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Team 03: Week 2

HYDROEUROPE

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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 Ahr

Team03: Report Week 2:
Modelling and Analysis of flash flood and propagation of a pollutant in the Ahr river catchment (July 2021)

List of Authors : M.BAILLET ; A. ILIGOGA ; K. KRYNIECKA ; A. MAZIERE ; A. PUCCI ; A. RACZYŃSKA ; H. REDMOND ; C. VICKERMAN ; E. ZGHEIB

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1 Introduction

1.1 Case Study

The Ahr is a small river in Germany, 89 km long. It rises in the Ahrgebirge near Blankenhein. The river's course begins at an altitude of 474m and ends at 53m in the Rhine. It flows through North Rhine-Westphalia and Rhineland-Palatinate. The River Ahr flows through the Eifel Massif and the town of Bad Neuenahr-Ahrweiler, a health resort with over 27,000 inhabitants. The catchment area covers 900 km² and the average flow measured at Altenahr is 7.15 m3/s.

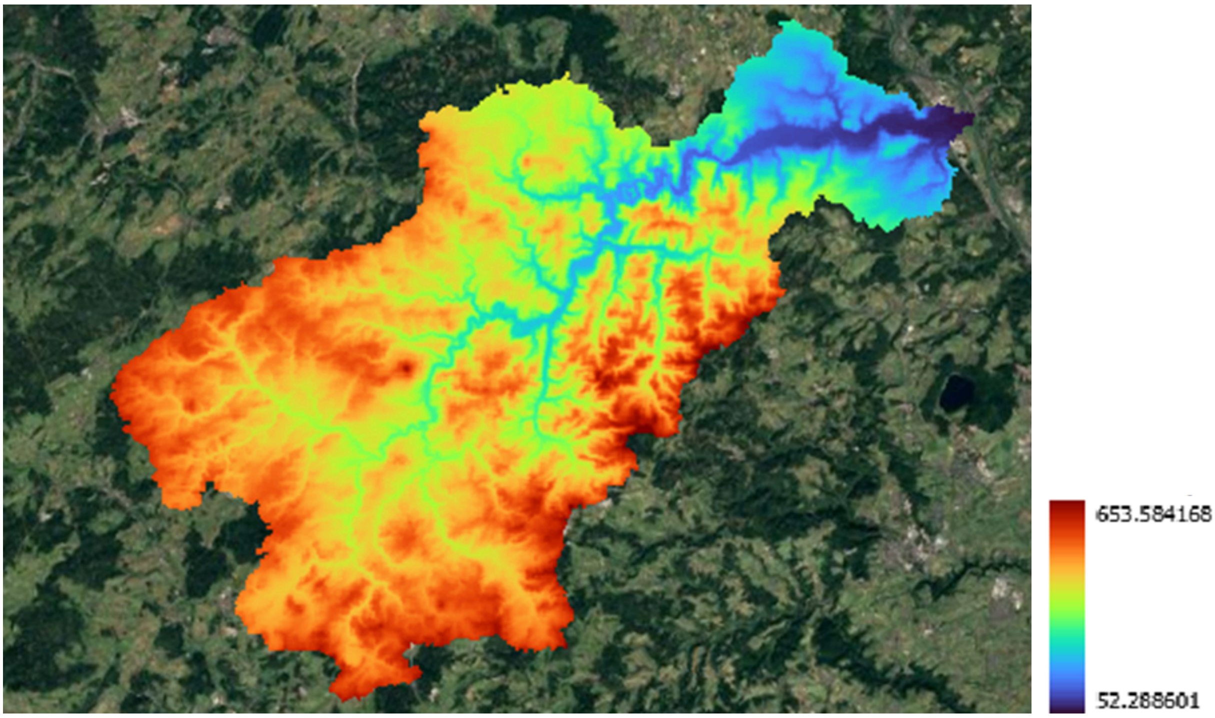

Figure 1. Ahr Catchment DEM

The Ahr Valley has historically been prone to severe flooding, with major flood events recorded in 2021. These events highlight the need for advanced hydrodynamic modelling to improve flood prediction and mitigation strategies. In addition to flood risks, the expansion of human activities has played a major role in the emergence of river water pollution problems. Population growth, industrial activities, and the rapid development and use of new chemicals pose a global environmental threat.

During flood events, pollutant dynamics differ significantly from normal flow conditions. Increased flow velocity and turbulence enhance mixing and dispersion, leading to a wider distribution of pollutants. Understanding these processes is crucial for effective water quality management and disaster preparedness. Especially, the main problematic raised by this phenomenon is how to get information about the pollution presence, and what are its variation.

The water quality in a river depends on the quantity of water in which the pollutants are contained. So, waterflow, level, and velocity are the variables which can determine the pollutant behavior. This is why 2D surface water quality models are proper tools to represent the behaviors of pollutants in water environment during flood. The methodology is to introduce the pollutant concentration in the hydrodynamic model as a function of time and space, and it follows the approach of the advection dispersion transport.

We have two study regions : the Altenburg region within the Ahr catchment is an ideal site for flood analysis due to its intricate topography, history of severe flooding, and hydrological importance. Characterized by steep valley slopes and narrow floodplains, the area is highly prone to rapid runoff and flash floods, as demonstrated during the devastating 2021 Ahr Valley floods.

Similarly, the Schuld region is well-suited for flood studies, as it is situated along a narrow, winding section of the Ahr River, making it particularly vulnerable to extreme flooding. The 2021 floods caused significant destruction in this area, underscoring its susceptibility to sudden water level surges and powerful flood currents. Moreover, the availability of historical hydrological data from previous flood events provides crucial reference points for model validation, enhancing flood risk assessment and mitigation strategies.

1.2 Objectives

The primary objectives of this study are:

1. Simulate Flood Dynamics and Hydrodynamic Behavior
   - Model the flow characteristics of the river during flood events using Telemac2D.
   - Analyze changes in water depth, velocity, and inundation areas to understand flood propagation.

