Report

Hydraulic study of the Magne stream

Interreg-EMR228-EMfloodResilience

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For:
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1	06/10/2023	Intermediate report 1
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1 Introduction

This hydrological and hydraulic study, commissioned from HydroScan SA/NV by Province de Liège, is part of a project to reduce the risk of flooding on the 2nd category watercourse, the Magne river, a right bank tributary of the Vesdre river. The catchment area and the length of the watercourse are illustrated in Figure 1 1. The aim of the study is to determine the most appropriate development proposals with a view to reducing flooding in the municipalities of Herve, Soumagne, Olne and Trooz, which are frequently affected by overflows from the watercourse. This study is also part of the INTERREG - EMR228 - EMfloodResilience project, the aim of which is to subsidise various projects and actions to reduce the risk of flooding in cross-border regions, including Province de Liège.

The study has a number of specific objectives:

- To carry out a hydrological and hydraulic study of the Magne stream (2nd category) along its entire length, from the commune of Herve to its confluence with the river Vesdre.
- Determining the most appropriate measures to reduce flooding on the Magne stream in the critical areas known to be at stake in the catchment area. This analysis forms the core of the contract and is based on an in-depth analysis of the hydraulic model, considering the situation on the ground. It includes a brief cost-benefit analysis to determine the list of the most appropriate schemes.

The following sections are detailed in this report:

- Situation of the watercourse studied;
- Analysis of the context and objectives of the study;
- Description of the topographic surveys used;
- Explanation of the development, calibration and validation of the models;
- Analysis of the existing situation through a diagnosis of the hydraulic functioning;
- Identification and/or optimisation of relevant solutions

To meet the objectives of the study, our design office carried out hydrological modelling (quantification of inputs to the watercourse) and hydraulic modelling (estimation of water levels in the minor and major bed in function of the flows in the watercourse). The model was parameterised in order to establish a reference situation that would enable a diagnosis to be made of the hydraulic functioning of the watercourse, and to design hydraulic structures according to the inflows and limiting structures in the section studied. The solutions were designed on the basis of discussions with the watercourse manager. The solutions were tested in the model to assess their impact on flooding in the various areas at stake.

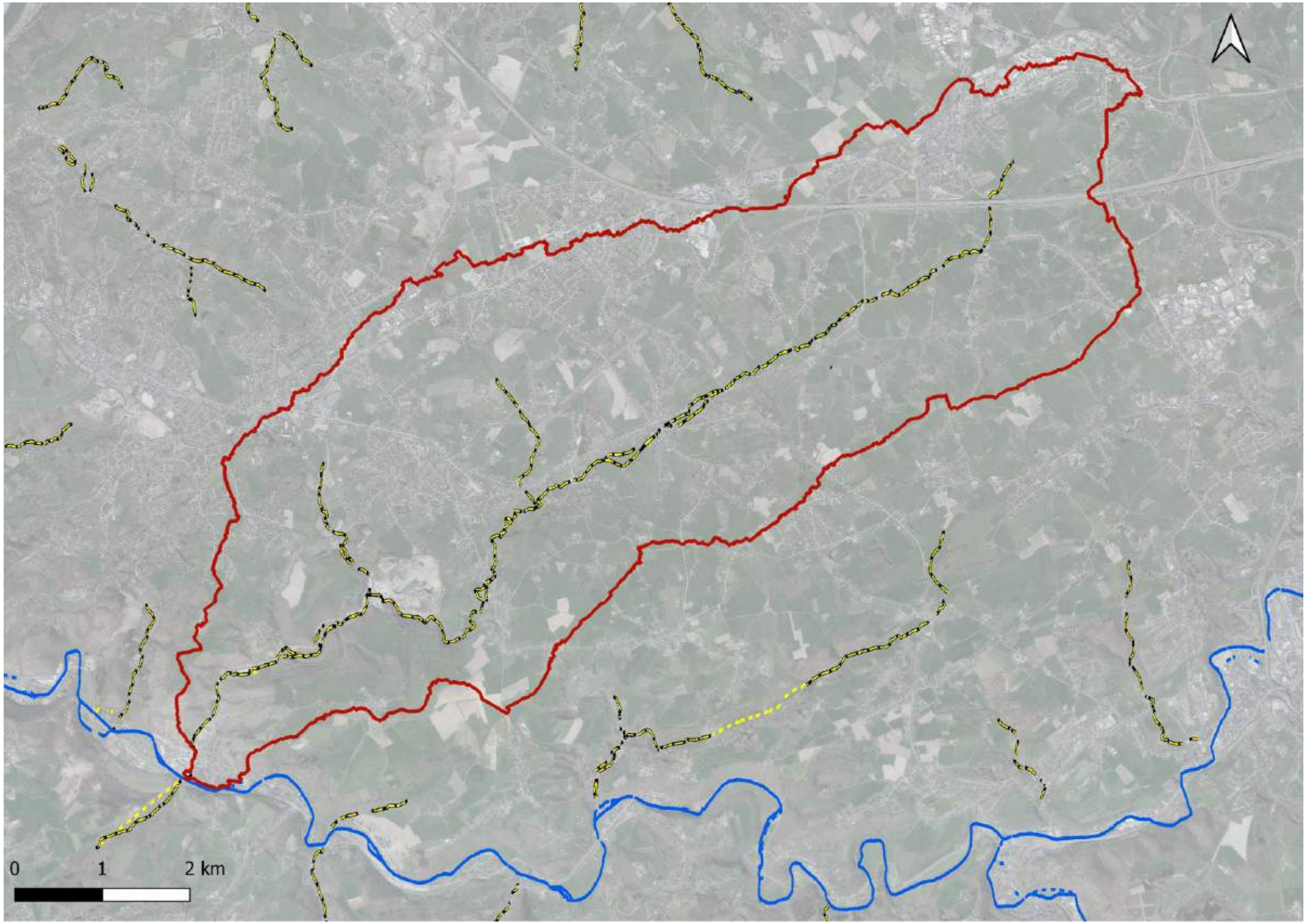

Figure 1-1 – Catchment area of the Magne stream and length of watercourse

2 Overall analysis of the study area

2.1 Situation of the watercourse studied

The river Magne catchment covers an area of approximately 42 km². The river rises in the town of Herve. It then flows through the town of Soumagne, through the Bay Bonnet quarry in Olne and on to the town of Trooz, where it flows into the river Vesdre. The length of the 2nd category watercourse to be modelled as part of this study is approximately 18 km, with some sections modelled in simplified form and others in detailed form.

The catchment is predominantly rural in character, as shown in Figure 2 1 and Figure 2 2, and is mainly made up of agricultural areas (68%) and man-made areas (15.2%). Urban areas are concentrated in the towns of Herve, Soumagne and Trooz. Forest covers 14.4% of the catchment area, bare land around 1.7% (mainly the quarry) and wetlands and water surfaces around 0.4%.

The average gradient is 12%, which is high and encourages rapid transfer of runoff to the outlet. Figure 2 3 shows the slopes in the catchment divided into 4 classes.

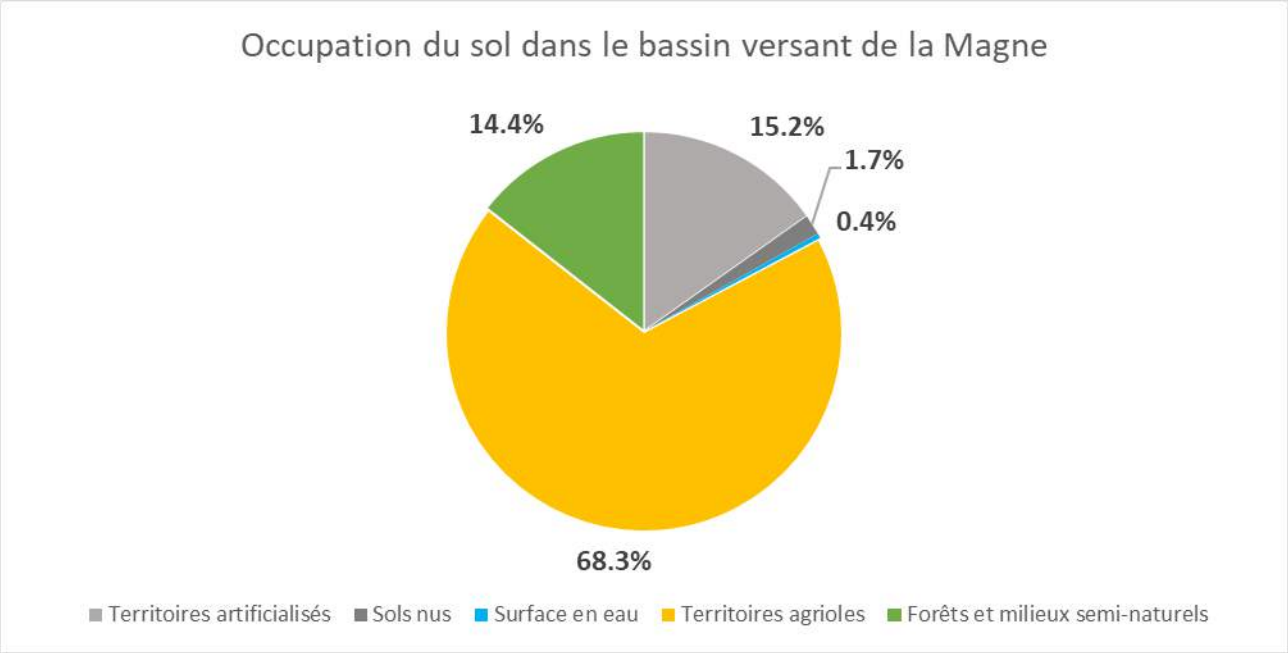

Figure 2-1 : Percentage of land use in the study area based on WalOus 2018.

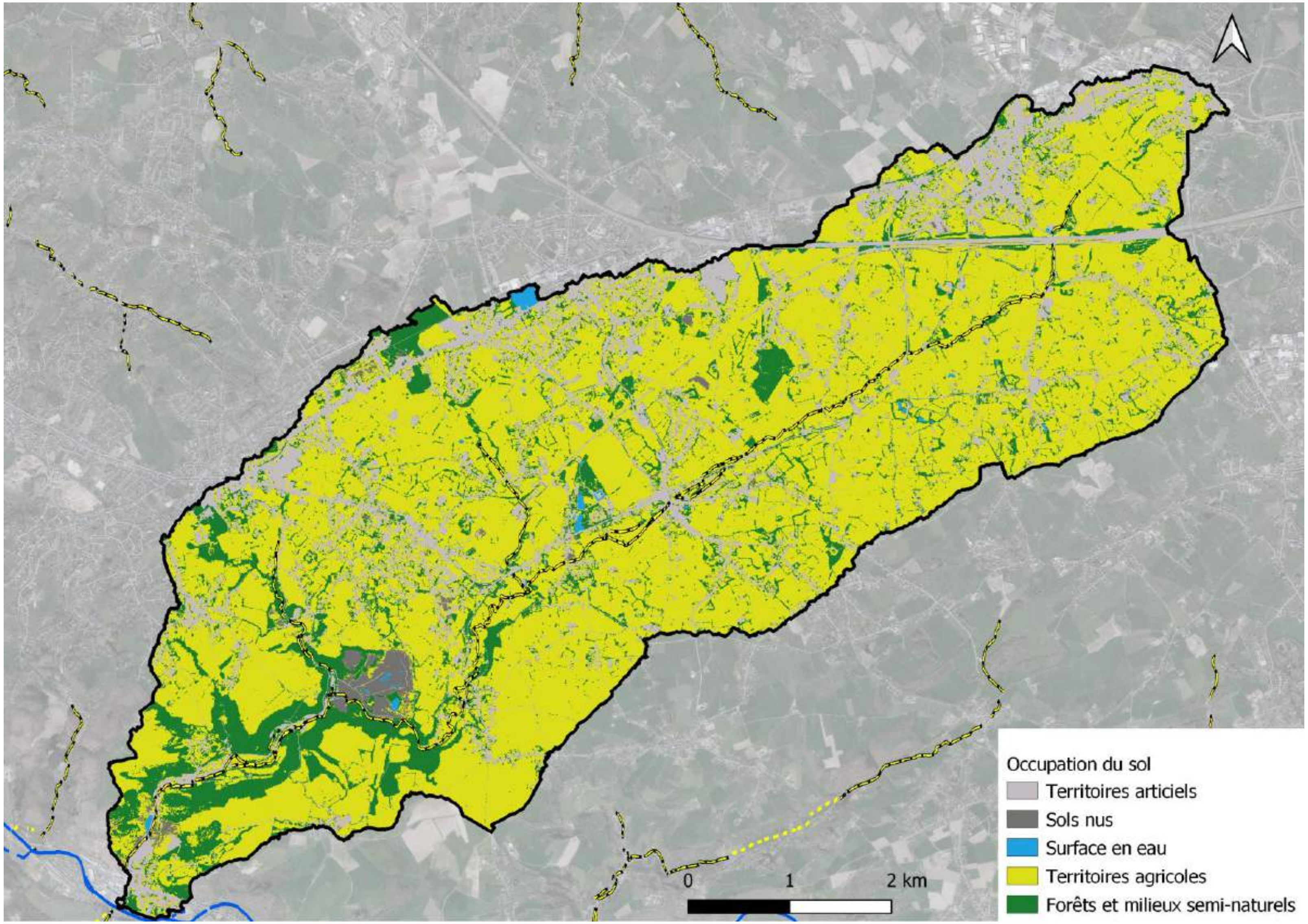

Figure 2-2 : Land use in the study area based on the Walloon land use map (WalOus 2018).

