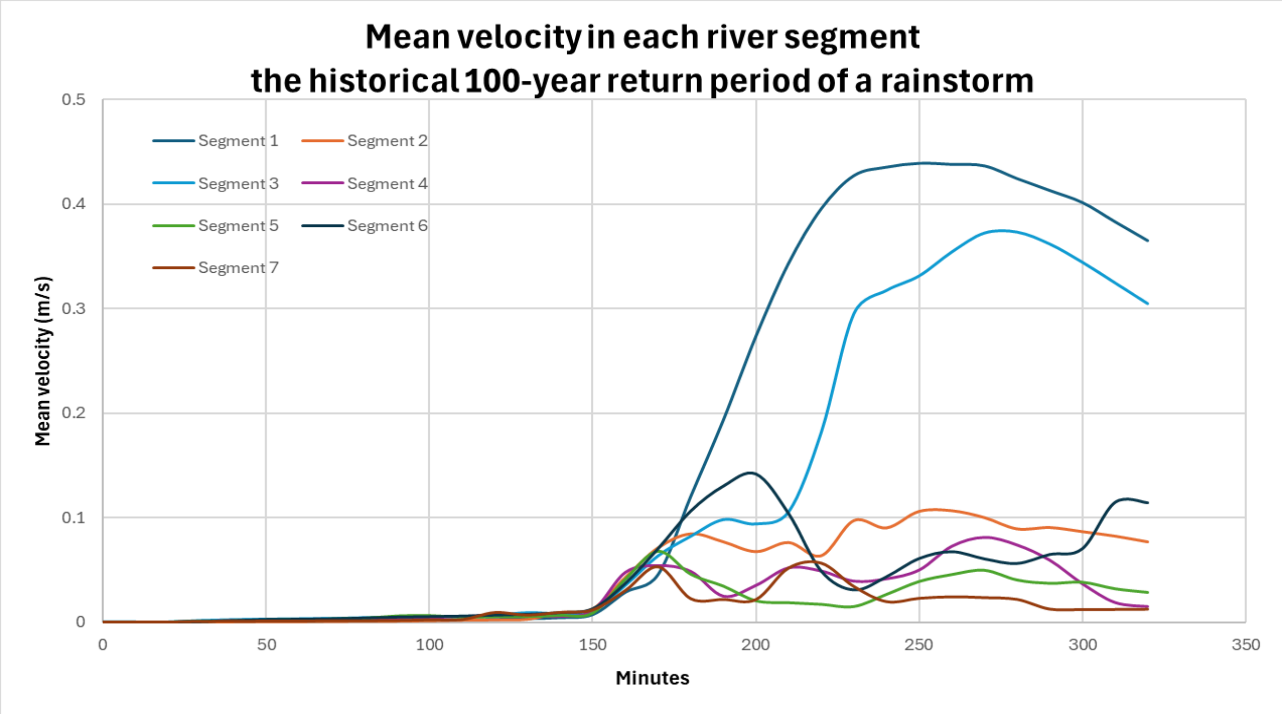

Figure 19: The variation of the mean velocity in each river segment under the 100-year return period of a rainstorm.

Under the climate change effect, the mean velocity generally increases compared to the historical rainstorm. With the back-loaded rainstorm pattern, only Segment 1 reaches the peak velocity of 0.6 m/s for summer and 0.5 m/s for winter storms. Segment 2's mean velocity increases to 0.15 m/s in 360 minutes. Similar to historical events, the other river segments vary more or less 0.1 m/s.

Considering Figures 20 and 21, summer rain storms have more intense rainfall over shorter periods, whereas winter storms are less intense but more uniform. Therefore, the peak velocity in river segments during winter is slightly lower and gradually reaches than during summer.

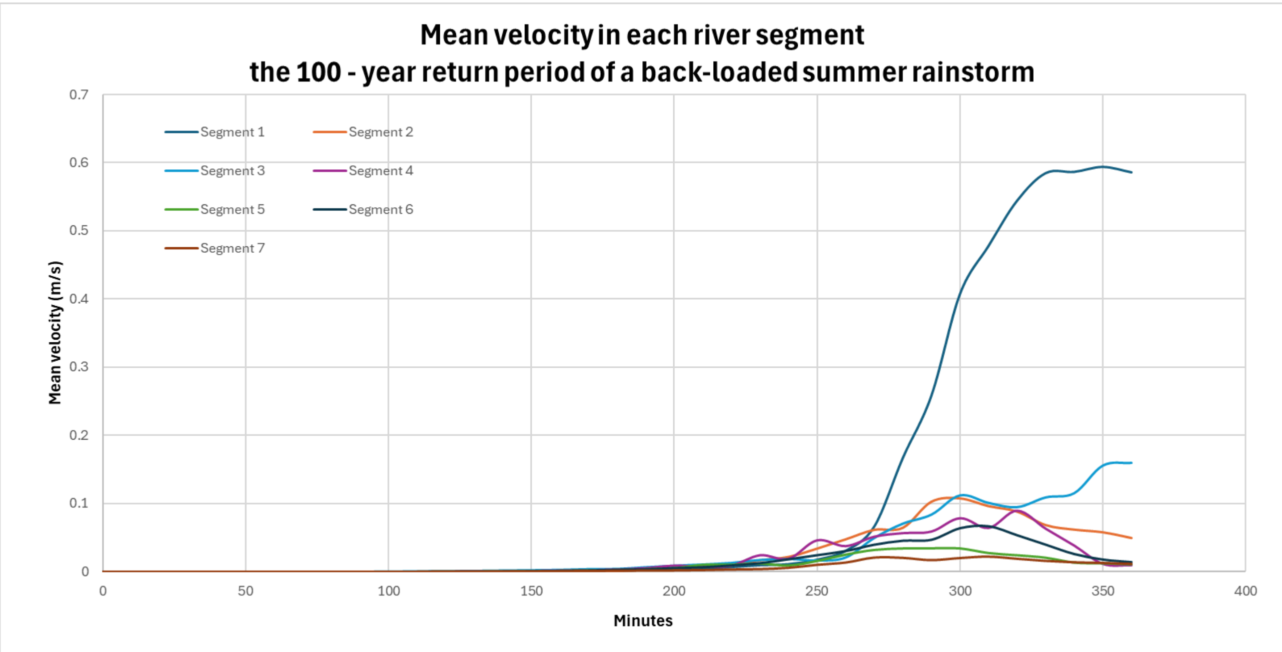

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Figure 20: The variation of the mean velocity in each river segment under the 100-year return period of a back-loaded summer rainstorm.

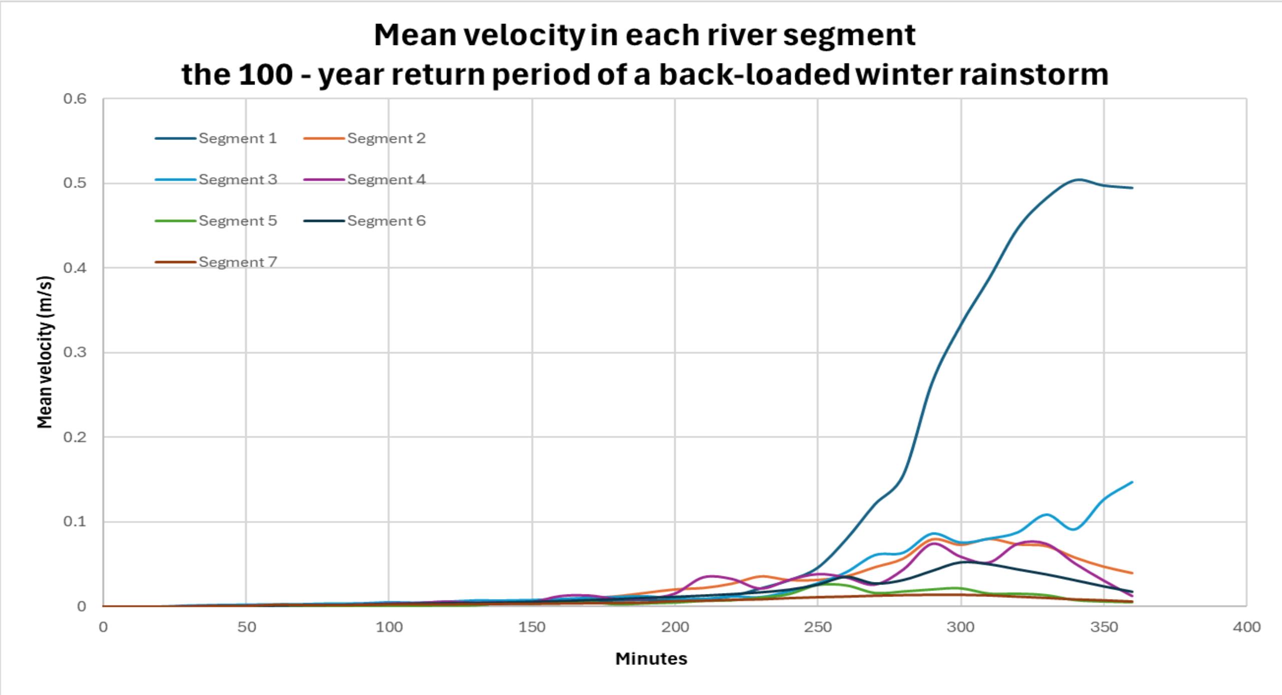

Figure 21: The variation of the mean velocity in each river segment under the 100-year return period of a back-loaded winter rainstorm.