2. Model the Transport and Dispersion of Pollutants
   - Simulate the movement of contaminants released during floods, considering advection, diffusion, and interactions with sediments.
   - Identify high-risk areas where pollutants accumulate and assess their impact on water quality.

3. Assess Risks and Propose Mitigation Strategies
   - Evaluate the potential environmental and public health risks of accidental pollution during floods.
   - Develop strategies for pollution control, emergency response, and flood management to minimize contamination impacts.

2 Flash flood 2021 modelling

For all our models, we use a stage discharge curve downstream of the domain. The Z values are water elevations above sea level.

Z(2)	Q(2)
m	m3/s
156.89	4.90
156.90	5.19
156.91	5.47
156.92	5.77
…	…
162.60	569.80

2.1 Altenberg steady case

To initiate the model, we decided to place three springs upstream of the domain to inject an initial flow. To obtain an output flow of 7.2 m3/s, we injected a flow of 2.4 m3/s into each of the springs.

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ABSCISSAE OF SOURCES = 356820.156; 356812.156; 356804.188

ORDINATES OF SOURCES = 5596823.500; 5596822.500; 5596823.000

WATER DISCHARGE OF SOURCES   = 2.4;2.4;2.4

By retrieving the result of this simulation, we were able to directly inject 7.2 m3/s on the condition at the edge to obtain a stationary case.

PRESCRIBED FLOWRATES   =7.2;0

This result file will form the basis of our unsteady cases.

2.2 Altenberg quasi steady

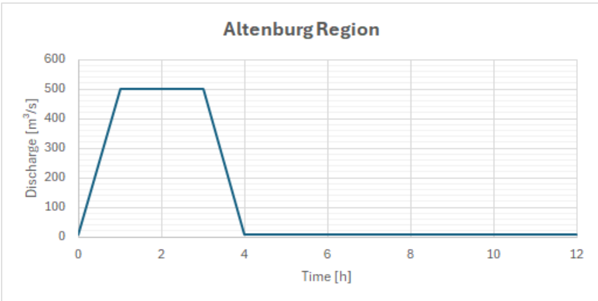
The next idea was to achieve flood flows. To achieve this, we first used 'quasi-steady' cases, where the initial flow corresponds to our stationary case and the final flow corresponds to the target flow. We performed this step for flows of 100 and 200 m3/s. The choice of flow rates as a function of time is made in the .liq file (liquid boundaries file).

T	Q(1)
s	m3/s
0	7.2
3600	100
7200	100
10800	100
14400	100
43200	100

2.3 Altenberg unsteady case

After that, we simulated flood waves with flood peaks reaching our target flows for a certain duration. This step was carried out on flows of 100, 300 and 500 m3/s.

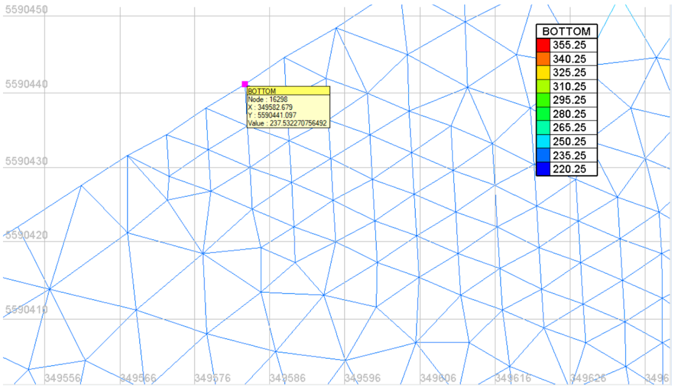
T	Q(1)
s	m3/s
0	7.2
3600	500
7200	500
10800	500
14400	7.2
43200	7.2



2.4 Schuld steady case

For the steady case, we tried to model a constant discharge of 40 $m/^3s$.

<u>Initial conditions for discharge :</u> We create 5 point sources at the upstream boundary and divide this discharge at these points. We found the coordinates (x and y) by opening the mesh file on QGIS or Blue Kenue. We encountered problems at the beginning, because Telemac didn't find the coordinates on the domain of the model. Indeed, we have chosen points that are too much at the end of the field.



Picture : Find coordinates on Blue Kenue

```
/---------------------------------------------------------------------/
/     INITIAL CONDITIONS
/---------------------------------------------------------------------/
INITIAL CONDITIONS = 'CONSTANT DEPTH'
INITIAL DEPTH = 0
/0 m everywhere at the beginning because dry

ABSCISSAE OF SOURCES=
349572.219;349577.469;349582.688
/349576.27;349577.89;349582.99;349588.31;349590.72
ORDINATES OF SOURCES=
5590434.500;5590438.000;5590441.000
/5590431.55;5590432.62;5590435.81;5590439.24;5590440.21
WATER DISCHARGE OF SOURCES =13.0;14.0;13.0
```

Picture : Initial conditions on the .cas file for Telemac

Initial conditions for the water depth : We put for the initial depth a value of 0 m because all is dry, apart from the discharge of the sources.

Boundary conditions : We apply the rating curve downstream. It is a .txt file describing the variations in water surface elevation (m) (water depth + terrain elevation => BOTTOM) according to the discharge (m^3/s). We have to put in the brackets the number of the downstream boundary (1 or 2). In our case it's boundary 2. However, we encountered some problems with the number of the boundaries and we changed them a lot of time.

```
#
# STAGE-DISCHARGE CURVE BOUNDARY 2
#
Z(2) Q(2)
m m3/s
220.59  4.90465983
220.6   5.186403771
220.61  5.47418332
220.62  5.767917422
```

Moreover, in the .cas file we use the keyword : "STAGE-DISCHARGE CURVES", and we put 0 for upstream (no rating curve) and 1 for downstream (to apply the rating curve). The keyword "STAGE-DISCHARGE CURVES FILE" is to put the name of the .txt file containing the data. There are no prescribed elevations downstream, because we already have the discharge curve.