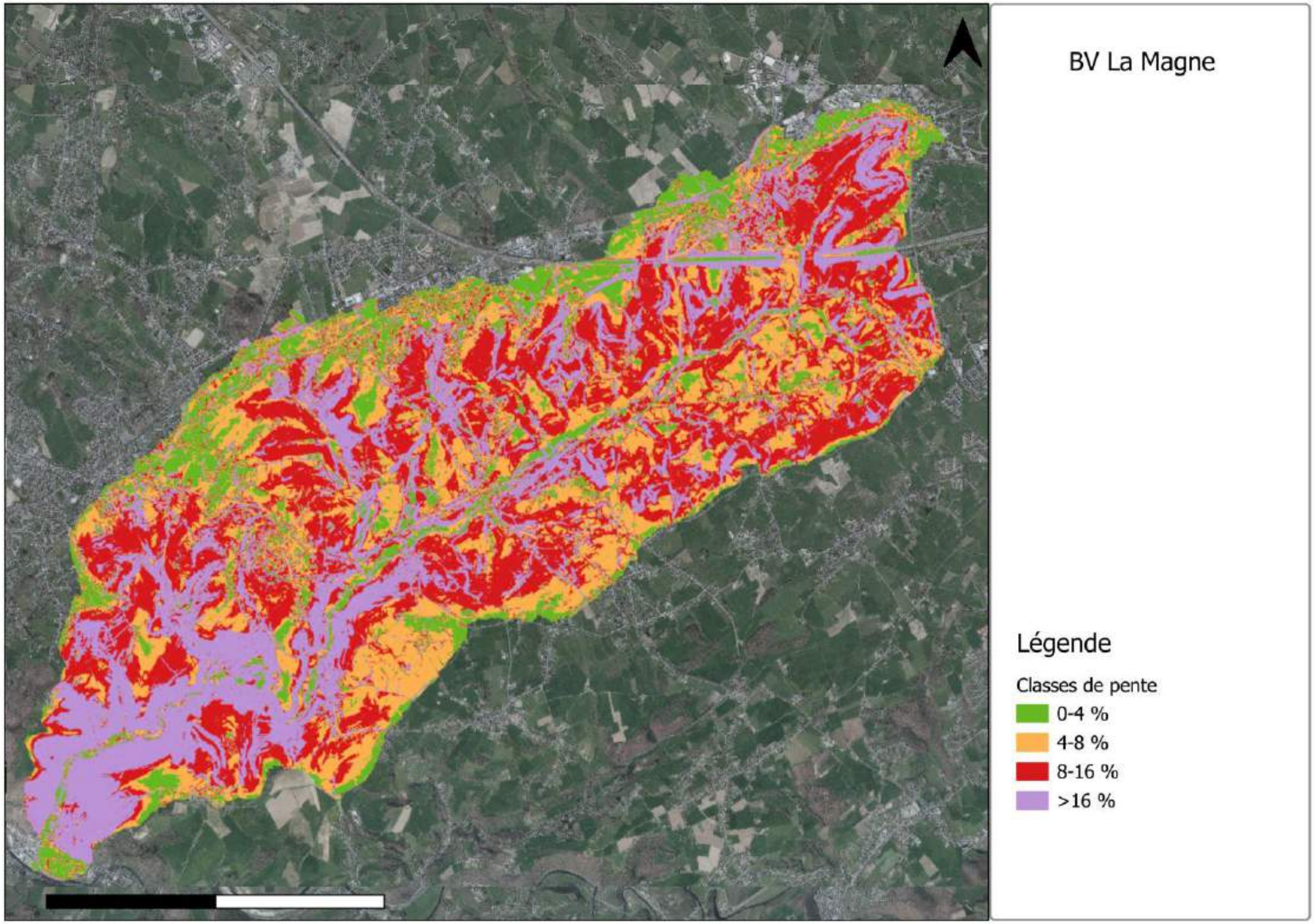

Figure 2-3 : Slope in the river Magne catchment area.

3 Available data

3.1 Description of the topographic surveys used for the minor bed

There is no precise topographical survey of the minor bed in the study area. Consequently, topographic surveys were carried out in order to build and validate the model.

Three types of topographic survey were carried out in the study area in order to build and use the hydraulic model:

- Surveys for **Type S (Simplified)** sections, covering stretches totalling around 10 km. For these sections of the watercourse, a few representative flow sections are surveyed to consider flow capacity. Structures are not included in this approach, the principle being above all to be able to represent the transfer of flows between the upstream and downstream parts of the catchment (hydraulic routing).
- Surveys for **Type S+S (Simplified with Structures)** sections, applying to a stretch of approximately 1.5 km of watercourse and mainly concerning stretches near the Bay Bonnet quarry. In this case, the structures are theoretically well considered in order to consider the effect of these structures on the flow and to have a detailed representation of the overflow of the watercourse. However, as detailed later in this report during the field visit, the situation of the watercourse in this sector is particularly complex due to the historical context (presence of the quarry, old coal-mining pipeline on the 2nd category tributary of Ruisseau des Carrières) and also due to the karstic context where the river Magne disappears and reappears further downstream (information collected during the field visit to the Bay Bonnet quarry). This sector was therefore included in the modelling assumptions, with the aim of allowing water to flow through the sector.
- Surveys for **Type D (Detailed)** sections, covering several sections totalling around 6.5 km and 40 structures. These sections are being surveyed to a high degree of accuracy in accordance with the requirements of the special specifications issued by GlobeZenit Wallonie srl, a firm of chartered surveyors acting as subcontractor for this study. The surveys consist of cross-sections at regular intervals, and the structures and all hydraulically relevant structures are considered and modelled. Structure sheets are also produced for these sections. All the detailed surveys (cross-sections, structures, etc.) are shown in appendix 8.1.

The locations of the different types of section along the length of the watercourse are shown in Figure 3 1 on the following page.

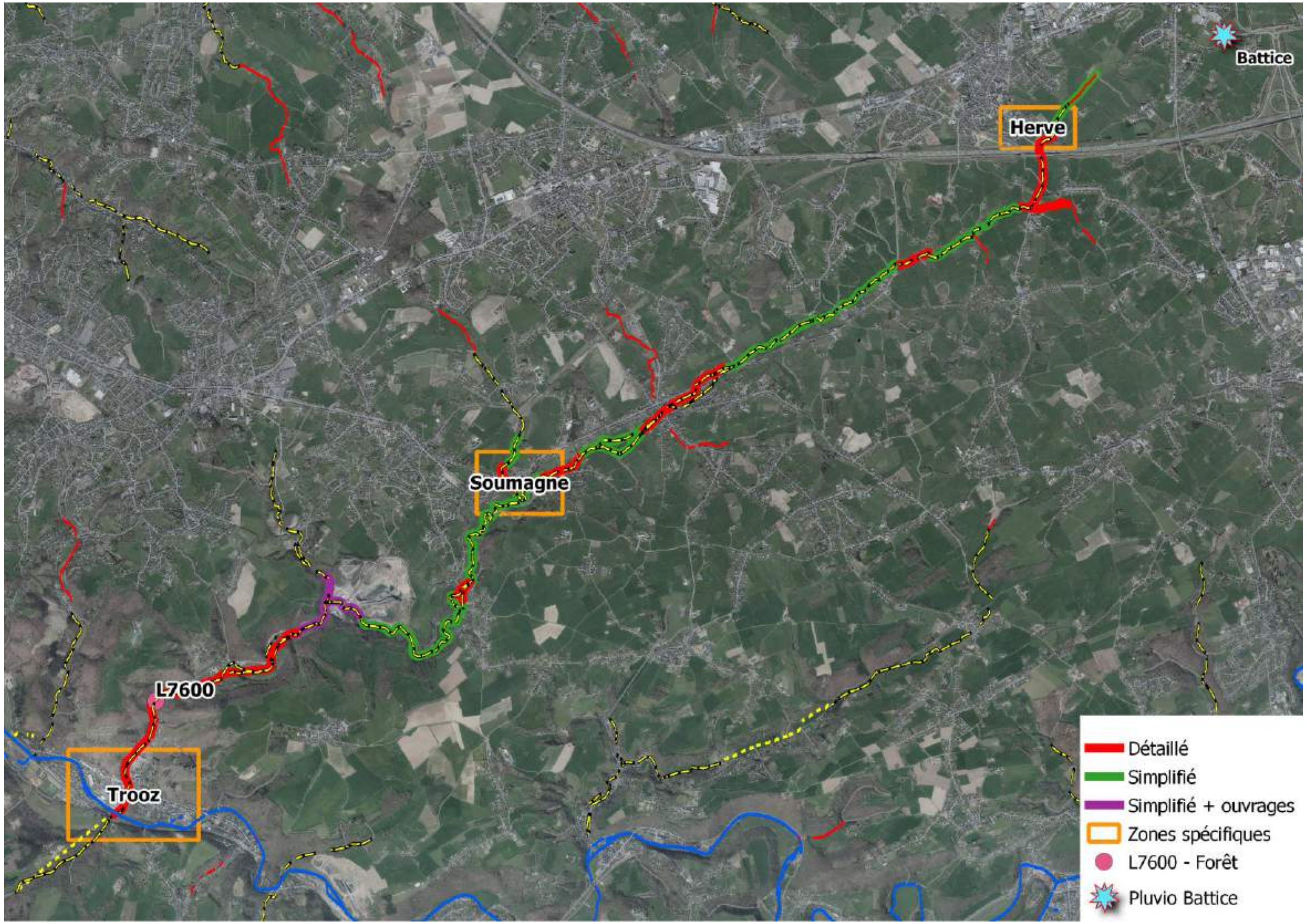

Figure 3-1 : Location of the different types of section (D, S and S+S)

3.2 Other topographical data

The following data are also used to build the hydrological and hydraulic model:

- Plan of the storm basin in the town of Soumagne provided by Province de Liège. The cross-sections at right angles to the storm basin were checked using precision GPS;
- At the level of the river Vesdre, a section of this watercourse was integrated on the basis of old 1960 surveys supplied by the SPW-DCENN. The aim of this addition is to have a downstream condition, at the confluence of the river Magne with the river Vesdre, which seems important for reproducing the overflow of the watercourse near the confluence.
- Hydrological and hydraulic models of the sewerage network of the towns of Herve and Soumagne supplied by AIDE in a transportable database with simulations in the InfoWorks ICM modelling software. These data are useful for modelling urban contributions to the stream. The data can also be used to obtain the locations of storm overflows and the urban areas of Herve and Soumagne.
- The Digital Terrain Model of the Walloon region with a 0.5m x 0.5m grid;
- Cartographic data (orthophoto, PICC, Atlas of watercourses, Walloon Land Use Map, WALOUS 2018);

The topographic surveys of the minor bed therefore come from several different sources. To summarise

- Drainage networks for the town of Soumagne and the town of Herve: The topographic and cadastral data for these networks were supplied by AIDE.
- Simplified section type S: The topographic surveys of this section were measured using precision GPS in June 2023.
- Detailed type D section: The topographical surveys for this section were measured by the survey company GlobeZenit.
- River Vesdre section: Topographic surveys of the river Vesdre in 1960 were provided by SPW.