Both of the models are used to obtain flood maps and characteristics like depth and velocity. A great way to compare the models is to obtain the difference between two rasters in QGIS. In this example, the winter storm has been studied with a return period of 100 years. By exporting the velocities after 6 hours of rainfall, a map (Figure 22) that contained the differences between the two results has been generated. What can be highlighted is that the variation of values is mainly between -0.5 m/s and +0.5 m/s. The higher value is 7.23 m/s, near the entrance of the river on the west side of the catchment (high slope).

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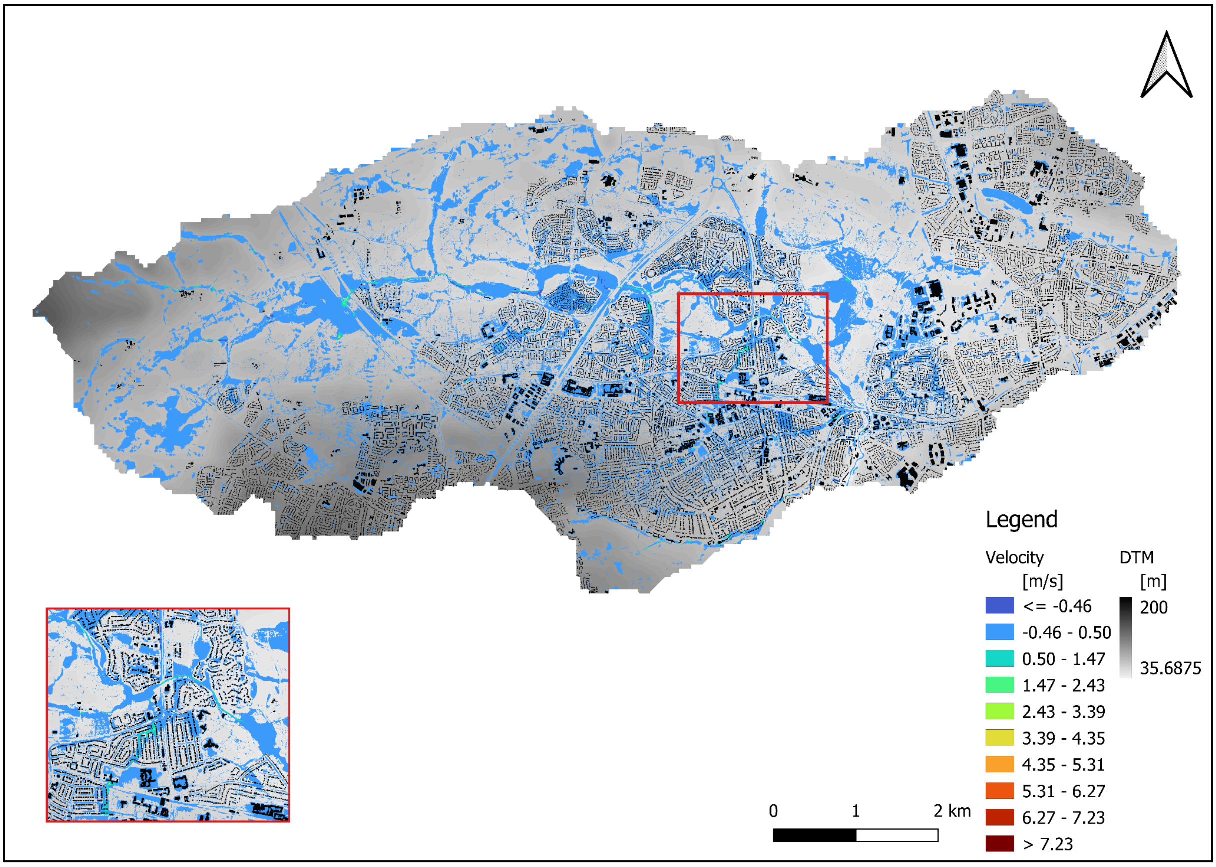

Figure 22: Velocity differences between HEC-RAS and CityCAT for the 100-year return period winter storm.

5.2 Impermeable Surfaces

5.3 Floodplains

With the application of floodplain areas, we choose the back-loaded winter rainstorm in the return period of 100 years to simulate in CityCat. In a comparison between Figure 23 and Figure 24, the mean velocity in Segment 1 reduces under 0.5 m/s, while that in other segments increases dramatically and becomes more turbulent. However, the peak velocity occurring time with floodplain action is generally delayed.

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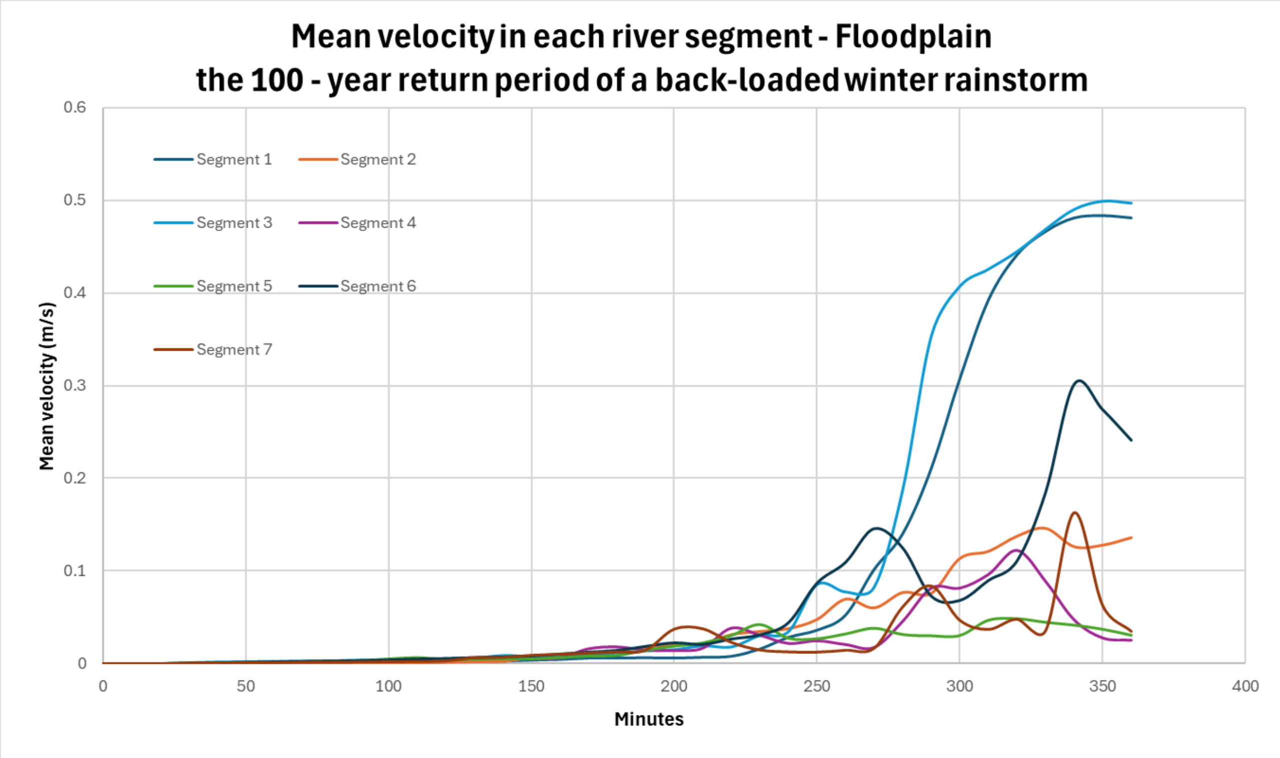

Figure 23: The variation of the mean velocity in each river segment under the 100-year return period of a back-loaded winter rainstorm with action.