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```
/---------------------------------------------------------------------/
/     BOUNDARY CONDITIONS
/---------------------------------------------------------------------/
PRESCRIBED FLOWRATES  = 40.0;0.0
/upstream ; downstream
/PRESCRIBED ELEVATIONS = 0.0;0.1
STAGE-DISCHARGE CURVES = 0;1
/upstream ; downstream
STAGE-DISCHARGE CURVES FILE ='stage_discharge_curve.txt'
/downstream ; upstream
/VELOCITY PROFILES     = 4;4
/STAGE-DISCHARGE CURVES =1;0
```

Picture : Boundary conditions on the .cas file for Telemac

We can also put a discharge of 0 m^3/s at the point sources, and replace them by a prescribed flowrate of 40 m^3/s at the upstream boundary. These point sources are useful for the other steps to apply tracers following the pollutants concentration.

2.5 Schuld unsteady case

For the unsteady case, the discharge changes with time. The liquid file describes in the first column the time, and in the second one the discharge. We need to put in the brackets the number of the upstream boundary, where we apply the discharge.

We had some problems with the number of boundaries. The liquid boundary file prescribing the discharge should be placed upstream, while the rating curve is located downstream. In these simulations we consider that the boundary 2 is upstream, however it is not logical with the previous steps, because we said that boundary 2 is downstream. The models are running when we put rating curve on boundary 1 and discharge on boundary 2, but there is some confusion and the results are probably not very reliable.

We have tested different discharges on our model : 100 m^3/s (Q100), 300 m^3/s (Q300), and 500 m^3/s (Q500). The purpose is to see the consequences on water depth in the river and floodplain, and also the impact on flooded areas. We put at the beginning of the simulation a discharge of 40 m^3/s (like for the steady case) and then the discharge increases to 100 or 300 or 500 m^3/s. After that, it decreases to 40 m^3/s. We also try to simulate the discharge measured by Altenahr station but It's not really representative of the flood event and it's downstream compared to Schuld region. The most representative discharge for the flood event is 500 m^3/s.

```
# Transient liquid boundary conditions
station Q500
# Created on Feb 4, 2025
T Q(2)
s m3/s
0       40
3600    100
7200    100
10800   100
14400   40
43200   40
```

Liquid boundary file Q100

```
# Transient liquid boundary conditions file
station Q300
# Created on Feb 4, 2025
T Q(2)
s m3/s
0       40
3600    300
7200    300
10800   300
14400   40
43200   40
```

Liquid boundary file Q300

```
# Transient liquid boundary conditions file
station Q500
# Created on Feb 4, 2025
T Q(2)
s m3/s
0       40
3600    500
7200    500
10800   500
14400   40
43200   40
```

Liquid boundary file Q500

```
# Transient liquid boundary conditions file
station
# Created on Feb 4, 2025
T Q(2)
s m3/s
0       99.048
900     108.34
1800    118.882
2700    130.788
3600    146.143
4500    161.251
5400    184.666
6300    207.166
7200    240.158
8100    272.958
9000    313.085
9900    346.782
10800   382.324
11700   415.305
12600   449.491
13500   488.578
14400   531.908
15300   585.769
16200   661.436
17100   749.686
18000   848.876
18900   957.655
19800   1085.747
20700   1152.92
```

Altenahr station

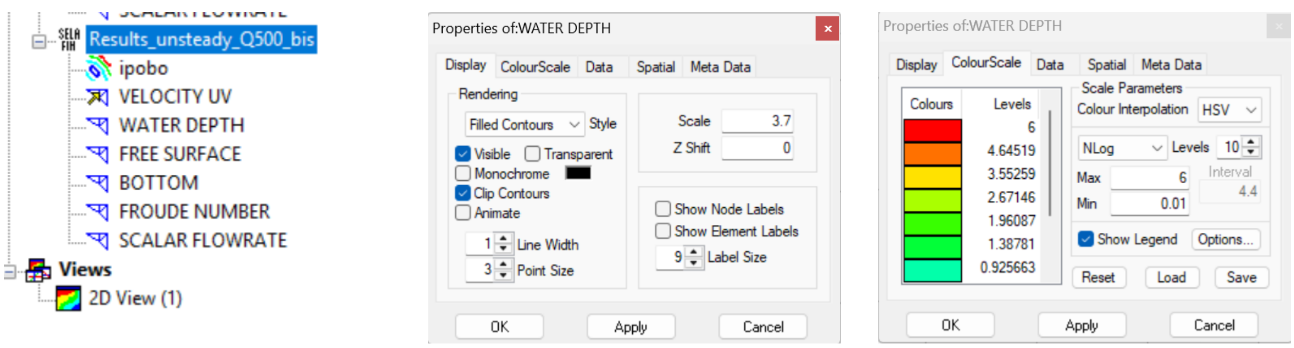
<u>Boundary conditions :</u> To apply this liquid file of the upstream discharges, we have to comment the line of prescribed flowrates upstream, and put the water discharge of sources as 0 m^3/s. Then, we use the keyword “LIQUID BOUNDARIES FILE” and we write the name of the file containing the data. <u>Initial conditions :</u> It is also necessary for the unsteady case, to use the results of the steady case with points sources : also, we use the keyword “PREVIOUS COMPUTATION FILE” with the name of the file.

```
/-----------------------------------------------------------
/     BOUNDARY CONDITIONS
/-----------------------------------------------------------