3.3 Hydrological data

3.3.1 Water level data

The hydrological data available is made up of height and flow data from the L7600 limnometric station in the DCENN network, located just downstream of the study area in rue Fond de Forêt. The station's hydrological data are hourly data from 2011 to July 2021. The main information concerning station L7600 is shown in Figure 3 2 below. Its location is also provided in Figure 3 1 above.

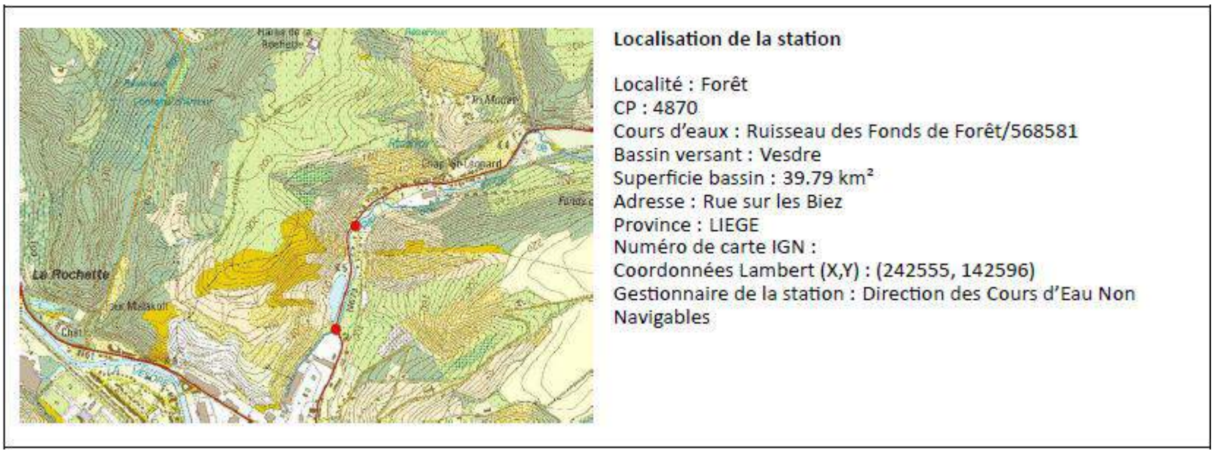

Figure 3-2: Information about station L7600 (Forest)

This gauging station has a relatively limited time series of flows. In addition, the maximum measured flow is 4.97 m³/s, which is much lower than the expected flows for the June 2018 and July 2021 events. This implies a very high level of uncertainty in the flow estimates for these floods. The graph in the following page shows the rating curve constructed and extrapolated from the gauging and the head/discharge curves simulated by the hydraulic model built in InfoWorks ICM with variable values of Manning's roughness. There is a potentially significant difference between the rating curve and the curves calculated from the hydraulic modelling for the highest flows above 10 to 15 m³/s. This leaves a significant uncertainty in the estimation of flood flows, and the data will therefore be of little use for the remainder of the project, particularly in validating the model.

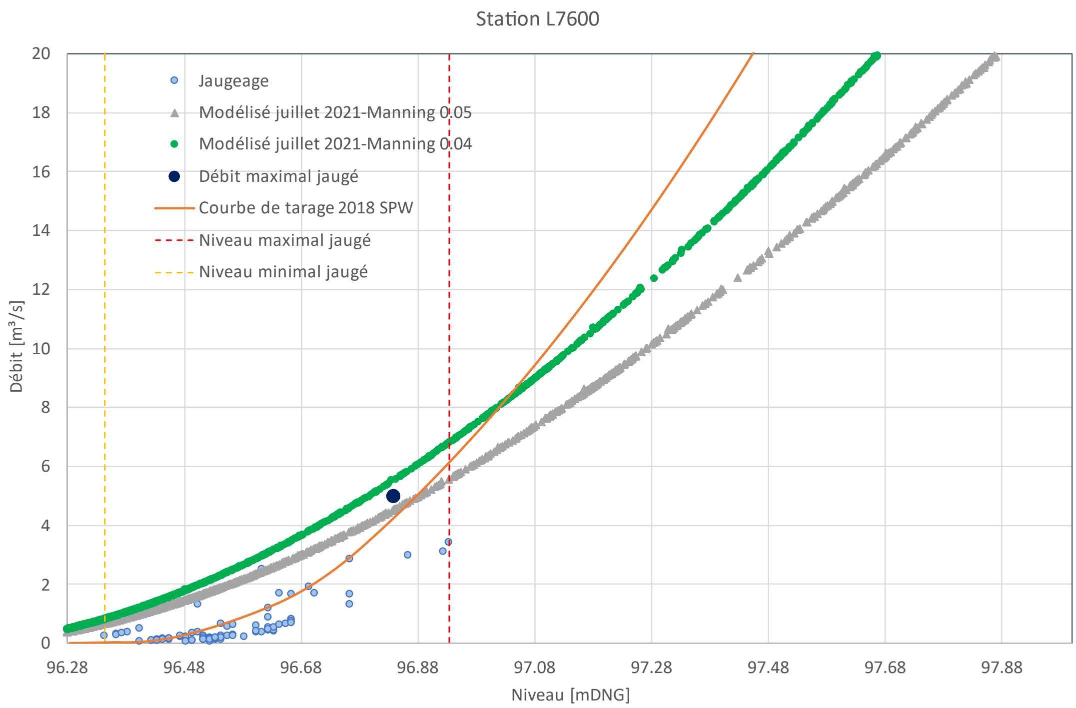

Figure 3-3: Simulated height/flow curve compared with gauging at station L7600 (Forest)

3.3.2 Rainfall data

Observed rainfall

There is little rainfall data available in or near the study area. The observed data collected comes primarily from the Battice rain gauge located in the upstream part of the study area near Herve (see location in Figure 3 1, previously included in this report). This rain gauge has hourly and 5-minute data.

Radar rainfall data for the July 2021 event were made available by the IRM. These data show that the event is particularly critical for long periods (12-48 hours). Given these durations and the relatively low intensities measured, it was above all the volumes of precipitated water that caused the river to overflow its banks. This contributed to the saturation of the soil and the significant recharging of the water table (thereby increasing runoff and flow in the river).

Figure 3-4 shows the spatial and average rainfall time series (over the catchment area) for this event. Figure 3-5 shows the estimated maximum return periods for this event over the entire catchment area (based on radar rainfall data and IRM IDF curves). They are obtained for a duration of 48 hours. The figure shows that return periods are greater than 150 or even 200 years for most of the catchment area.

Synthetic rain

The statistical data available on the IRM site for the municipality of Trooz, using Intensity-Duration-Frequency (IDF) curves, has been collected to construct design rainfall for different return periods. Projected rainfall for return periods of 2 years, 5 years, 10 years, 25 years, 50 years, 100 years, and 100 years with flow increased by 30% will be constructed in accordance with the special specifications. Data from the town of Trooz has been used because there is no significant difference with the data from municipalities further upstream (Soumagne, Herve and Olne).

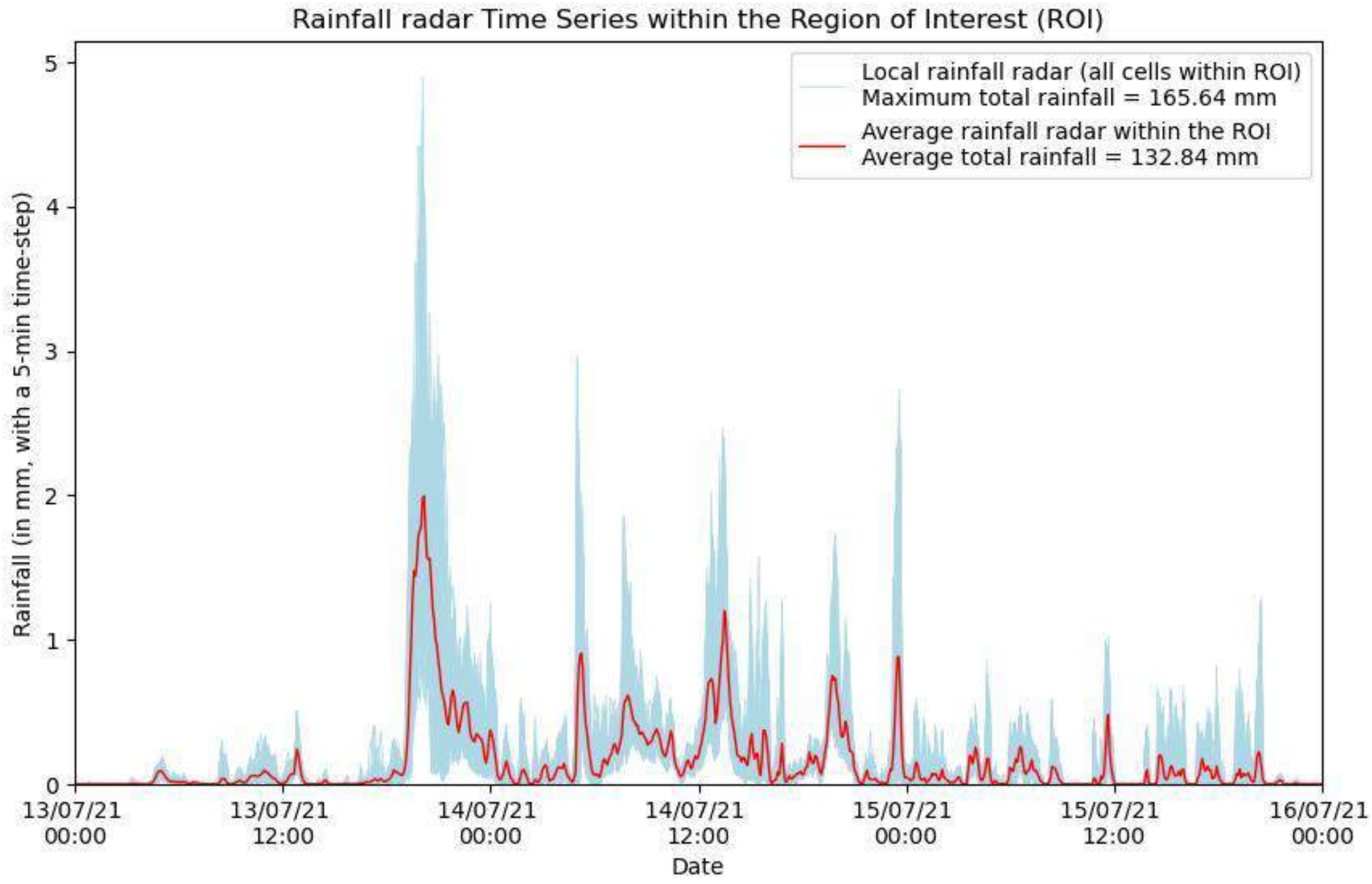

Figure 3-4 : Spatialized and average rainfall for the July 2021 event based on IRM radar data for the river Magne catchment area