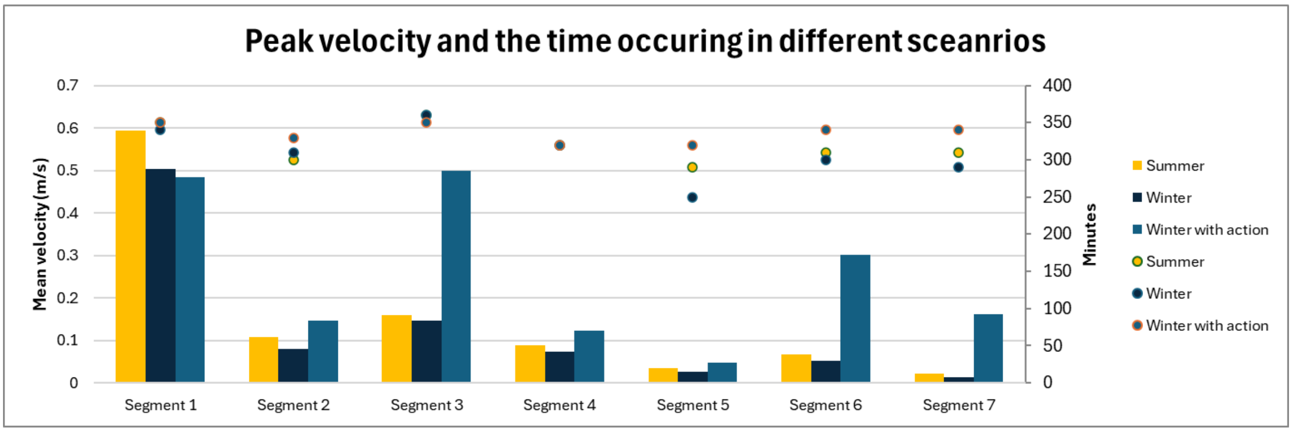

Figure 24: Comparison of peak velocity and time occurring in different scenarios under winter back-loaded future rainstorm, the square shape represents the peak velocity value, and the dotted spot represents the time occurring of the peak velocity

5.4 Pollutants

The nature-based solution that has a more positive effect on pollution transport is the floodplains. Considering the analysis of the velocities flow obtained by Citycat, the section with the highest variation is segment 3 (Figure 18).

Considering the impact of the variation in the flow velocities in the most extreme future scenario considering with and without the incorporation of the floodplains, the time of the pollutant through the segment 3 is increased significantly from 0.09 m/s to 0.45 m/s. That difference affects the movement of the pollution through the river based on the advection-diffusion principle (Figure 25).

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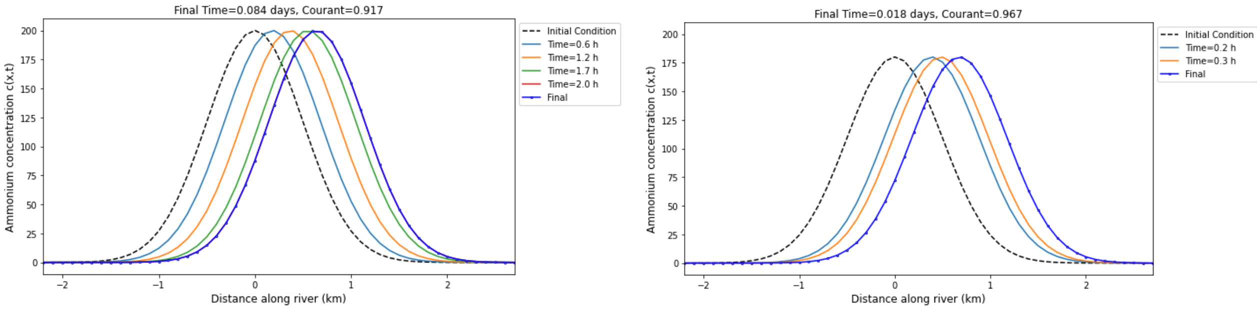

Figure 25: Comparison of the movement of the pollutant in the segment 3. In the left, it is shown the behaviour of the pollutant without any mitigation action. In the right, it is shown the variation in time of the pollutant considering the implementation of the floodplains.

In other segments of the river, there are no significant variations in the movement of the pollutant considering the implementation of the floodplains. Additionally, it is noticed that the reduction of the concentration of the pollutant considering the inflows in the river(Segments 3, 4 and 6). The results per segments are shown in Figure 26.

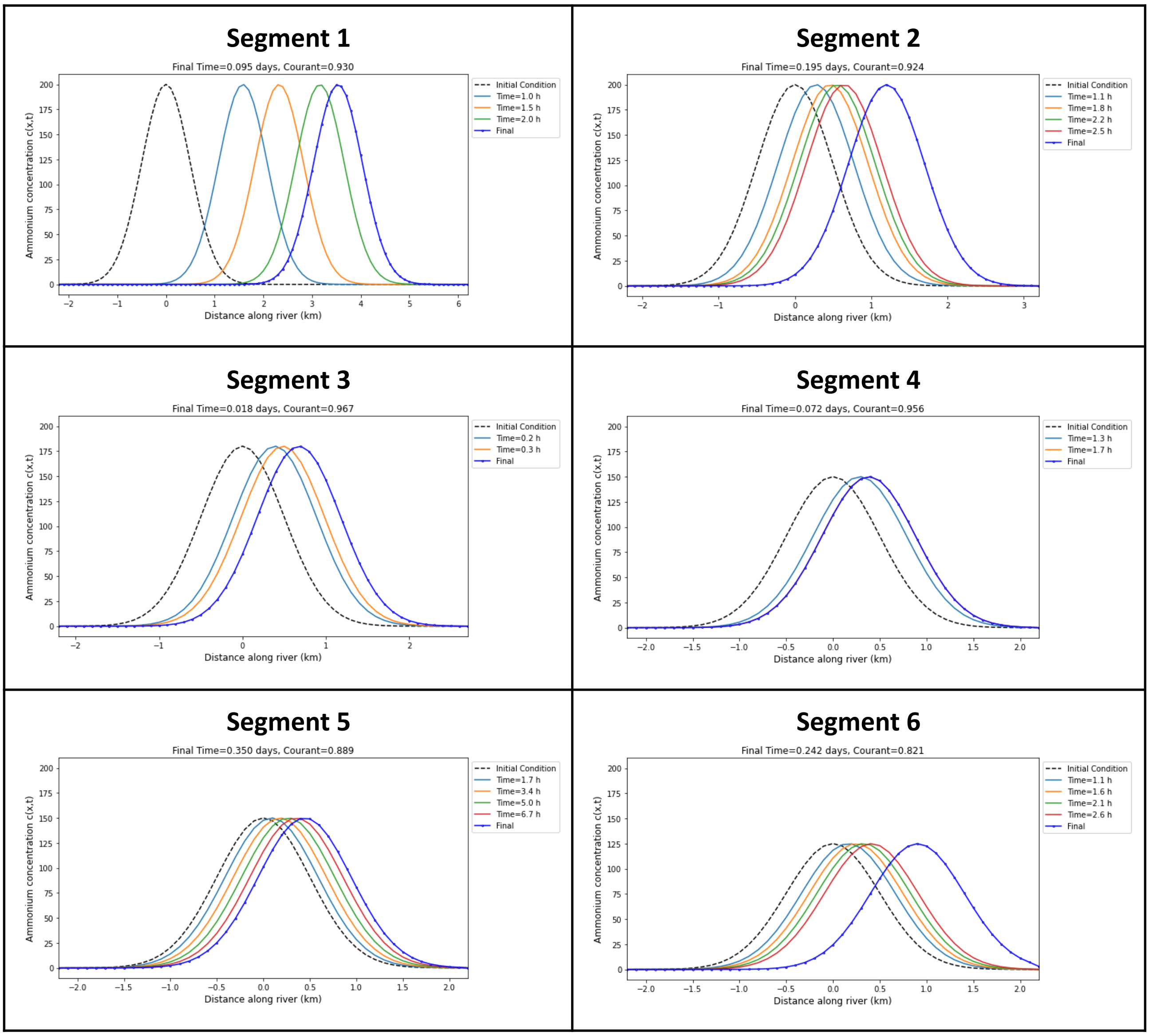

Figure 26: Movement of the pollutant into the different segments in the river.