/PRESCRIBED FLOWRATES  = 0.0;40.0
/downstream ; upstream
/PRESCRIBED ELEVATIONS = 0.1;0.0
/downstream ; upstream
STAGE-DISCHARGE CURVES = 1;0
/downstream ; upstream
STAGE-DISCHARGE CURVES FILE ='stage_discharge_curve.txt'
/VELOCITY PROFILES      = 4;4
LIQUID BOUNDARIES FILE ='discharge.liq'
```

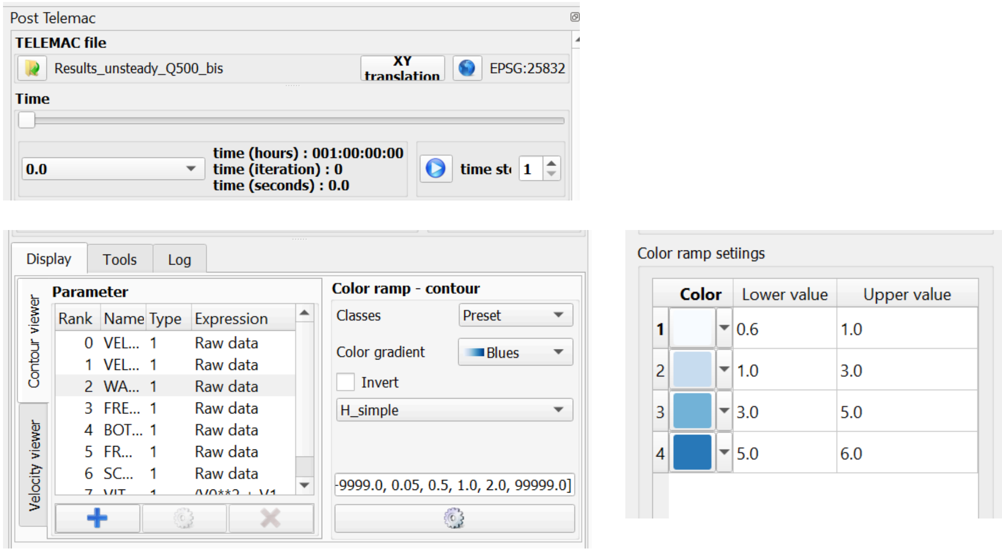
Picture : Boundary conditions on the .cas file for the unsteady scenario

```
/----------------------------------------------------------------------/
/     INITIAL CONDITIONS
/----------------------------------------------------------------------/
/INITIAL CONDITIONS = 'CONSTANT DEPTH'
/INITIAL DEPTH = 0
/0 m everywhere at the beginning because dry

COMPUTATION CONTINUED =true
INITIAL TIME SET TO ZERO =true
PREVIOUS COMPUTATION FILE ='Results_sources_discharge_curve.slf'