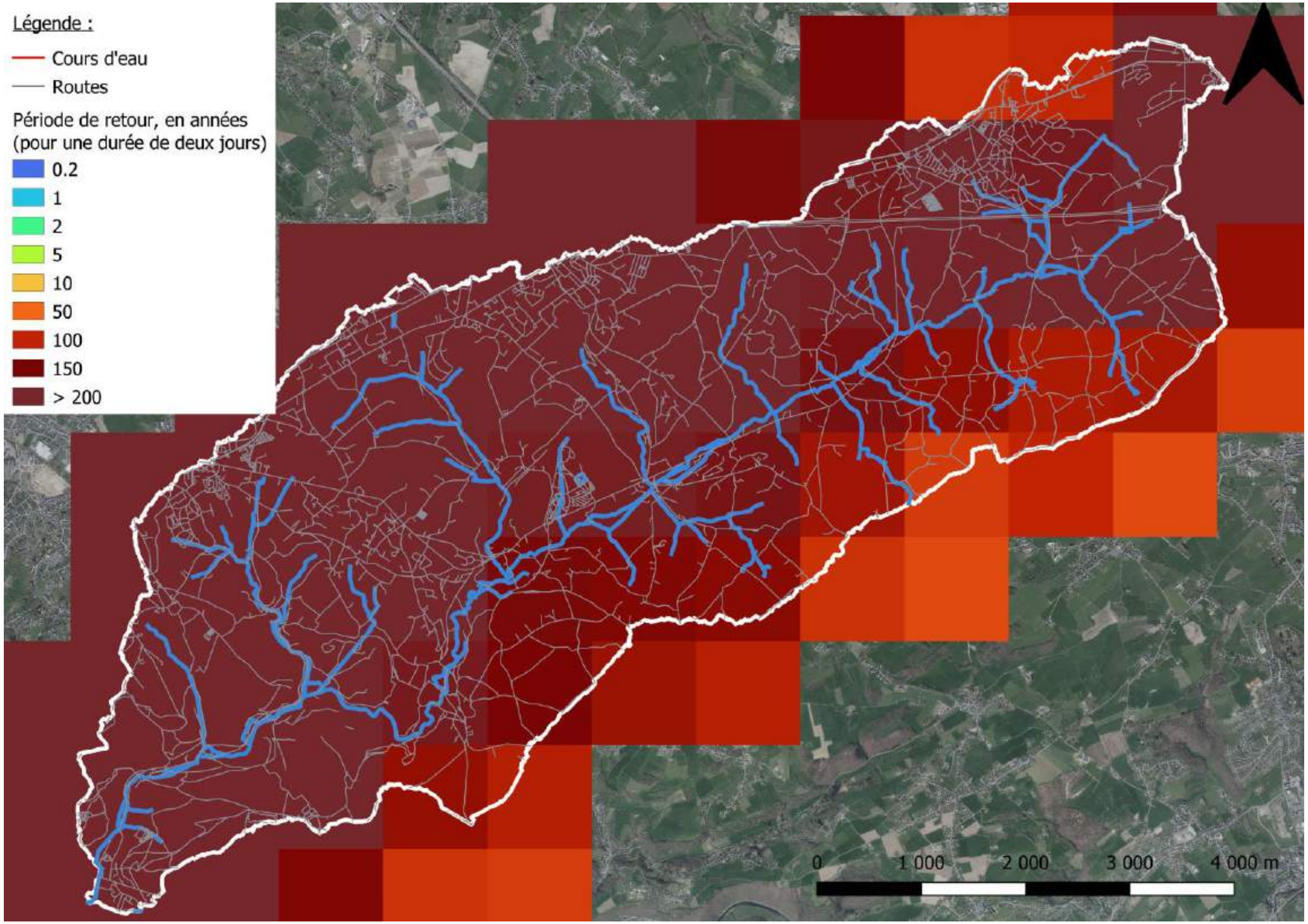

Figure 3-5 : Maximum return periods for the event of 14-15 July 2021 in the river Magne catchment area (coloured pixels). The return periods are derived from radar and statistical data from the IRM. They are presented for the most critical duration of the whole event (duration of 48 h)

3.4 Historical data

Historical information was collected at the start of the study. This information will be used to validate the model by comparing the observed and simulated flooded areas in the various critical sectors. This information mainly concerns the two extreme events of 1 June 2018 and 14-15 July 2021.

The main historical information consists of:

- Photographs and videos of historical flooding provided by the Province of Liège. This information, dating from June 2018 and July 2021, shows the extent of the flooding in the various critical sectors;
- Photographs and videos of historical flooding provided by AIDE. These data relate to the July 2021 event.
- The study and hydraulic simulations of the Soumagne and Herve models carried out by AIDE (Association Intercommunale pour le Démergement et l'Epuration des communes de la Province de Liège).
- Testimonies from local residents gathered during field visits.
- A field survey carried out by the University of Liège, showing the high-water marks along the river Magne. The water levels reached during the peak of the flood are mentioned.
- Various studies of the area indicating water levels or providing photographs of historical events (*Flood hazard study as part of an application for planning permission by the consultancy Traqua s.a*. and *Influence of the external works at the nursing home on the risk of flooding for the nursing home, the dwellings in Rue Pont Al'Plantche and Rue Baudrihaye and the meadows upstream and downstream* by the consultancy Artesia Environnement sprl).

The historical information mentioned is examined in the next chapter, which focuses on the description of the in-depth site visit carried out with the project owner.

3.5 In-depth site visit to critical locations and sectors

An initial field visit took place with the river manager at the start of the study in June 2023 in order to gain a good understanding of the situation on the ground and the context of the study. During this visit, the study area was covered from upstream to downstream, with particular attention paid to known critical areas. A 2nd field visit was carried out in August 2023 by the HydroScan teams to revisit some key areas and enable the model to be built in certain sectors. The various important elements, as well as the historical data, are listed below by municipality.

Municipality of Herve

Three areas have been identified as critical along the river Magne in the municipality of Herve:

- **The water treatment plant**. In 2021, the plain near the treatment plant was submerged by water, almost reaching the level of the plant without touching it.
- **Rue d'Elvaux**. This street, located below the town of Herve and the motorway, is a well-known area of frequent flooding. Photographs and videos are available for the events of June 2018 and July 2021. The watercourse leaves its bed at the structure upstream of rue d'Elvaux to run off the road and join the watercourse further downstream. High velocities and water heights of around 50 cm were observed for these extreme events.
- **La Fromagerie du Vieux Moulin**. A local resident reported that the maximum water level was at least 1.2 m higher than the road level. A structure located to the right of the cheese dairy is smaller than the gauge of the watercourse and could play a role in the flow in the sector.

Figure 36 shows the location of critical areas in the municipality of Herve.

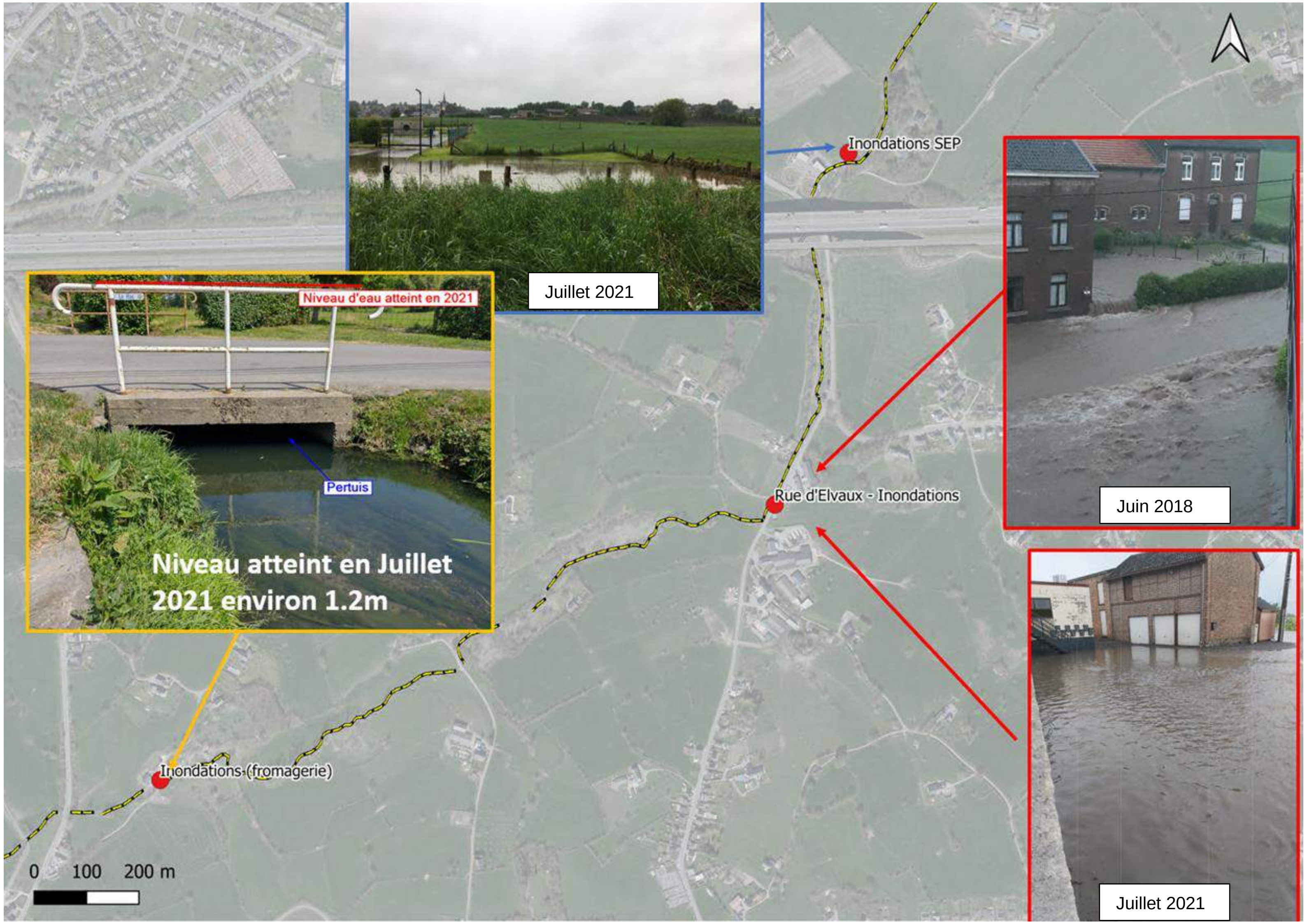

Figure 3-6 : Location of critical areas in the municipality of Herve

Municipality of Soumagne

The main points to note about the municipality of Soumagne from this site visit are as follows:

- The storm water basin upstream of Soumagne has a storage capacity of 13,000 m^3. The control structure currently consists of a variable rectangular valve with manual adjustment. We did not see any noticeable lowering of the gate during our field visits or in the photos available of this sector during flooding. The opening currently available for this gate is 1.05 m high and 3.40 m wide.
- According to the information received by the municipality, the Soumagne stormwater basin did not overflow onto the road next to it in 2021.
- In 2018 and 2021, there was flooding downstream of the structure crossing the main road (N621). A low wall was built between these two flood events, and videos show flooding caused by water rushing downstream from the low wall, flooding the garden (Giannotti plot).
- The river Magne passes through a sluice in Soumagne, the size of which varies throughout the area. The double-arched masonry channel then becomes a single channel under the road (the second channel visible downstream is in fact the result of a tributary). It should be noted that the entrance to the sluice is not directly aligned with the axis of the watercourse, and that its dimensions are smaller than the watercourse's gauge. These factors may increase the hydraulic constraints in the sector.
- The centre of Soumagne was severely affected by the extreme events of 2018 and 2021. Water levels reached more than 1 m above road level in July 2021.
- The nursing home in Rue Pont Al'Plantche in Soumagne was flooded in 2018, a few days before it was due to open. A berm was built on the banks of the river Magne to protect the nursing home. A study was carried out by the engineering firm ARTESIA to analyse the influence of external development on flooding at the nursing home. The configuration of this merlon has been modified over time, in particular as a result of the break in the dyke during the July 2021 event, which had a direct impact on the nursing home.
- The 2nd category stream Fond des Gottes is known to have caused flooding in Rue de La Longue Voie and Chaussée de Wégimont. Nearby homes have been flooded as a result of the filling in of this basin area, with significant water heights of up to 1 m inside homes. Camera inspections carried out by the team of surveyors confirmed a less-than-optimal junction between upstream and downstream.

The location of the elements described above, together with photographs of some of them, are shown in Figure 3 7.