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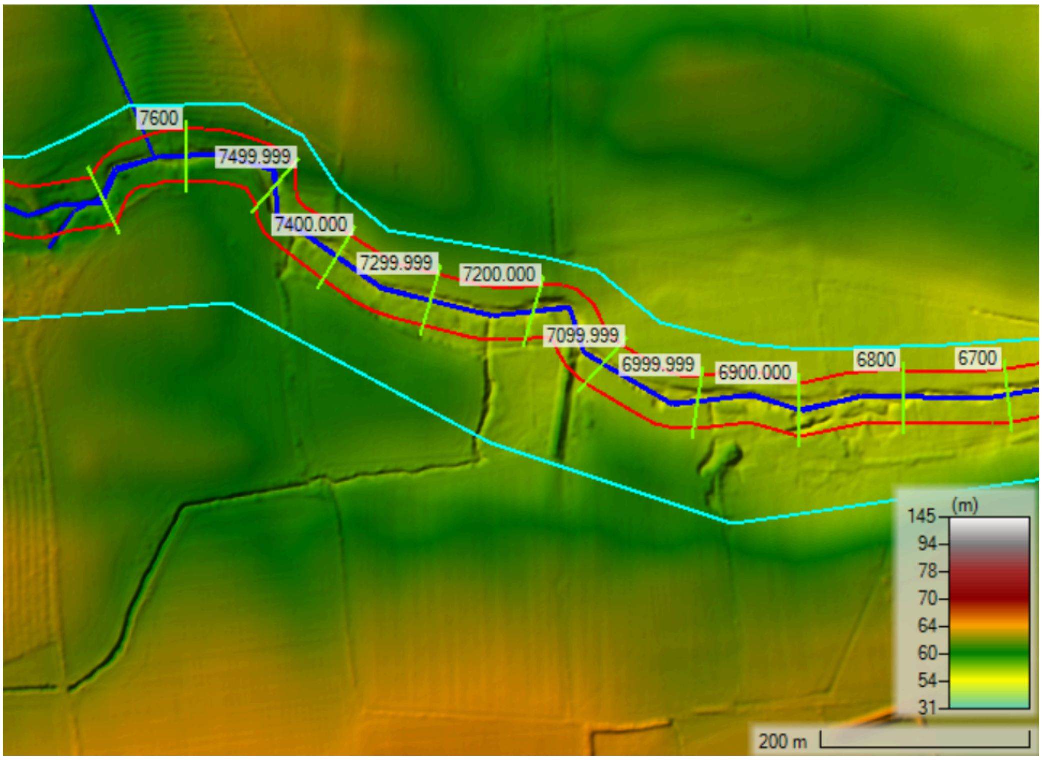
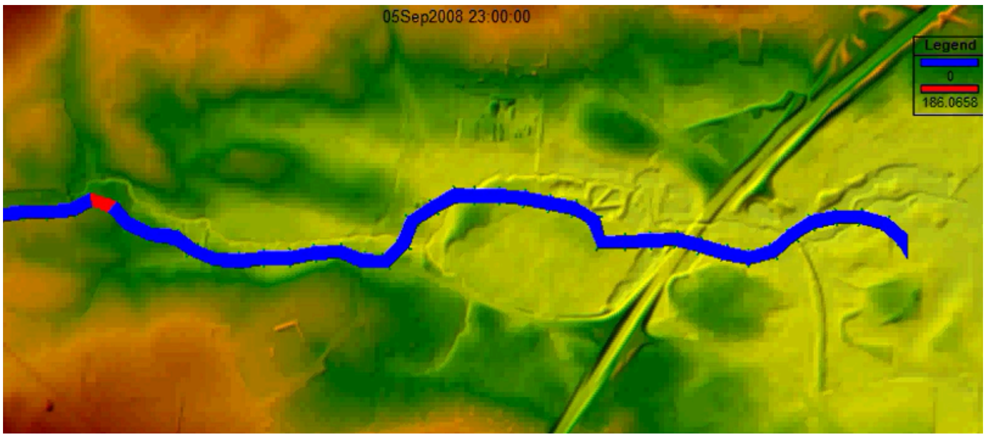
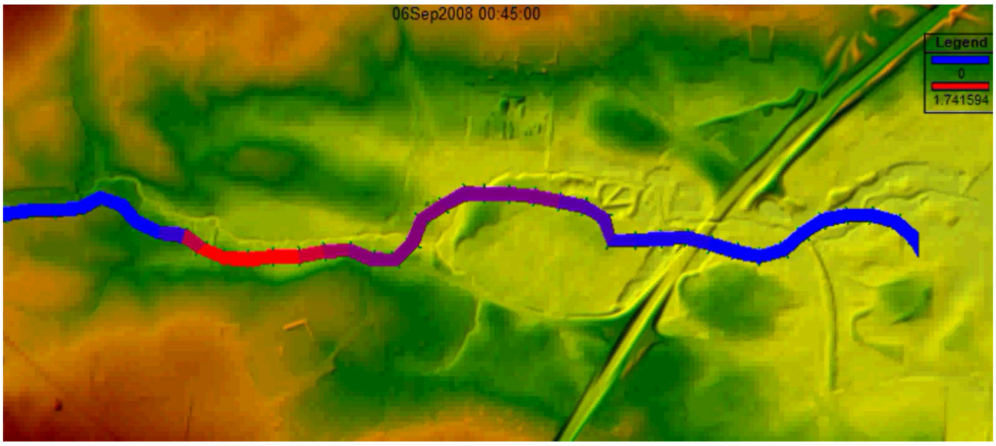
It is now proposed to model the pollution by coupling a 2D model originally presented above with a 1D model to model the dispersion and diffusion of ammonium. Indeed, the north-west region of Ouseburn is at risk for ammonium pollution.



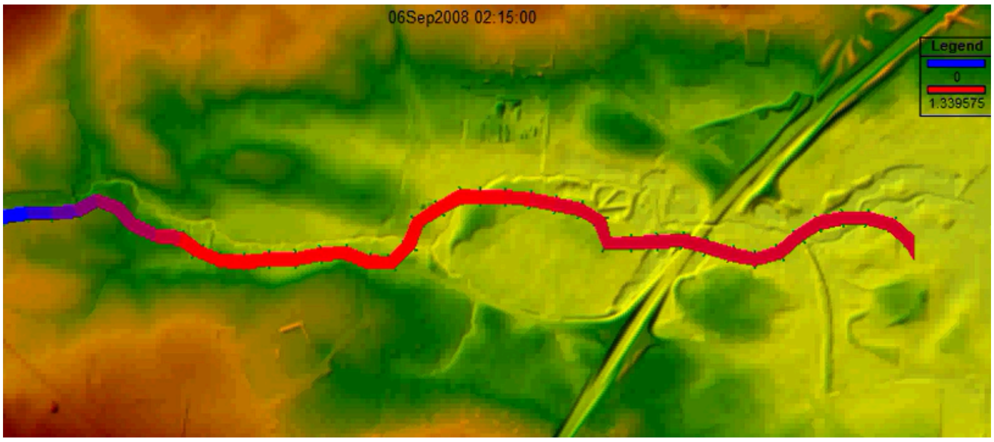
As presented in Figure 1, we chose to model the ammonium pollution and thus observe its concentration at three selected monitoring points. The initial concentration at the 7600 cross-section was 200 mg/L of the pollutant discharged into the river. Authorities estimated the permitted limit at 2.5 mg/L. The initial conditions imposed in the area take into account a water height of 10cm initially in the river and rainfall chosen for the "summer" event."