ABSCISSAE OF SOURCES=349576.27;349577.89;349582.99;349588.31;349590.72
ORDINATES OF SOURCES=5590431.55;5590432.62;5590435.81;5590439.24;5590440.21
WATER DISCHARGE OF SOURCES =0.0;0.0;0.0;0.0;0.0
/discharge of point sources is equal to zero
```

Picture : Initial conditions on the .cas file for the unsteady scenario



Pictures : Observation of the results on BlueKenue



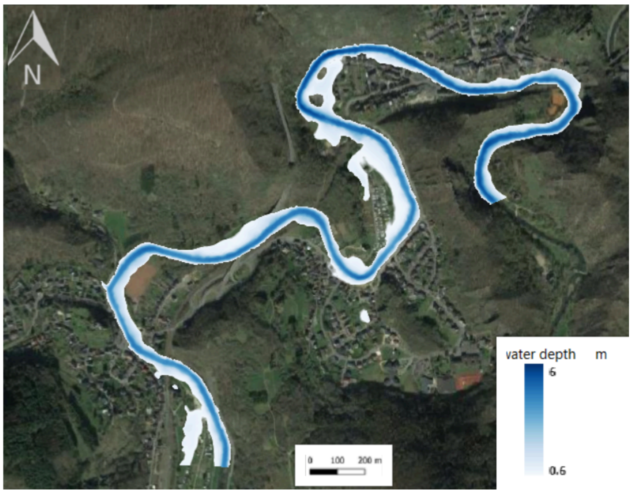
Pictures : Observation of the results on QGIS

The result file is a Selafin file. We can open it on BlueKenue, or on QGIS with the Post Telemac plugin. We can observe the velocity, the water depth, the scalar flowrate… In Bluekenue, we have to put these elements on "2D View" to see the results. Then, with a right click we tick "Animate", and we go on the properties to change the rendering style, and the colour scale. We choose "Nlog" to change the minimum and maximum values of water depth, and we display the legend. In QGIS, we load the result file and choose the right coordinate system (EPSG 25832). We select the water depth and we click on the parameters to change the scale of the colors representing the water depth. We apply also as a background, the google map satellite.

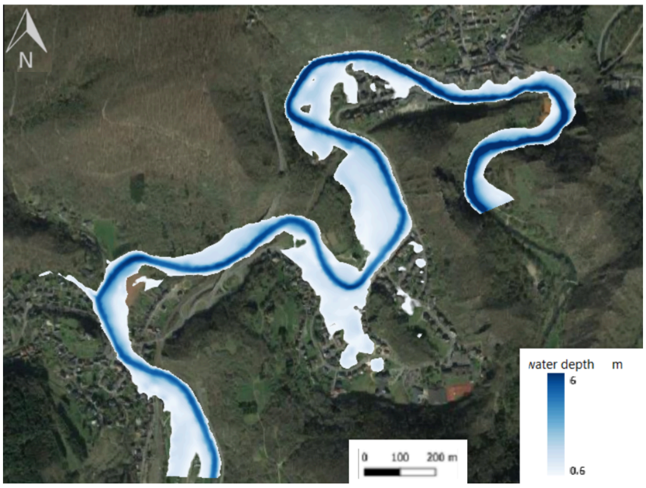
3 Flash flood simulation results

3.1 Altenberg unsteady

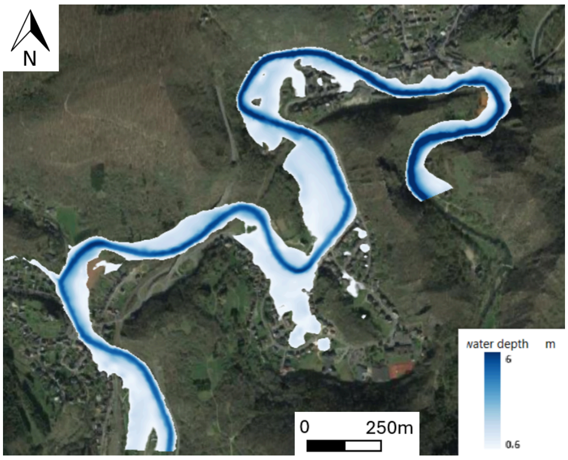
Q = 100m³/s (quasi-steady)



Q = 300 m³/s



Q = 500 m³/s



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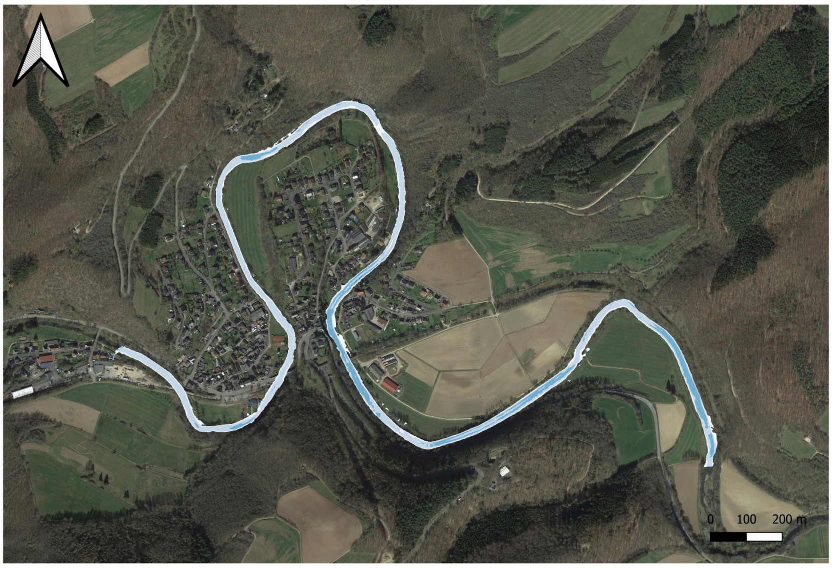
3.2 Schuld unsteady

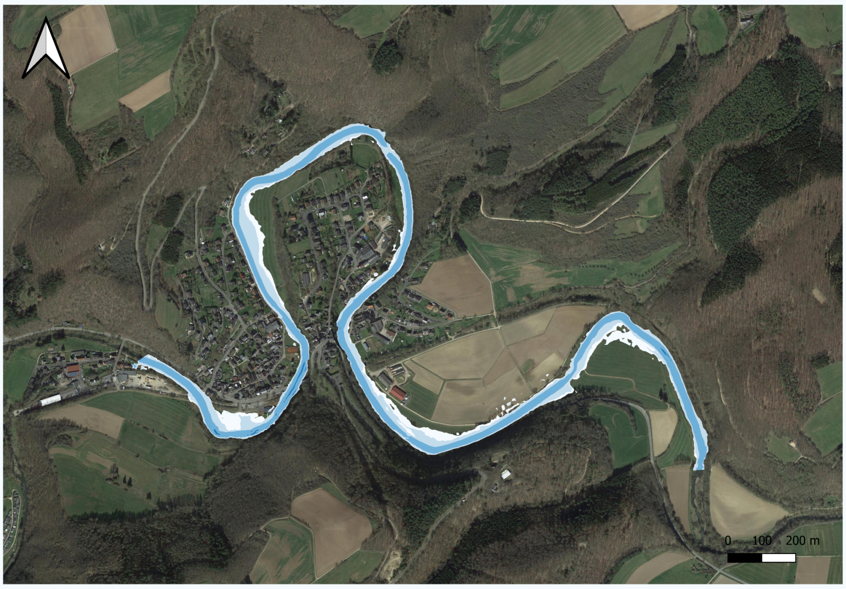


Color ramp setiings

	Color	wer valu	Upper value
1		0.001	1.0
2		1.0	2.0
3		2.0	3.0
4		3.0	4.0

Q = 100 m^3/s

t = 7200 s



Color ramp setiings

	Color	Lower value	Upper value
1		0.6	1.0
2		1.0	3.0
3		3.0	5.0
4		5.0	6.0

Q = 300 m^3/s

t = 7200 s

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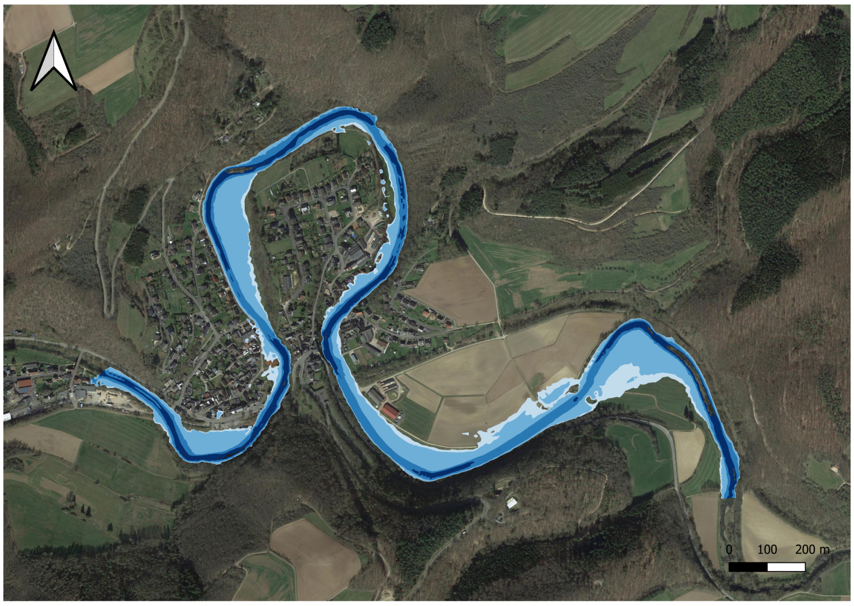
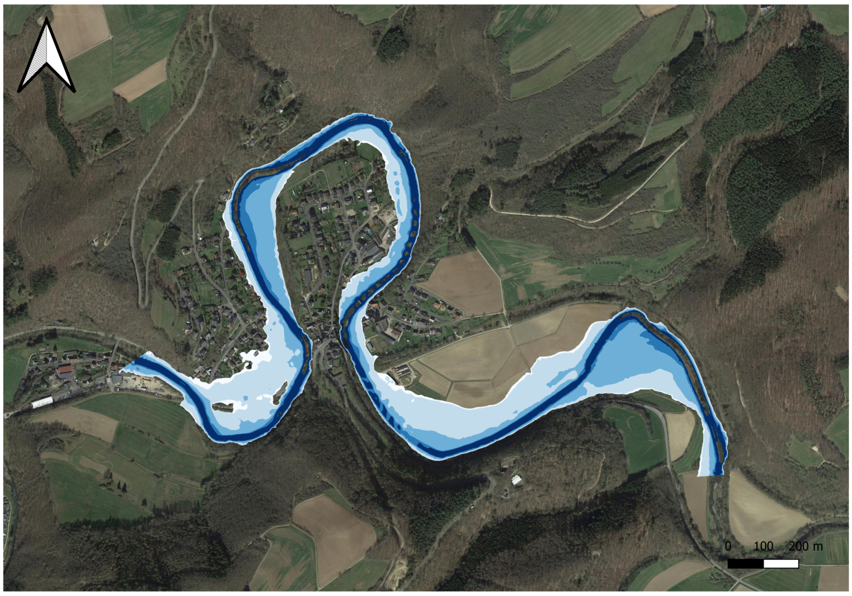


	Color	ower valu	Upper
1		0.6	1.0
2		1.0	3.0
3		3.0	5.0
4		5.0	6.0

Q = 500 m^3/s

t = 7200 s



Color ramp setiings

	Color	Lower value	Upper value
1		0.6	1.0
2		1.0	3.0
3		3.0	5.0
4		5.0	6.0
5		6.0	8.0

Data of Altenahr station

t = 24300 s at the peak discharge (Q = 1226 m^3/s)