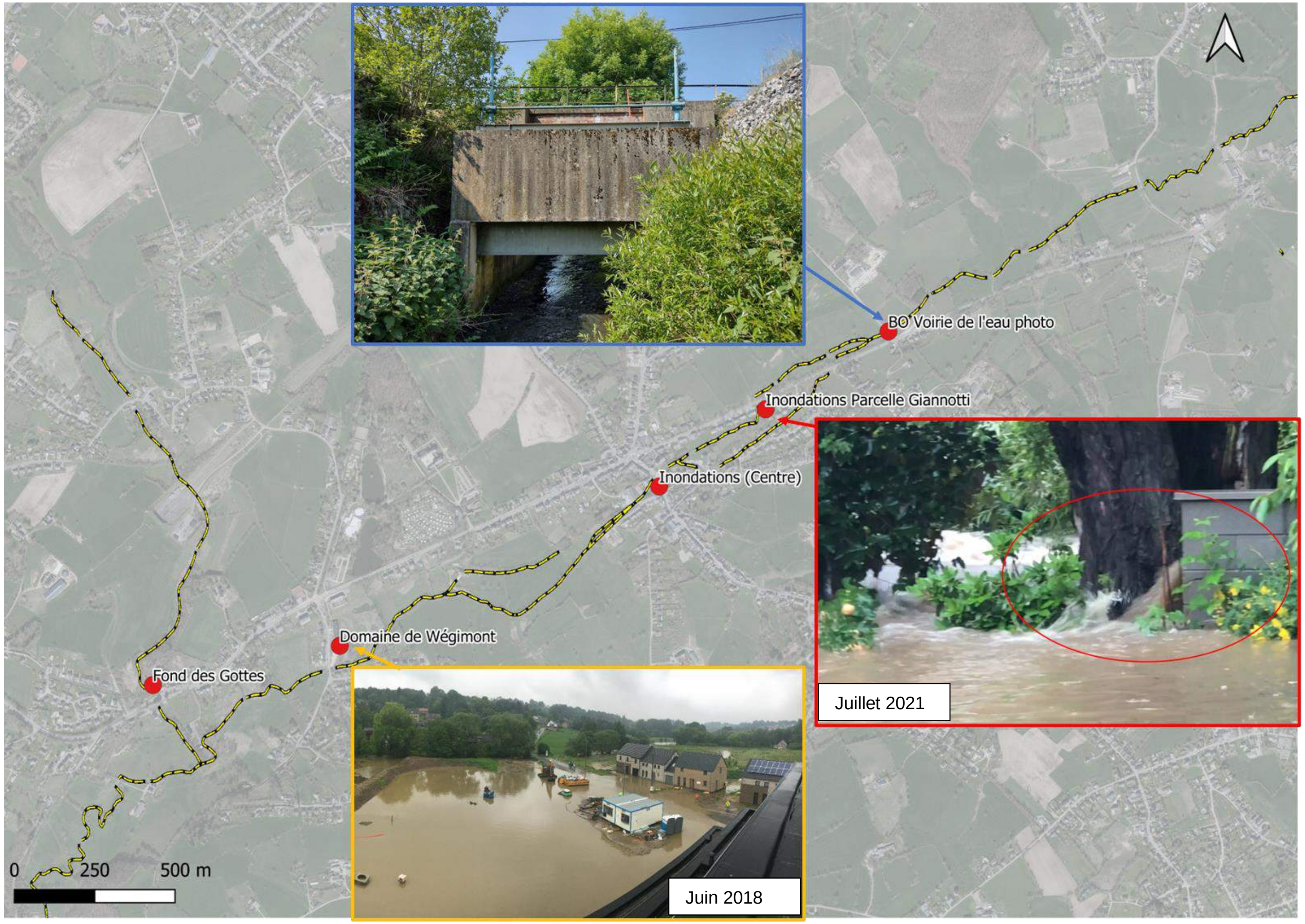

Figure 3-7: Important historical points covered during the field visit to the municipality of Soumagne.

Municipality of Olne

The field visit in August 2023 provided an opportunity to meet Mr. François Graillet, operations manager of the Bay-Bonnet S.A. quarry. He provided us with some interesting information about the flow of the river Magne and its right bank tributary. It appears that:

- The area is karstic and the river Magne disappears near the upstream end of the site. Access is very difficult and it was not possible to see where it disappears. According to the Director, part of the river Magne, although clearly visible on the DTM, is dry.
- Flows reappear further downstream of the site, but it is not known exactly how the system works.
- At the level of the 2nd category tributary (ruisseau des Carrières), the path of the water is also not well known. The flows are also taken up by an old colliery pipe that joins the river Magne (see photo below).
- The quarry is currently being excavated to a depth of 70m DNG (second general levelling). The bed of the river Magne is approximately 140 m DNG at quarry level.

  These various elements are illustrated in Figure 3 8.

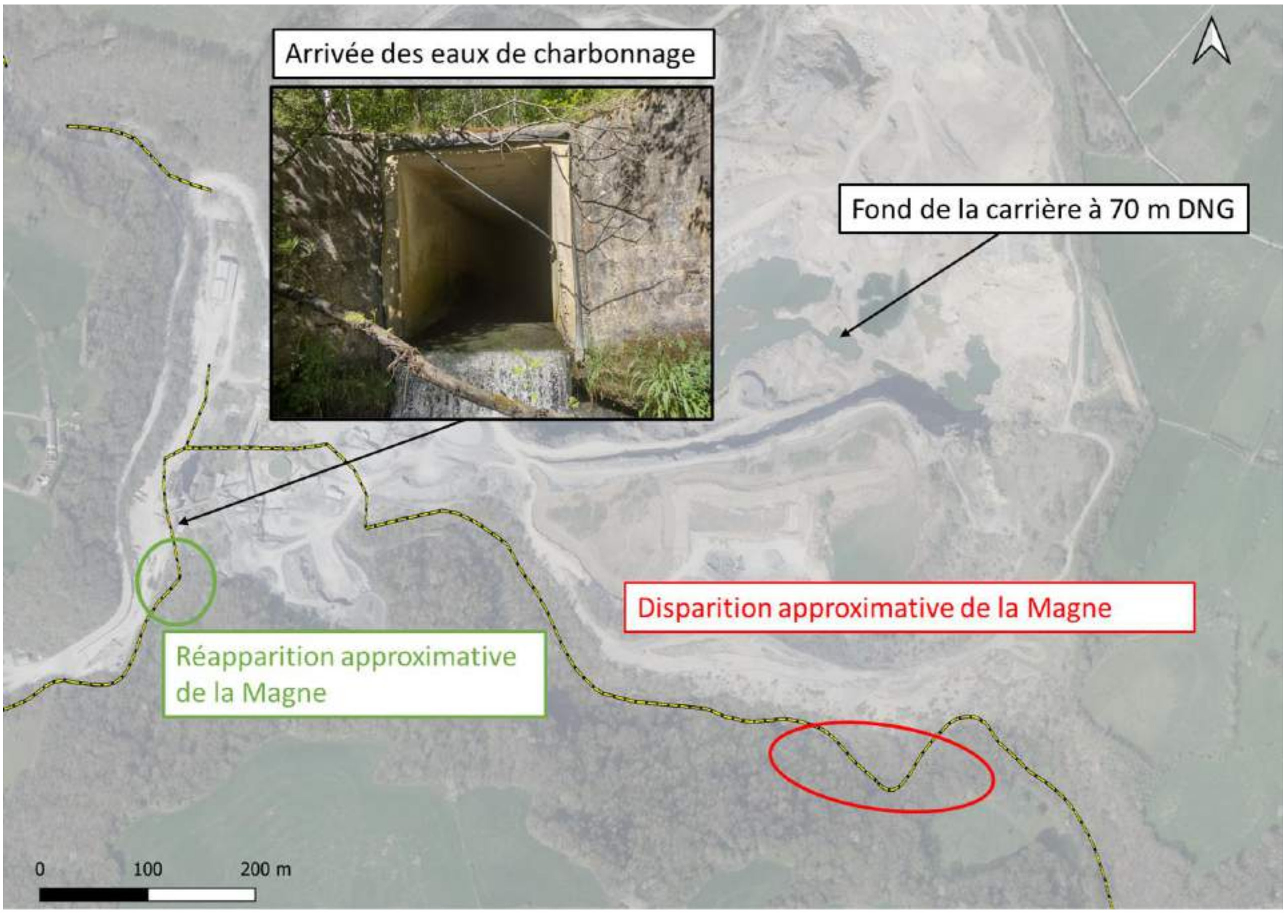

Figure 3-8: Bay Bonnet quarry.

Municipality of Trooz

The main points to note about Trooz from this site visit are as follows:

- The downstream section of the river Magne has been extensively modified, with a redesigned rectangular gauge which, due to its low roughness, certainly allows rapid transfer of flows to the river Vesdre.
- As shown in Figure 3 9, several houses were flooded along Rue Bay Bonnet and Fond de Forêt during the 2021 event. Water levels could reach up to 75 cm above the banks. A maximum level of 96.6 m DNG was estimated on the basis of flooding photos by the Traqua consultancy (a study carried out as part of an application for planning permission).
- Upstream of this sector, there is a low wall on the right bank of the watercourse to prevent the river Magne from overflowing towards the road. This wall was rebuilt over the entire section after the flood of July 2021. There are no discontinuities in the wall except at certain structures.
- The Trooz sector most affected in 2021 is located at the confluence of the Magne and Vesdre rivers. This watercourse has certainly contributed significantly to the saturation of the downstream sector near the confluence. Water levels reached more than 2.5 m in some buildings.

Figure 3-9: Location of key points covered during the field visit to Trooz

Figure 3-10 : Photo showing the low wall on the right bank of the watercourse upstream of Rue Fonds de Forêt.

4 Explanation of model development, calibration and validation

4.1 Hydrological modelling

4.1.1 Catchment areas and hydrological responses

Surface hydrology models are used to simulate the surface runoff generated for a given rainfall at the scale of a catchment. In the context of this study, 2 types of hydrological models are combined: a rural module covering the mainly rural areas of the catchment and an urban module covering the sectors where information on the underlying drainage network is available in detail (see Figure 4 1 below showing the parts of the catchment considered as rural and urban).

Runoff from rural areas using the SCS method

The available hydrologically continuous DTM is used to determine the catchment area and its sub-catchments using various GIS procedures (flow direction, flow accumulation, etc.). This division takes into account the configuration of the hydrographic network, its physiographic characteristics (land use, soil type and topography), the structuring elements (structures, roads) and the modelling objectives. Figure 4 1 shows the sub-basins delimited using DTM.

Rural runoff is estimated using the SCS-CN hydrological model, which is widely used in the Walloon region for small rural catchments. The production function of the SCS method is based on the calculation of the Curve Number (CN), which is a function of the hydrological group and land use. The transfer function associated with the SCS method is a function of the time of concentration calculated for each sub-basin. For each contributing sub-basin, a weighted average CN is calculated on the basis of land use and hydrological groups. The time of concentration for each sub-catchment is estimated using several empirical formulae: Kirpich, Passini. Ventura. A summary of the CN and time of concentration values is given in Appendix 8.3.

Runoff from urban areas using the fixed coefficient method

Urban sub-basins have been considered in those parts of the study area where an AIDE model is available. These are the urban areas in the municipalities of Herve and Soumagne. This means that the urban areas in the municipalities of Olne and Trooz are modelled using an SCS-CN module, in the absence of detailed information on the drainage network.

The AIDE sewerage model made available for the study in the InfoWorks ICM software already contains a detailed delimitation of the urban sub-basins, the representative cadastre of the sewerage network and simplified modelling of certain parts of the river Magne or some of its tributaries. Figure 4 1 shows the urban sub-basins that have been integrated in this way. It should be noted that there is no overlap between the urban and rural sub-basins so that the contributing surfaces are not taken into account twice.

The runoff from each urban sub-basin is also estimated using a combination of a hydrological model with a fixed runoff coefficient and a Wallingford transfer function (double reservoir in series), which is a function of a routing coefficient. This hydrological model is well suited to simulating the hydrological response of impervious surfaces with a rapid response time to rainfall. The different surfaces in the catchment generate different contributions depending on their type (see table below). The runoff coefficients considered according to the type of surface are shown in the table below.