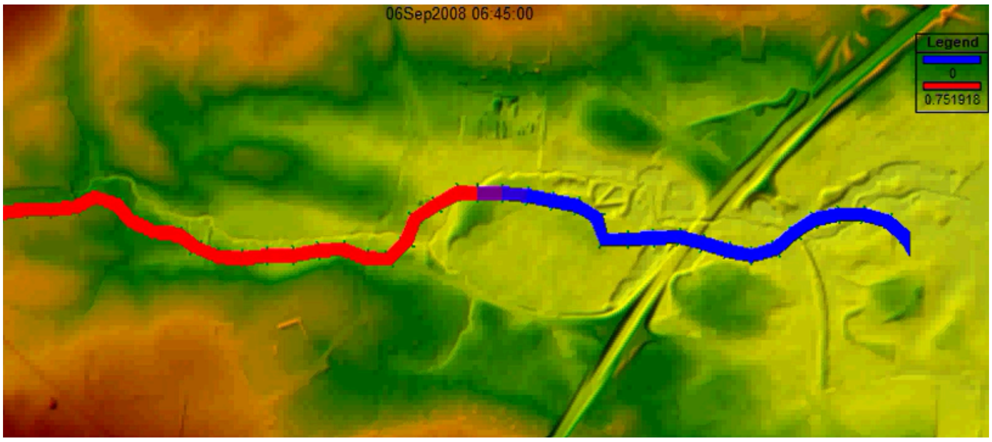
Ammonium transport at t=0



Ammonium transport at t=1h45



Ammonium transport at t=4h15



Ammonium transport at t=8h45

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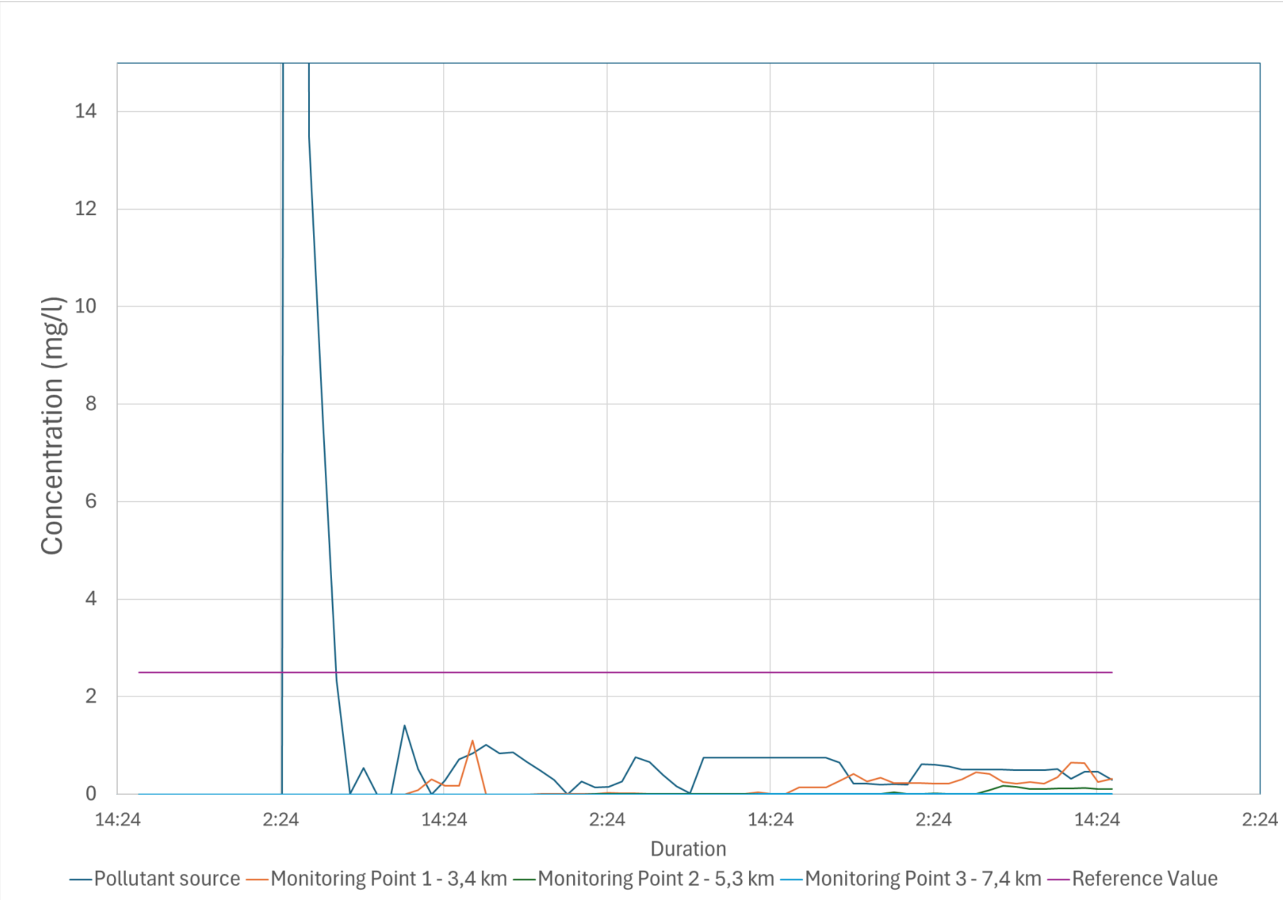
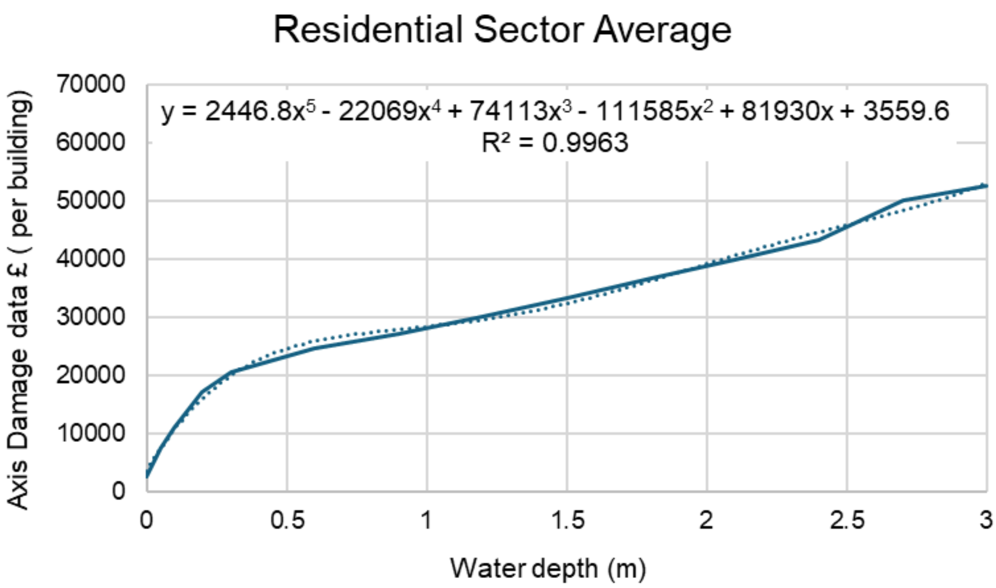
Time	Ammonium Concentration at cross section 7600 (injection source - 0 km) [mg/l]
0	200
1h45	3.73E-05
4h15	0.6550845
8h45	0.7473736
10h30	0.2179329



6 Cost Benefit

6.1 Initial Results

The scale of the damage that results from urban flooding is due to two factors: the storm intensity and duration and the relationship between the storm and the surface and subsurface flow paths across a catchment (Iliadis, 2023). The associated costs of such a flood event occur due to the distance the flood water has covered. However, this is not limited to economic damages to property. Costs include the number of people affected in surrounding communities and ecological damage from contact with flood water. Using 2D HEC-RAS modelling, the runoff pathways of rainfall for a return period of 10 years can be observed (Figure 11), giving an indication of the areas most vulnerable to surface water flooding at. Damage costs associated with buildings in the residential sector of the catchment have been calculated using the 'Residential Sector Average Damage Data' curve (Figure 24) which estimates costs associated with mean flood water depth (in meters) and is specific to Newcastle Upon Tyne.