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Pollutant propagation analysis

In TELEMAC, tracers can be introduced either at boundary conditions or at point sources, depending on the simulation requirements.

4.1 Schuld Point Source Fertilizer pollutant

Tracers on point sources are applied when pollution originates from specific locations, such as industrial discharge points, wastewater outlets, or accidental spills. These sources are defined by coordinates and discharge values in the model.

For the following analysis it is key to define a few keys terms:

- Medium-long term scenario: this is the scenario at a time step of 95 hours, which is 62 hrs 10 mins after the initial release of the pollutant.
- Short-term scenario: this is the scenario at a time step of 34 hours, which is 10 mins after the initial release of the pollutant.

For Schuld it was decided to analyse only the medium-long term scenario under the given pollutant levels for point source 3 only. The reason to only analyse the medium-long term pollutant levels is due to the fact that the damage from the volume of water during the flood event itself would be more destructive than the small amount of pollutant suspended in this discharge (Figure 4).

However, for the medium-long term case, when all of the flood water has receded, there are still some levels of pollutant that have been deposited on the previously flooded areas (Figure 4.1)

It was also decided to only analyse point source 3 for a few reasons. The first is that the project time constraint meant there was only time to analyse 1 point source out of the 4 point sources. In addition, 2 of the point sources were artificial. So out of the 2 point sources left, one of them would only affect rural and crop areas, whereas the other would affect residents (point source 3).

	Color	Lower value	Upper value
1		-9999.0	0.05
2		0.05	0.1
3		0.1	0.25
4		0.25	0.5
5		0.5	1.0
6		1.0	1.5
7		1.5	2.0
8		2.0	3.0
9		3.0	4.0
10		4.0	5.0
11		5.0	9999.0

[Figure 4: Pollutant concentration: Short term scenario]

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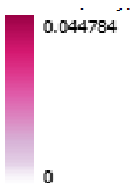
	Color	Lower value	Upper value
1		-9999.0	0.05
2		0.05	0.1
3		0.1	0.25
4		0.25	0.5
5		0.5	1.0
6		1.0	1.5
7		1.5	2.0
8		2.0	3.0
9		3.0	4.0
10		4.0	5.0