Tableau 4-1 – Fixed runoff coefficient according to land use.

Type of soil	Runoff coefficient
Buildings	0.9
Roads and impermeable areas	0.9
Semi-permeable areas	0.4
Meadows/gardens/crops	0.1
Meadows suitable for urbanisation	0.1
Remote meadows	0.1

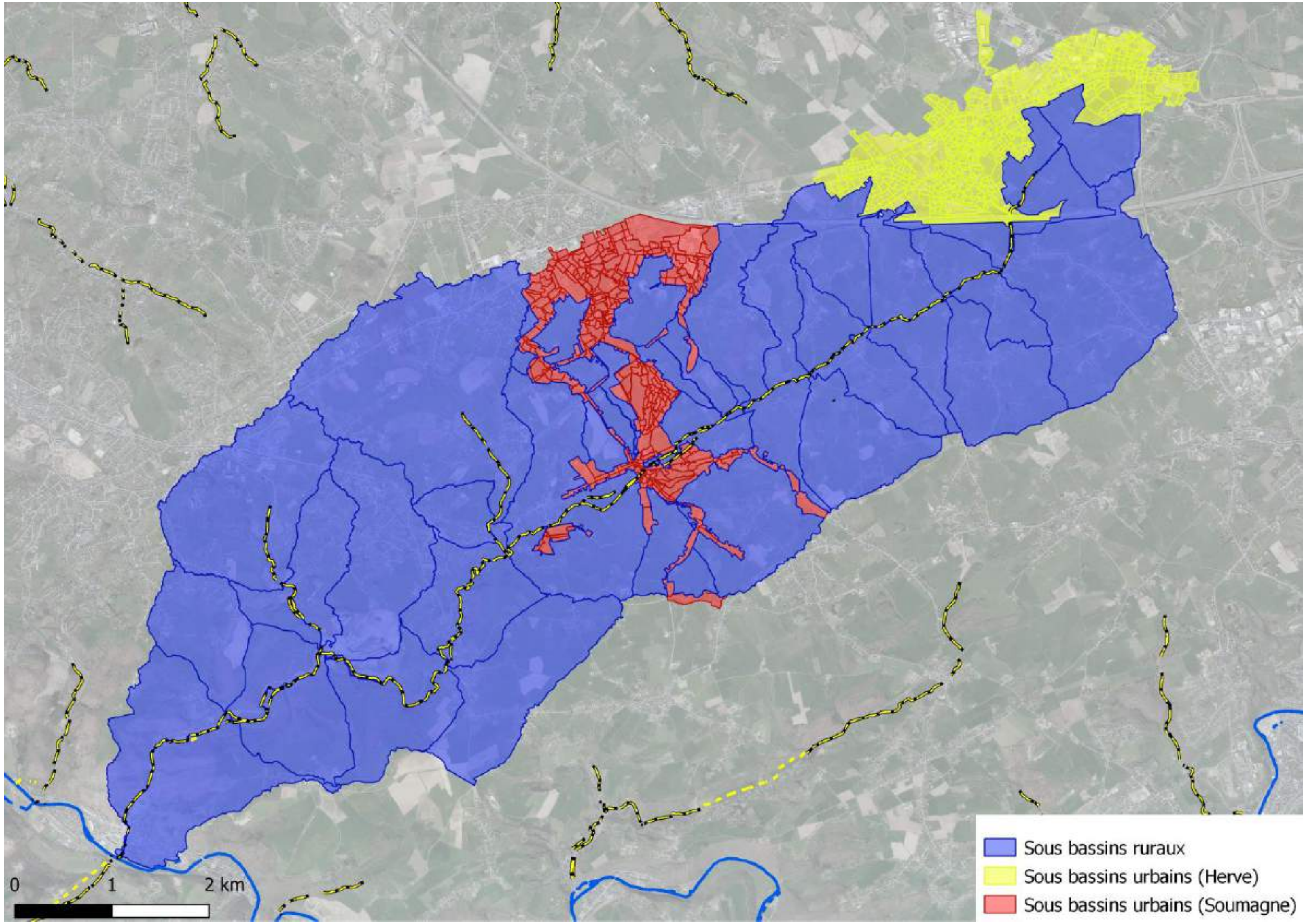

Figure 4-1: Soumagne (red) and Herve (yellow) urban sub-basins and SCS (blue) rural sub-basins for the study area.

4.1.2 Observed and synthetic rainfall as input to the model

The rainfall used in the study is observed and composite rainfall.

The observed rainfall from the Battice rain gauge and the IRM radar data were stored in the Time Series Database module of the ICM software, making it possible to use and view the time series efficiently. The observed rainfall is used to validate the model results for the June 2018 and July 2021 events.

Synthetic rainfall is used to produce maps of flooding caused by overflowing rivers for different return periods, to carry out detailed hydraulic diagnostics and to design flood reduction schemes. This rainfall is based on the statistical data available on the IRM website for the municipality of Trooz, showing the Intensity-Duration-Frequency (IDF) curves for different return periods.

The composite rainfall applied as input to the model is of the double-triangle type, making it possible to model both intense events that are more representative of summer thunderstorm events, and less intense but longer events that are more representative of winter and spring volumetric events. The return periods considered for the analysis are, in accordance with the special specifications, 5 years, 10 years, 25 years, 50 years and 100 years (see example in Figure 4 2) for a duration of 12 hours. The extreme scenario associated with a return period of 100 +30% is obtained on the basis of hydrographs generated downstream of each sub-basin with simulation for a rainfall return period of 100 years, multiplied by 1.3. These are then injected into the hydrographic network.

Composite rainfall is applied uniformly to all sub-catchments in the model. This assumption therefore does not take into account an abatement coefficient that could account for the non-simultaneity of rainfall over the entire catchment. Applying rainfall uniformly over the contributing catchment of this size is nevertheless reasonable, given the surface area involved, but is also intended to be safe.

This is a safe approach, as it is rare for an extreme rainfall event to apply with the same level of intensity across an entire catchment of this size. In this respect, the July 2021 event is an exception. For this type of event (extreme and with a very large spatial coverage), the return period of the rainfall is generally lower than that observed for the flow. In other words, for such events and watershed sizes, the response in terms of flow is even more extreme/exceptional than that of rainfall.

Thus, it is expected that with the chosen methodology, the application of a composite rainfall with a given return period will generate a flow (and flooding areas) with a higher return period. This suggests that, working with such an approach, the sizing of structures and facilities planned for the future situation will be safe in terms of protection objectives.

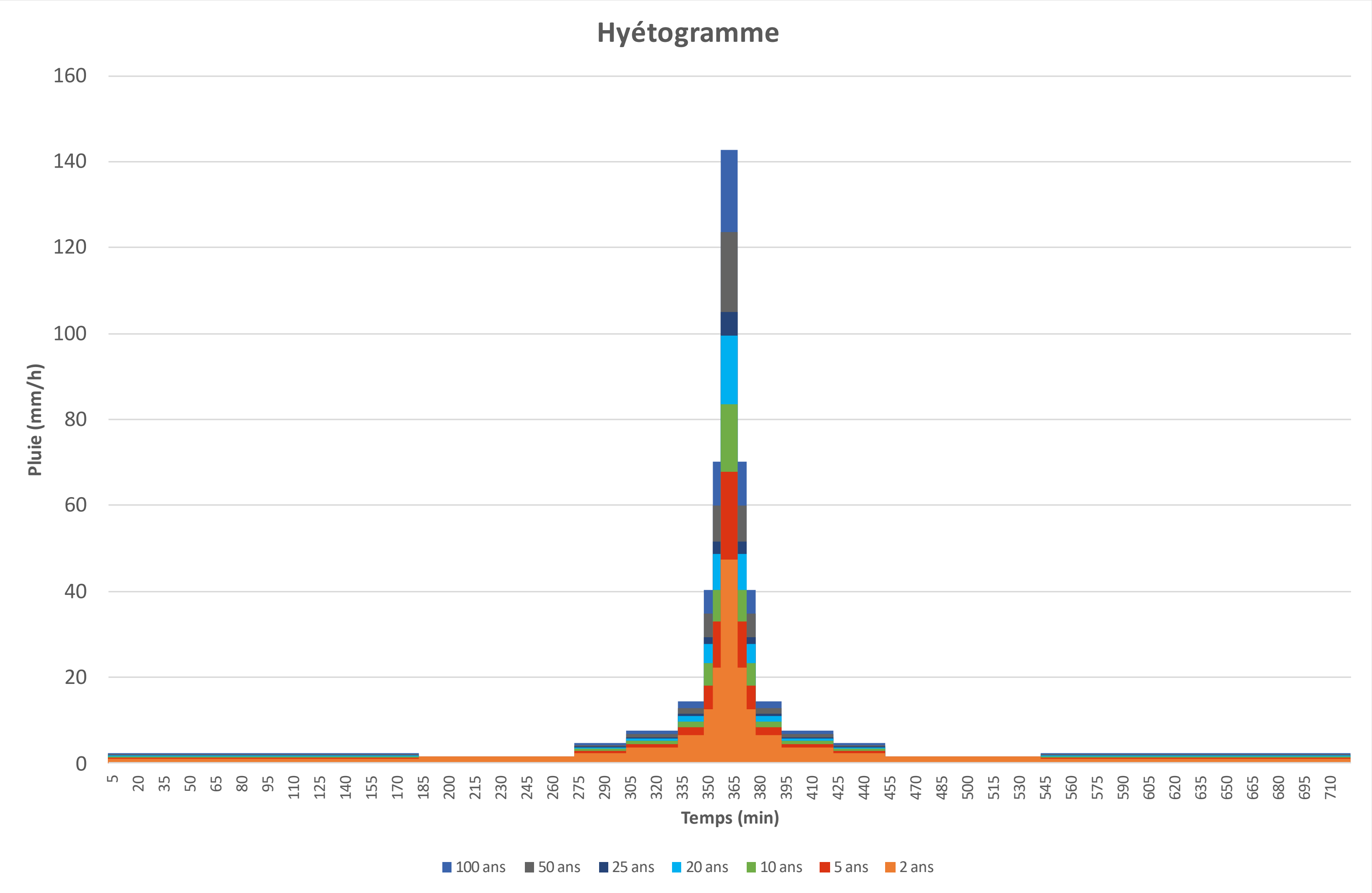

Figure 4-2: Composite rainfall of the double triangle type applied as input to the model, based on the IDF for the municipality of Trooz.

4.2 Hydraulic modelling

The creation of the hydraulic model is more or less detailed depending on the sector:

- On S-type sections, the 1D model only partially integrates the presence of structures. The simplified 1D model was coupled with a 2D zone, allowing the river to overflow into the major bed. This enables the hydraulic routing of sub-basins down to the sections that need to be accurately modelled.
- On the S+S sections, mainly near the Bay Bonnet quarry, the model is essentially built in 1D, due to the topography involved (very steep valley) and the lack of information available on this section. Modelling this section gives a good representation of the configuration and transfer of flows from upstream to downstream in this area.
- For the D sections, the model is built in 1D/2D (one-dimensional flow in the minor bed and two-dimensional flow once the river has overflowed). This section includes structures. The aim is to model the hydraulic functioning of the area in detail. The coupled 1D/2D approach enables a detailed characterization of the flood hazard at any point in the flooded zones

4.2.1 1D modeling in the minor bed

Construction of the 1D part relating to the watercourse's minor bed: this takes into account the hydraulic capacity of the watercourse via cross-sections measured at regular intervals, and the capacity of the structures by integrating the characteristics of each structure (size, shape, etc.) into the model. The main stages in the construction of 1D sections are:

- **Import and parameterization of cross-sections** surveyed by surveyors:
  o Verification of cross-sections that have been extended or recut, depending on terrain, presence of low walls, etc.
  o Definition of roughness. Given the global nature of the study area, an average Manning's coefficient value of 0.05 is assumed. However, in meandering and non-straight sections of the river, a higher value of 0.06 was applied to take account of the effect of these features on flow. In urbanized areas where there are significant modifications to the cross-section of the watercourse, a value of 0.04 was used to represent a lower roughness.
- **Integration of structures**:
  o Hydraulically relevant engineering structures, i.e. those with a hydraulic influence on flows, are integrated into the model according to their respective configuration (gates, weirs, footbridges, bridges, etc.). Modelling is carried out on the basis of structure data sheets and site visits.
  o Generally speaking, bridge crossings and openings are modelled in the form of a pipe, the shape of which depends on the structure (rectangular or vaulted). For rectangular bridges and culverts, the limiting passage area of each structure is estimated on the basis of topographic surveys and then transformed into an equivalent area. The invert levels are determined on the basis of the equivalent height and the upstream and downstream invert levels. If necessary, an inline bank link is used to take account of flows over the deck.
  o Hydraulic coefficients for structures are defined in a standard way for the study area, but can be adjusted according to observed conditions or particular configurations.