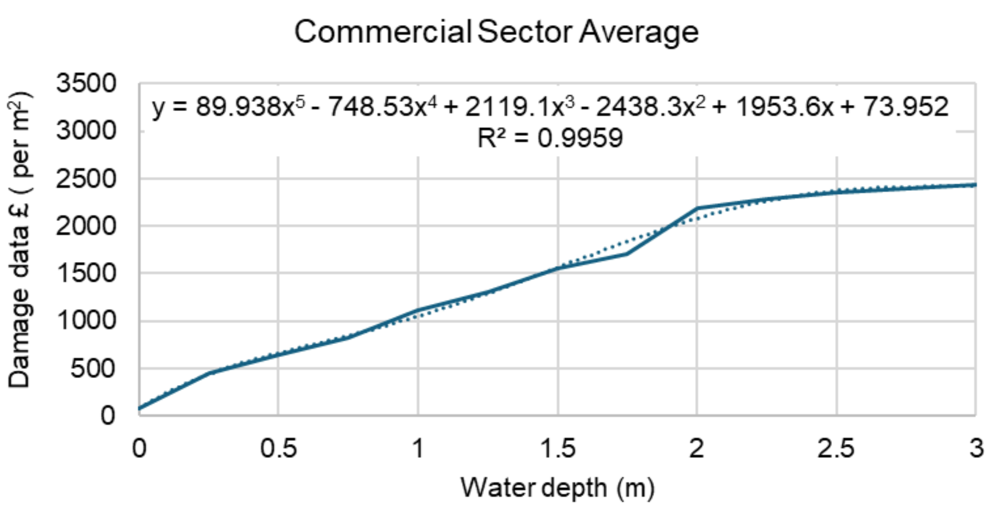


Figure 24: Damage curve (£) for individual properties for residential and commercial sector of Newcastle. Calculated using £ (y axis) against flood water depth in meters (x axis).

In order to facilitate an economic losses analysis, a specific area (Figure 25) is selected for comparison between a range of different mitigation measures. This approach is adopted in order to facilitate a more comprehensive understanding of which of the mitigation measures has the greatest impact. The study will be conducted in a specific area comprising 3,099 buildings (Figure 26), which has been identified as a critical area with regard to flood impacts

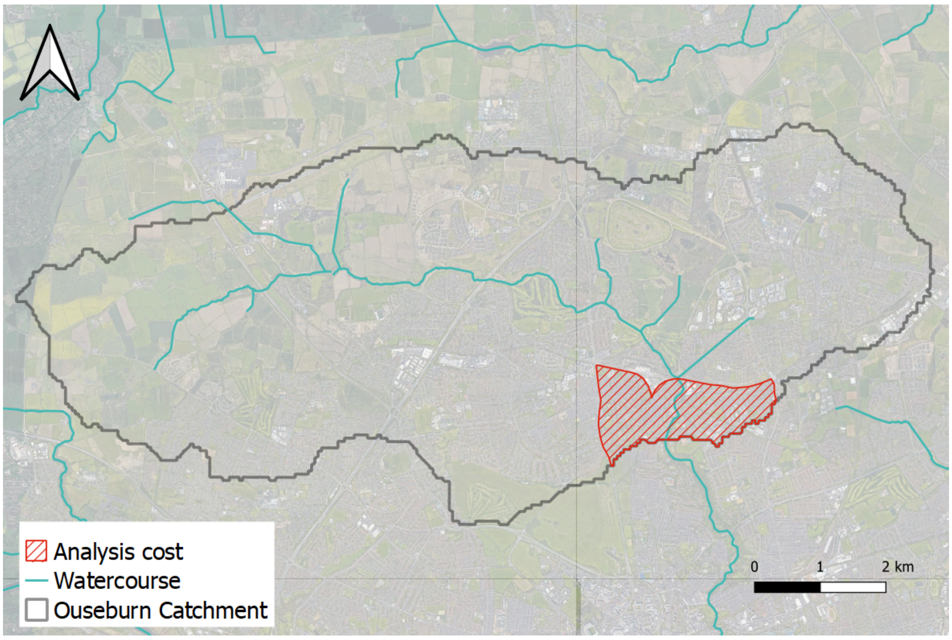


Figure 25: Localisation of the area where the cost-benefit analysis has been applied.

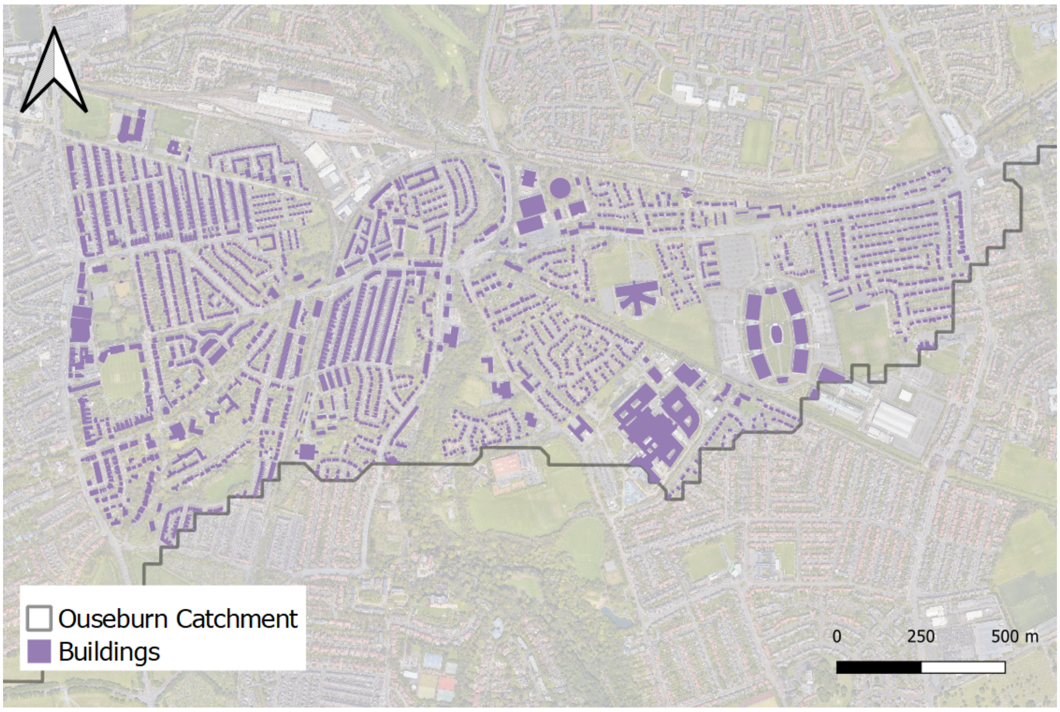
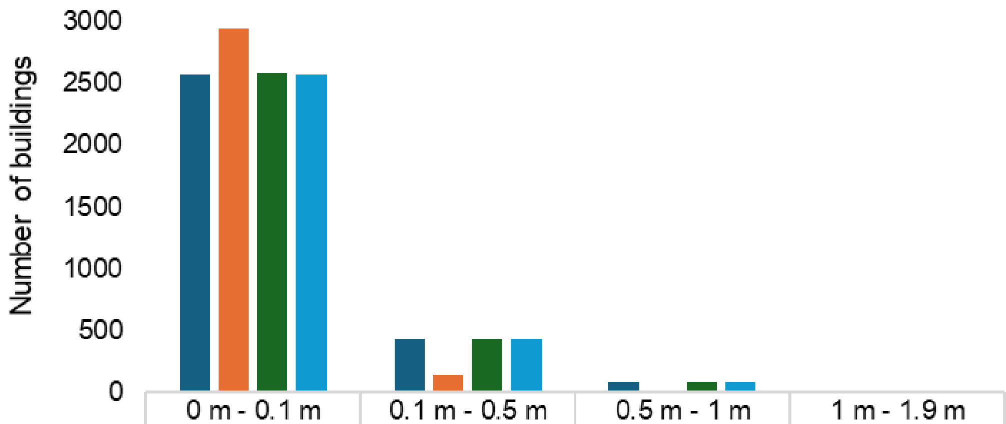


Figure 26: Buildings where the cost-benefit analysis has been applied.

Currently, solutions for flood risk adaptations are not feasible due to the high costs associated with such strategies (Iliadis, 2023). Understanding the potential costs associated with flood risk is important as it leads to the selection of suitable BGI to be implemented to mitigate the future flood damage costs across the catchment by managing the flood at its source using strategies to mimic infiltration, storage and interception of water (Iliadis, 2023., Ur Rehman, 2024).