11		5.0	9999.0

[Figure 4.1 : Pollutant concentration: long term scenario]

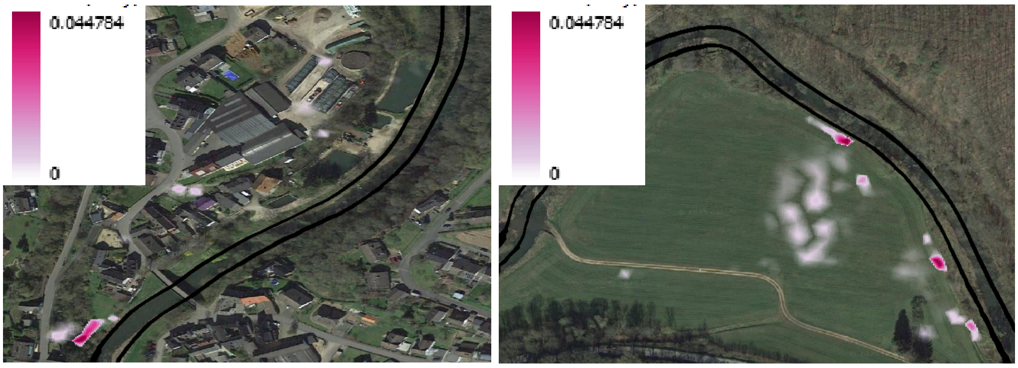
The key limitation of the figures above is that it only shows concentration of the pollutant, which is not a key representative. It negates the effect of water depth on the pollutant levels. In order to make the analysis more accurate, water depth needs to be accounted for. In order to do this the following process was followed:

- Creation of a rasterized mesh dataset using the tool "rasterize mesh dataset" (Figure 4.2 next page)
- Multiplication of the water depth and concentration levels using the "raster calculator expression" tool (Figure A1) to create layer which accounts for water depth (Figures 4.3 & 4.4)

[Figure 4.2- Rasterized mesh dataset layer]



[Figure 4.3: Rasterized mesh calculator outputs- 2 risk areas identified; central and eastern]



[Figure 4.4: Risk areas: central (left) and eastern (right)]

Now that we have accounted for the water depth in our pollutant analysis we can directly see between the original infographic (Figure 4.1) and the final infographic (Figure 4.3) that the levels of pollutant are greatly decreased. Figure 4.4 also identifies two key risk areas in which there is left over pollutant from the flood event. This analysis is crucial as it shows the local government where they would need to reinforce infrastructure to avoid the pollutant infiltrating into the top soil down to the subsurface water structures and into potential groundwater sources, like wells and aquifers.

https://docs.google.com/document/d/1R6Fi5q_Xh__NaekbtPkFGJ4vhCtKWuIr5RE6WZfk_Yw/edit?usp=sharing

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4.2 Altenberg upstream boundary pollutant (salt)

Tracers on boundary conditions are used when pollutants enter the system through inflows, such as upstream river boundaries or tidal inlets. The concentration is prescribed at the boundary and transported downstream by the flow.

To initiate the TELEMAC model for a pollutant, you need to add certain keywords in the .cas file and tracer values to the .liq file.

Boundary file :

T	Q(1)	TR(1,1)
s	m3/s	KG/M3
0000	7.2	0
3600	500	0
7200	500	0
7201	500	10
10800	500	10
10801	500	0
14400	7.2	0
43200	7.2	0

.cas file :