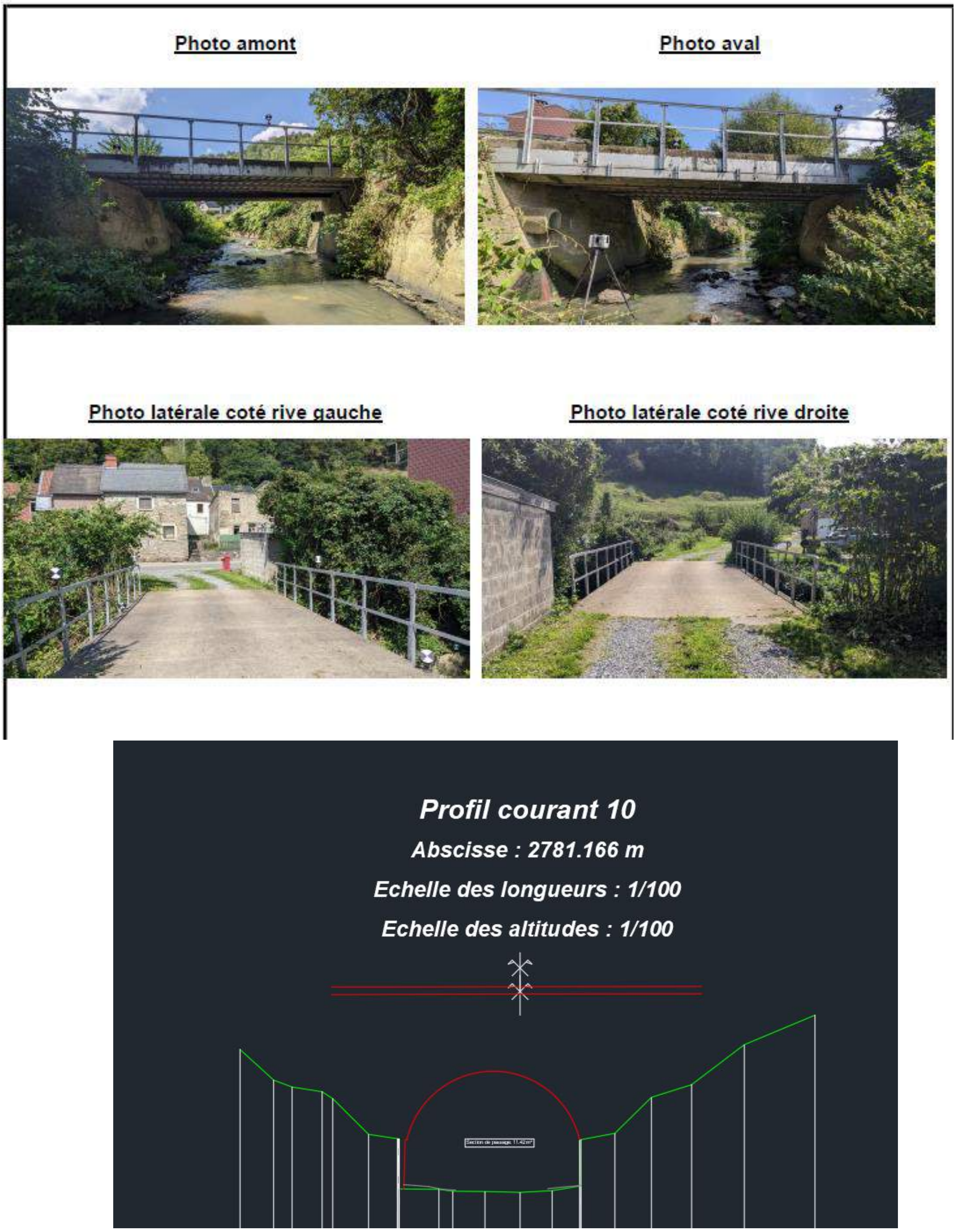

Figure 4-3 - Detailed work sheet for modelling hydraulic structures on the watercourse.

4.2.2 2D modelling in the major bed

The major river bed is modelled using a two-dimensional mesh. The 2D zone is constructed on the basis of the topography of the terrain, the information for which is contained in the 0.5*0.5 m DTM. The mesh is refined by integrating certain buildings, low walls, roads and variable roughness depending on the zone (roads and parking lots, meadows and areas with vegetation). The boundary condition for zone 2D consists of a normal condition.

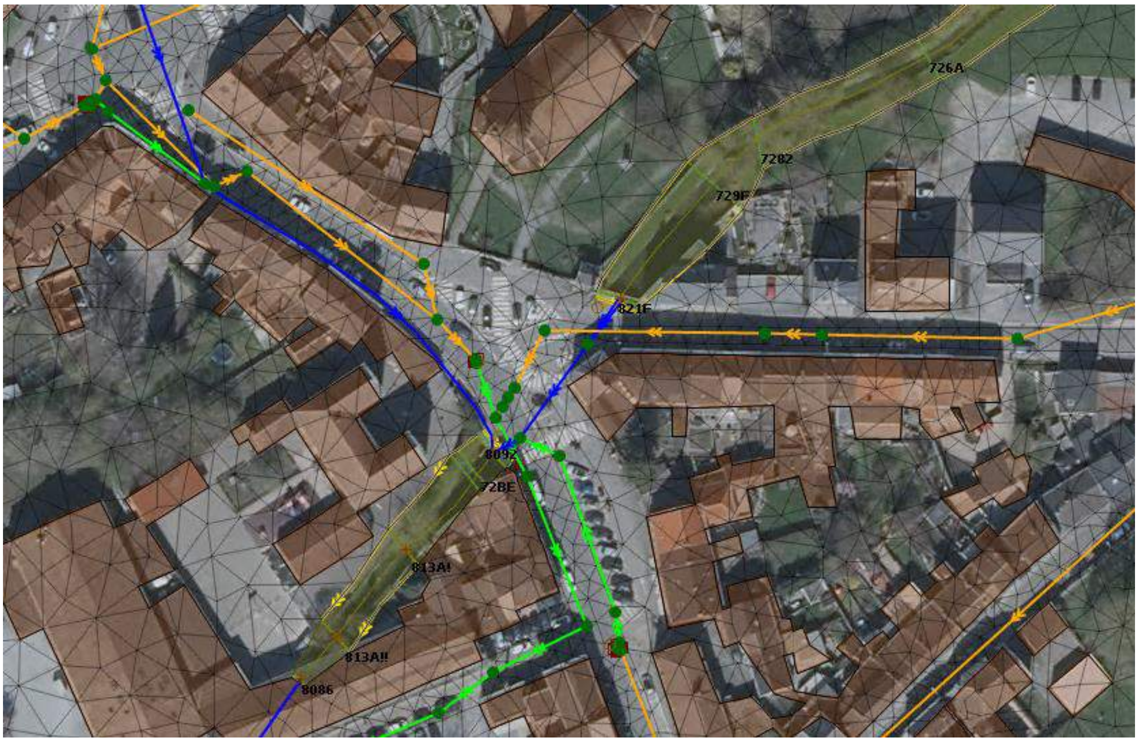

Figure 4-4- Illustration of the integration of the buildings in Soumagne into the major riverbed.

4.2.3 Point specific to the modelling of the river Magne near the quarry

There are many uncertainties concerning the watercourse in the area near the quarry, due to the historical context (coal mining, quarrying) and the geological context (karstic zone) specific to this area. The valley is very steep in this section of the river, which means that it is essentially a transfer zone. The river Magne disappears and reappears here, but the working of the system are complex and poorly understood. What's more, the Ruisseau des Carrières tributary flows through an old coal-mining pipe to emerge on the open surface. All these factors led us to put forward certain modelling hypotheses for this sector:

- It is assumed that the river Magne disappears near the quarry and gradually reappears further downstream, depending on resurgences. Without further information on the karstic system, the transfer of water from upstream to downstream is ensured via a 1D (conceptual) link. It is therefore assumed that all flows can pass from upstream to downstream in the area without any limitation of hydraulic capacity.
- The Ruisseau des Carrières tributary is connected to a 2 m*2 m pipe, representing the former coal-mining line. In view of the slopes involved and the uncertainties regarding water transfer in this sector, it is also assumed that all flows join the river Magne via this pipe.

4.2.4 Coupling the AIDE drainage model to the river Magne model

For the parts of the study area where the AIDE hydraulic model exists, in Soumagne and Herve, the hydraulic sewage model containing the sewage network and some tributaries of the river Magne is coupled to the river Magne model. This is one of the advantages of ICM software, which enables all systems to be integrated into a single model. Coupling involves connecting existing outfalls to the drainage model via breaknode link nodes. The current 1D/2D AIDE model has also been converted back to 1D on the upstream sections, as the focus of the present study is on the Magne watercourse, and the main interest of this model lies in the proper reproduction of the inflows to the watercourse and the integration of key hydraulic information, such as the tributaries under the Soumagne sluice.

4.2.5 Integration of a section of the river Vesdre in Trooz

At the time the study was carried out, there were no recent topographical data for the Vesdre at the confluence with the river Magne. In addition, the flood of July 2021 significantly modified the gauge and level of the river Vesdre in this sector. However, in order to partially reproduce the effect of the overflow of the river Vesdre on its tributary for the July 2021 event, we were able to use old topographic data of the river Magne minor bed dating from 1960 and supplied by the SPW-DCENN. Based on these cross-sections, the river Vesdre minor bed is constructed in a sector between upstream and downstream of the confluence with the river Magne. The minor bed modelled in 1D is coupled to the 2D zone to allow partial reproduction of the effect of the river Vesdre on its tributary. This does not, however, constitute a detailed model of the river Vesdre in this sector, given the data used above.

Figure 4-5- Integration of a section of the river Vesdre in Trooz.

4.2.6 Boundary conditions

Upstream boundary conditions

For each simulation, the upstream boundary condition of the hydrological model is made up of an observed or synthetic hyetogram injected into the model input:

- The rainfall observed is for the events of 14 July 2021 and 1 June 2018. For the rainfall of July 2021, this is the radar rainfall data from the IRM, which offers significant added value for integrating the spatialization of the rainfall. For the rainfall of 1 June 2018, the Battice rain gauge data is applied uniformly over the catchment area, which is a strong assumption regarding the spatialization of the rainfall over the event. Unfortunately, there is not enough rainfall data in and near the study area to provide a better hypothesis for rainfall repair in this catchment for this event;
- Composite (or synthetic) rainfall is rainfall of the double-triangle type, making it possible to model both intense events that are more representative of summer storm events and events that are not very intense but long, more representative of winter and spring volume events. The return periods considered for the analysis are 2 years, 5 years, 25 years, 50 years and 100 years for a duration of 12 hours.

Based on the simulations, the upstream boundary condition of the hydraulic model for the section of the river Vesdre considered is:

- Observed hydrographs of the river Vesdre at the Chaudfontaine gauging station (L6228) for the events of June 2018 and July 2021. The hydrograph is shifted by (-)35 min to consider the transfer of the latter between the confluence with the river Magne and the Chaudfontaine station;
- For the synthetic simulations, a base flow of 7.5 m³/s is considered. This flow is derived from limnometric data from the Chaudfontaine station (L6228).