6.2 Cost Benefit Analysis

It is evident that the implementation of mitigation measures has a significant impact on the depth of the building analysis. To this end, the figure presents a comparison between the flood level and the number of buildings affected. It is apparent that permeable pavements have a considerable impact (Figure 27).



	0 m - 0.1 m	0.1 m - 0.5 m	0.5 m - 1 m	1 m - 1.9 m
Baseline (No intervention)	2568	430	82	16
Pavements permeable	2944	139	8	2
Infiltration garden	2578	429	79	10
Flood plains	2566	429	81	14

Figure 27: Comparison between the different scenarios for mitigation reduction

This reduction in the water level is also evident in the damage cost (Table 3), for permeable pavements is expected a reduce of 25.4% of economic impacts. The scenario with flood plains and infiltration garden has less impact, 1.9% and 0.3% of reduction in Table 3.

Table 3: Economic losses for each scenario and their reduction respect baseline scenario

	DAMAGE COST	% REDUCTION
Baseline (No intervention)	£ 74 759 754.89	
Pavements permeable	£ 55 790 640.62	25.4%
Infiltration garden	£ 73 366 468.71	1.9%
Flood plains	£ 74 535 949.41	0.3%

The annual damage cost projections, considering a return period of 100 years, are also presented.

Table 4: Annual expected damage

Annual expected damage	100 Tr
Baseline (No intervention)	£ 747 597.55

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Pavements permeable	£	557 906.41
Infiltration garden	£	733 664.69
Flood plains	£	745 359.49

7 Conclusion

By using multiple methodologies and technologies, it has been possible to predict the flow of water during an extreme flood event. Considerations have also been made to potential water contamination during this event. Applying CityCAT and HEC-RAS flood modelling, it has been possible to determine and verify the reach of water from this event.

The reduction in water levels also translates into lower economic damage costs. Permeable pavements are expected to reduce economic impacts by 25.4%, while scenarios with floodplains and infiltration gardens show smaller reductions of 1.9% and 0.3%, respectively. Additionally, the expected annual damage cost has been assessed, considering that the return period of the flood event is 100 years. These findings highlight the effectiveness of certain mitigation measures in reducing flood-related economic losses.

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9 Appendices

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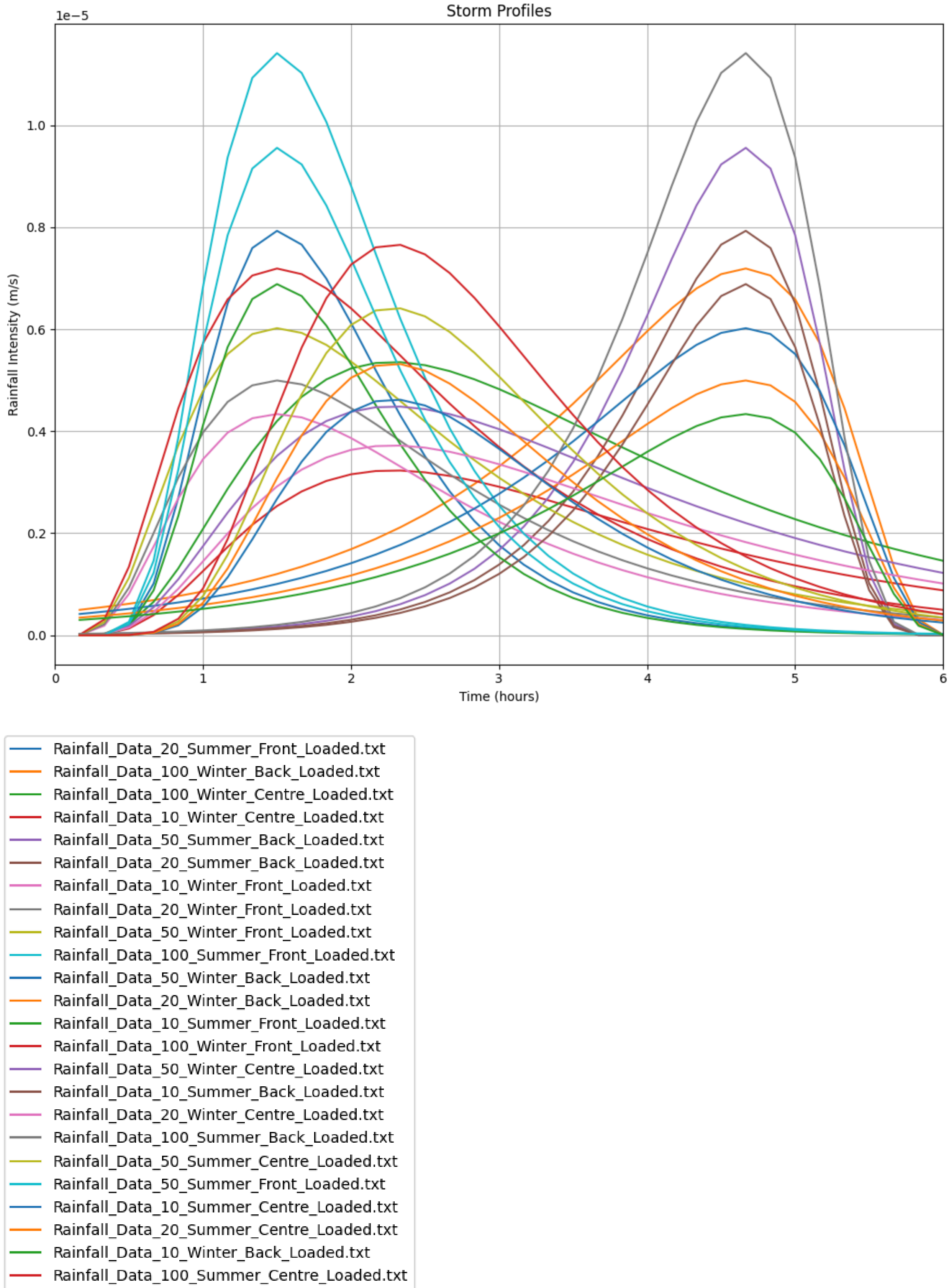
Annex A



(a)