```
NUMBER OF TRACERS =1
NAMES OF TRACERS =Salt
INITIAL VALUES OF TRACERS =0.
PRESCRIBED TRACERS VALUES =0;0
DIFFUSION OF TRACERS =Yes
COEFFICIENT FOR DIFFUSION OF TRACERS =1.E-6
OPTION FOR THE DIFFUSION OF TRACERS =2 / chapter 9.6
SCHEME FOR ADVECTION OF TRACERS =4 / N distributive scheme, mass-conservative
SCHEME OPTION FOR ADVECTION OF TRACERS =4 / LIPS locally semi-implicit predictor-corrector scheme
TREATMENT OF NEGATIVE DEPTHS =2 / flux control
MASS-LUMPING ON H =1 / maximum mass lumping also for tracer
MATRIX STORAGE =3 / edge-based storage method (default)
CONTINUITY CORRECTION =YES / chapter 7.3.3
NUMBER OF CORRECTIONS OF DISTRIBUTIVE SCHEMES =3
MAXIMUM NUMBER OF ITERATIONS FOR ADVECTION SCHEMES =100
NUMBER OF SUB-STEPS OF DISTRIBUTIVE SCHEMES =2
```


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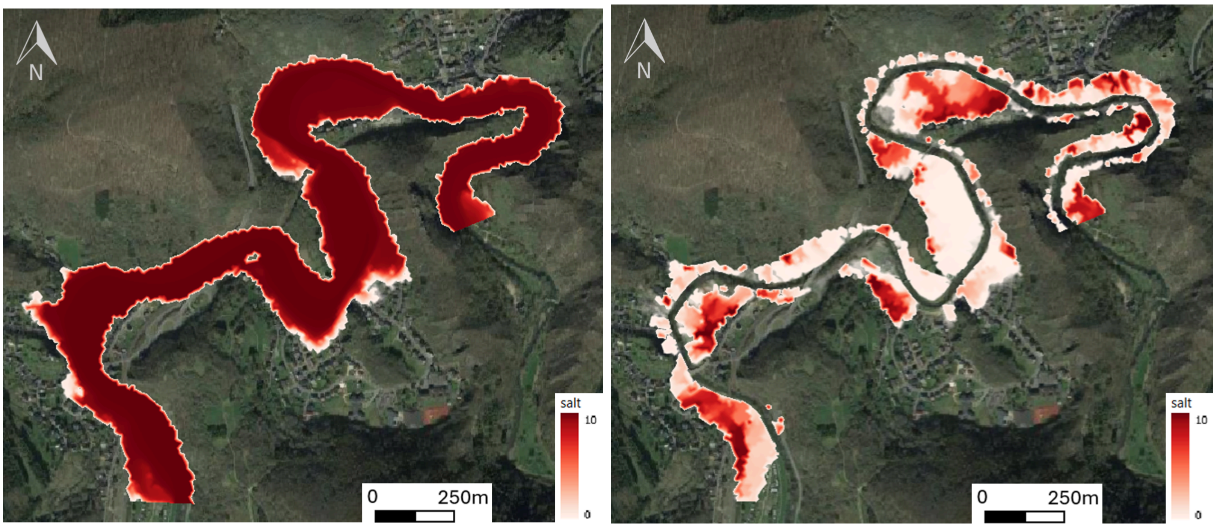
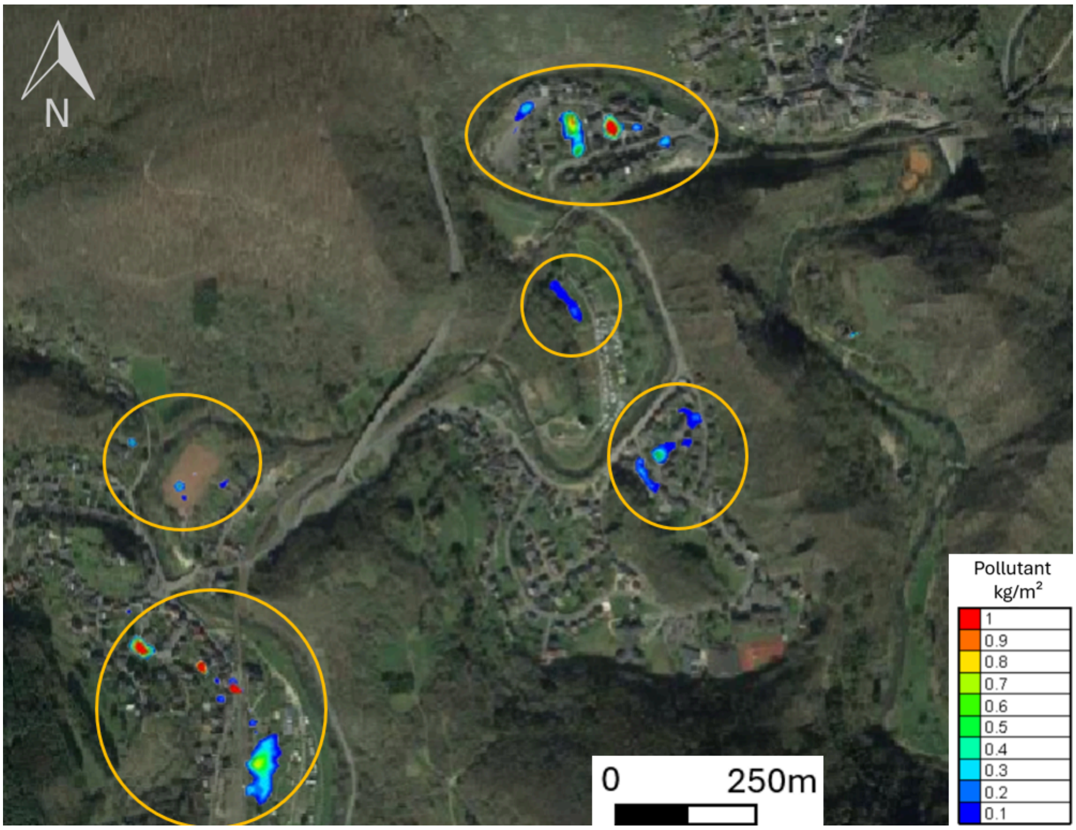


Pollutant distribution (Altenberg) : at the peak of 500 m^3/s event (left) ; steady state of 7.2 m^3/s (right)

The most important analysis is when the flood has passed, when we return to a steady state. This is when we can observe where the pollutant has remained trapped.

However, these maps show the pollutant in kg/m3, which is not really representative. To find out the real concentrations, simply multiply the concentration of the pollutant by the water depth in the same area.

$$\text{Pollutant (kg/m}^3\text{)} * \text{Water depth (m)} = \text{Pollutant (kg/m}^2\text{)}$$



Pollutant distribution (kg/m^2), steady state : 7.15 m^3/s, 500 m^3/s event (Altenberg)

This map shows five areas in the Altenberg region affected by pollution. In particular, one upstream and one to the north. At certain points (red zones) the pollutant reaches 1 kg/m².

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4 Conclusion

4.1 Pollutant on TELEMAC

TELEMAC allows for the simulation of pollutant transport in water bodies using the tracer module. Pollutants can be introduced through boundary conditions, representing continuous inflows, or point sources, simulating localized discharges.

The model accounts for key transport mechanisms such as advection, diffusion, and dispersion, ensuring a realistic representation of pollutant spread. Additional processes like sedimentation, resuspension, and chemical transformations can also be included depending on the simulation needs.

Results from pollutant simulations in TELEMAC help assess water quality, contamination risks, and environmental impacts, making it a valuable tool for hydrodynamic and ecological studies.

4.2 Pollutant simulation results

For the Schuld region, the pollutant propagation analysis has been conducted based on TELEMAC simulations. The image shows an aerial satellite view with an overlaid flood extent marked by black contour lines, representing the boundaries of the affected area.

The red zones indicate areas with higher pollutant concentrations, likely representing contamination hotspots within the flood-affected region. These concentrations are dispersed along the river path, with a more significant accumulation in urban areas and locations where the flow slows down, such as wider sections of the valley.

The results suggest that pollutants have been transported downstream, with noticeable dispersion patterns influenced by topography and hydrodynamic conditions. The agricultural fields and residential areas within the boundary lines appear to be at risk of contamination, highlighting the need for further assessment of water quality and potential mitigation strategies.

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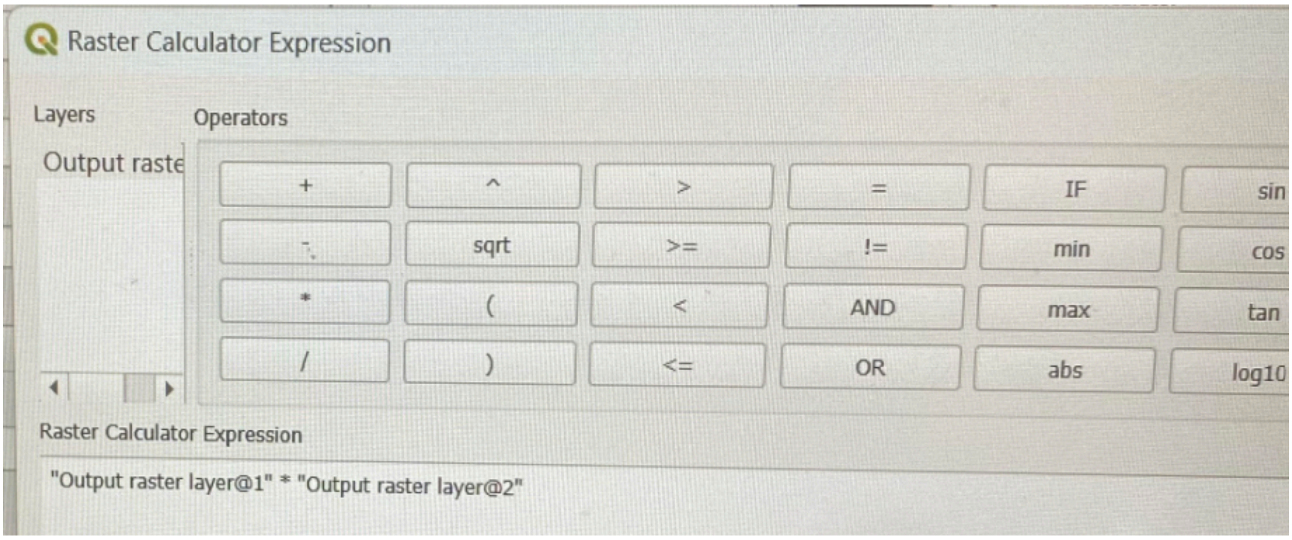
5 Annex



[Figure A1: Raster calculator formula]