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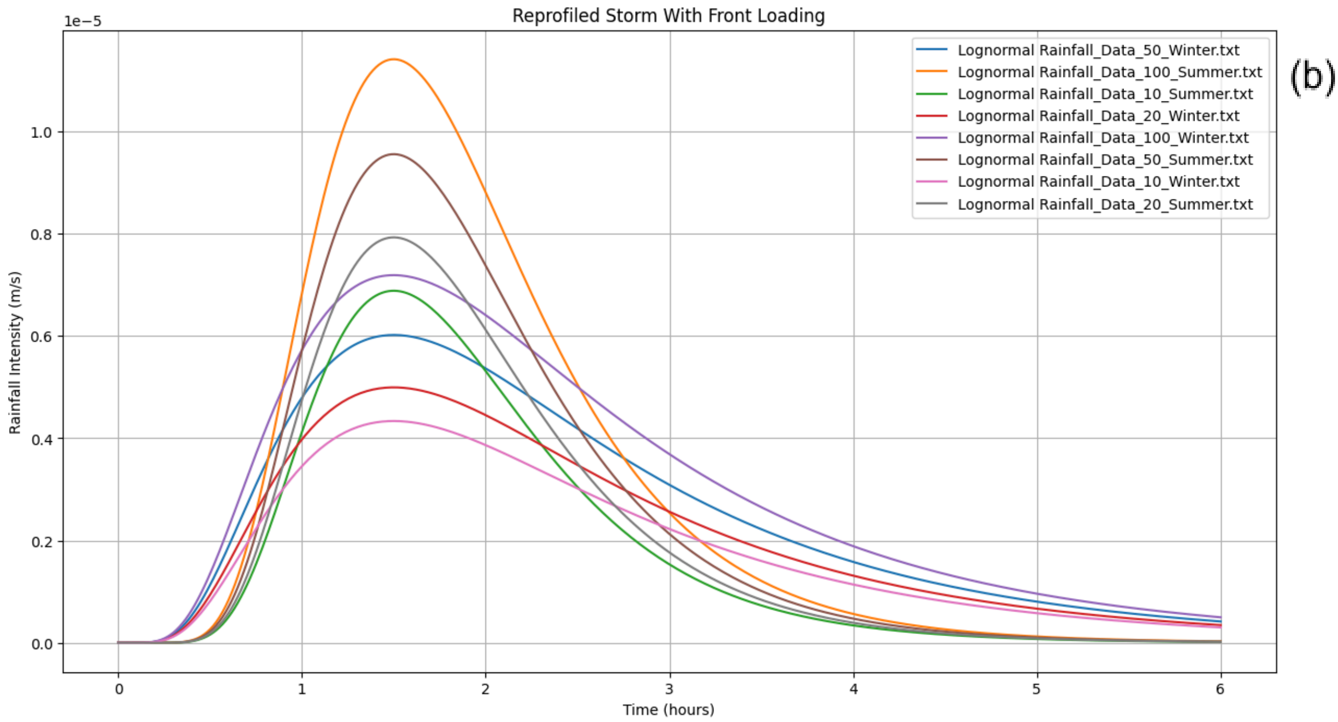
Reprofiled Storm With Front Loading
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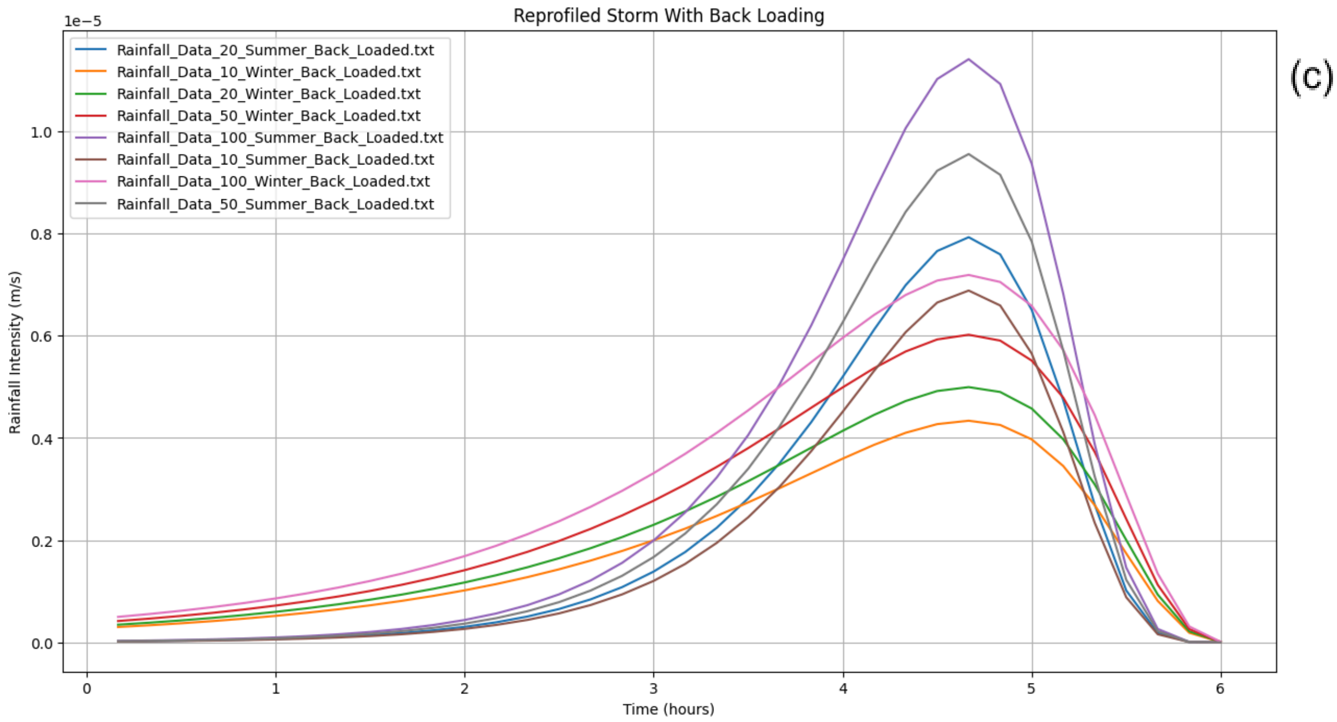
Lognormal Rainfall_Data_100_Summer.txt
Lognormal Rainfall_Data_10_Summer.txt
Lognormal Rainfall_Data_20_Winter.txt
Lognormal Rainfall_Data_100_Winter.txt
Lognormal Rainfall_Data_50_Summer.txt
Lognormal Rainfall_Data_10_Winter.txt
Lognormal Rainfall_Data_20_Summer.txt
(b)
Rainfall Intensity (m/s)
Time (hours)


Reprofiled Storm With Back Loading
1e−5
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Rainfall_Data_20_Winter_Back_Loaded.txt
Rainfall_Data_50_Winter_Back_Loaded.txt
Rainfall_Data_100_Summer_Back_Loaded.txt
Rainfall_Data_10_Summer_Back_Loaded.txt
Rainfall_Data_100_Winter_Back_Loaded.txt
Rainfall_Data_50_Summer_Back_Loaded.txt
(c)
Rainfall Intensity (m/s)
Time (hours)

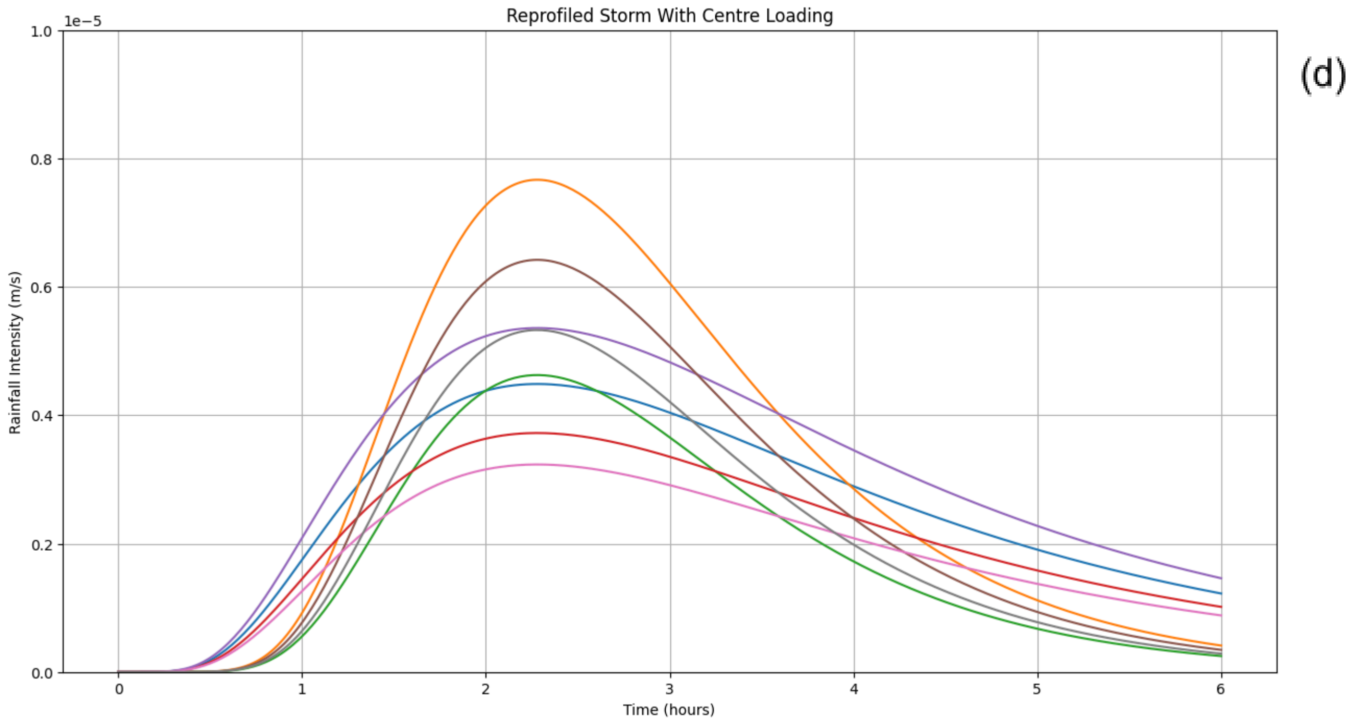

Figure xxx: Storm profiles during rainfall (m/s) over a 6 hour period (a) combined data (b) front loaded storms (c) back loaded storms (d) center loaded storms.