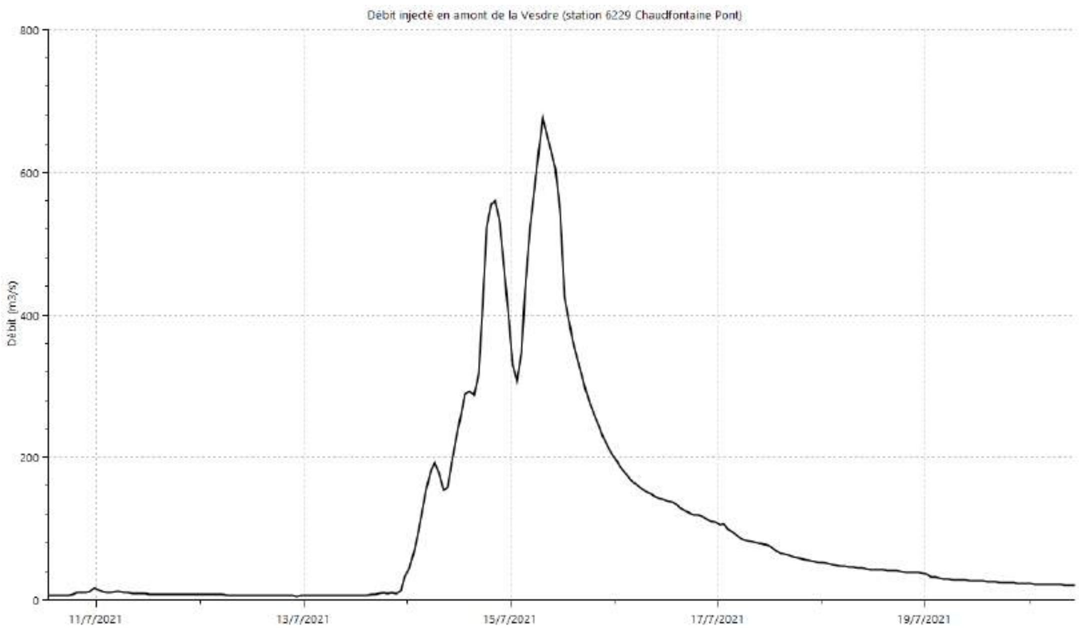

Figure 4-6 : Flood hydrograph observed at station 6229 for the event of July 2021

Downstream boundary conditions

The downstream boundary conditions are the conditions to be applied downstream of the hydraulic model (1D and 2D).

The downstream boundary condition applied to the 1D model is a normal condition applied to the last section of the hydraulic model. This condition is applied to the river Vesdre reach several hundred metres after the confluence with the river Magne.

The boundary condition for the 2D zone is also a normal condition.

4.3 Calibration and validation of the combined 1D/2D model of the existing condition

The model must be calibrated and validated to ensure that the results are representative. Calibration essentially involves modifying the parameters of the hydrological model (CN, time of concentration) and the hydraulic model (roughness parameters, head loss coefficients) in order to reduce the difference between simulations and observations.

Comparisons between observed and simulated flooded areas are made at the most critical time in the simulation, corresponding to the maximum flood extent, for the events of July 2021 and June 2018. With regard to the latter, only the municipality of Herve will be validated, due to its proximity to the Battice rainfall station used. The results for the other areas are considered uncertain due to the lack of representative rainfall data for the rest of the catchment. They are therefore not taken into account in the validation.

The study area was divided into several critical zones (Figure 4 7), defined from upstream to downstream for each municipality. The following paragraphs present the results of this analysis.

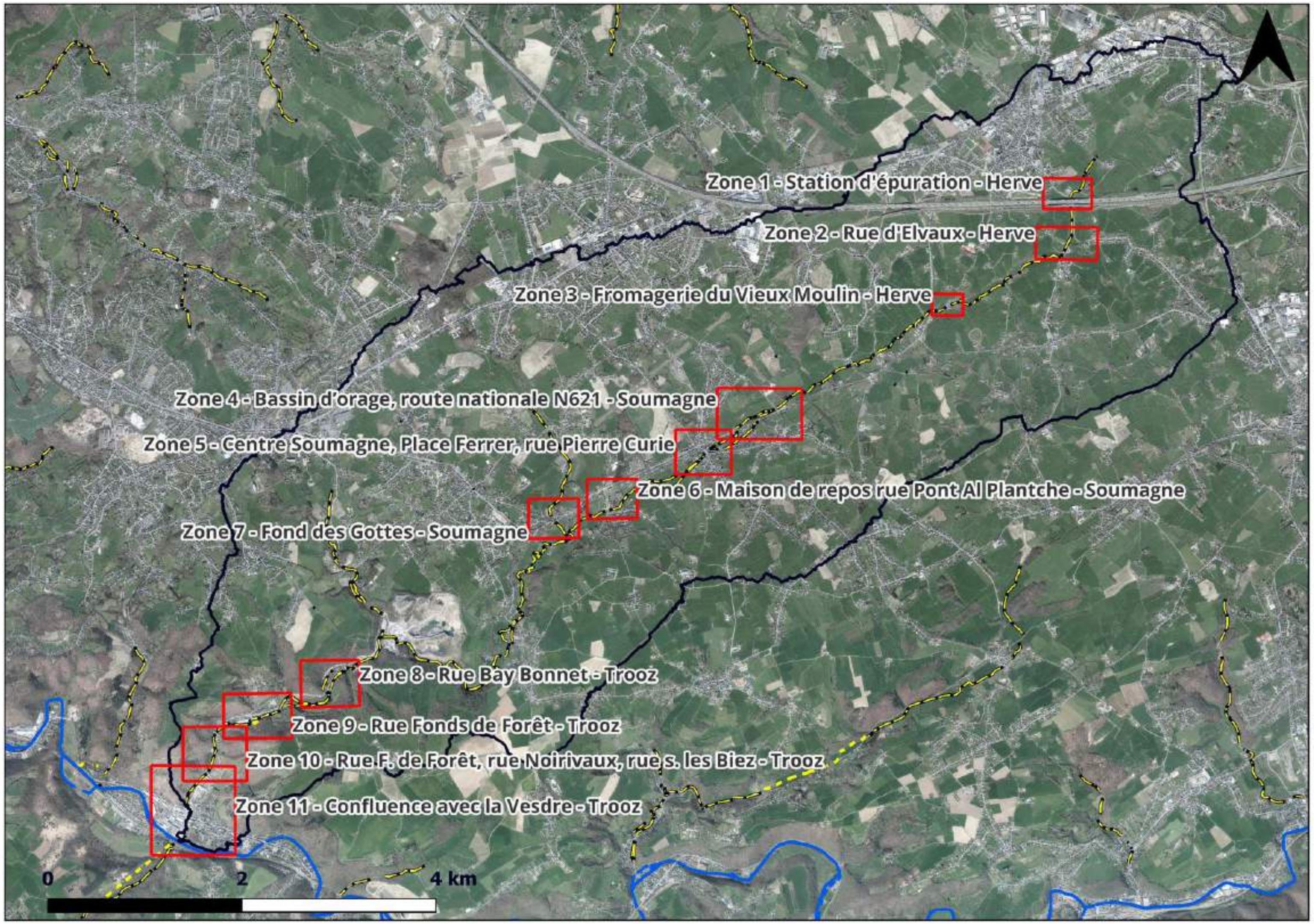

Figure 4-7 : Overall map of the various sensitive areas in the river Magne catchment area

4.3.1 Herve

Zone 01 - Water treatment plant

The model reproduces well the flooding observed in this area. Figure 4 8 shows that the overflows occur on the right bank upstream of the structure and reach the entrance barrier of the treatment plant, which corresponds to the photos available for this event and to the testimonies gathered during the field visit. The observed level is around 30 cm, while the simulated level is slightly lower, by around 20 cm.

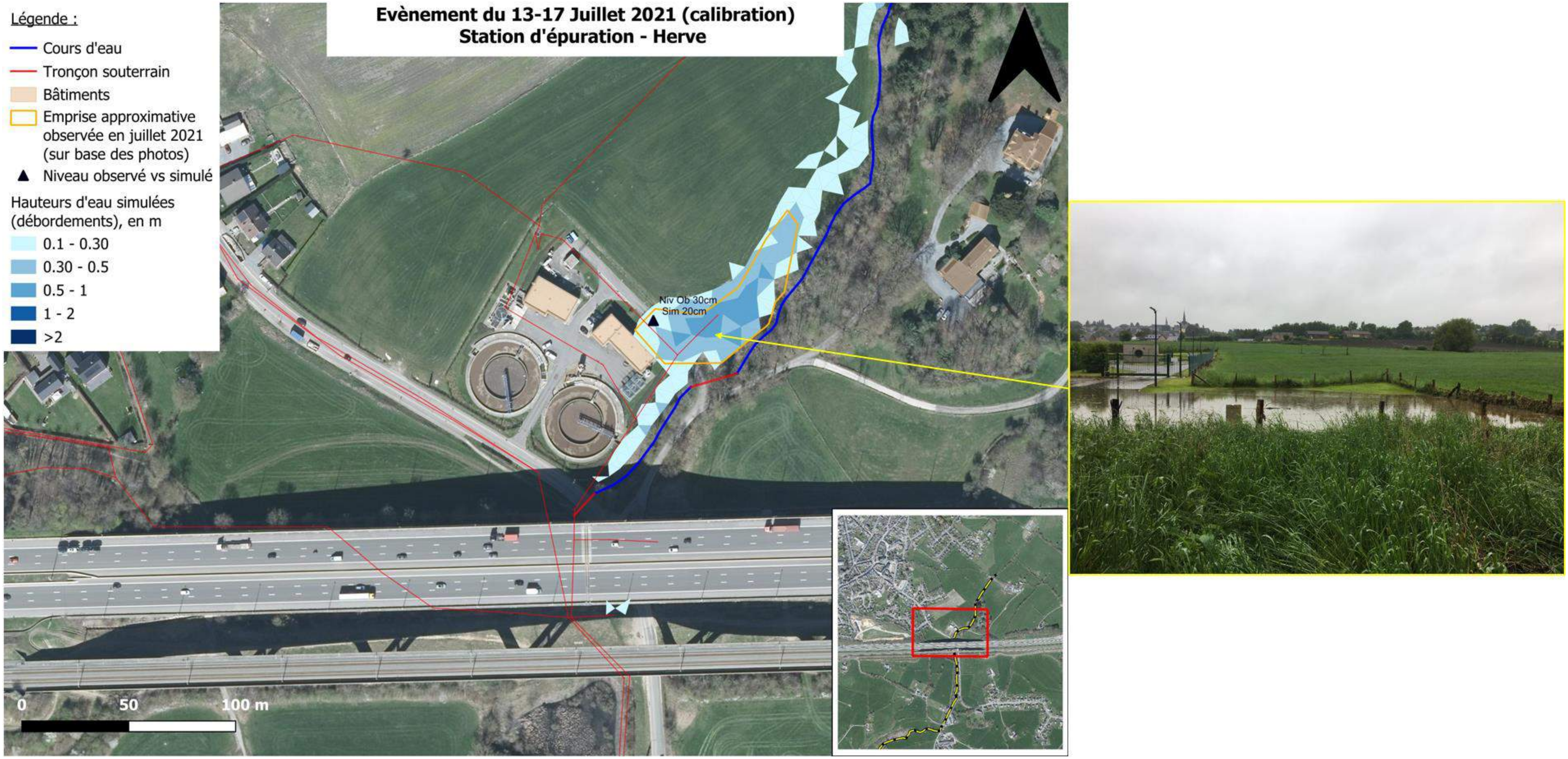

Figure 4-8 : Results of 1D-2D modelling at the most critical time of the simulation for the July 2021 event at the Herve wastewater treatment plant.

Zone 02 – Rue d’Elvaux

As shown in Figure 4 9, the model reproduces relatively accurately the overflows observed along Rue d'Elvaux. The overflows occur upstream of the structure that crosses the street, and propagate towards the houses located further downstream, in particular by passing over the road. The floods reached the houses in Rue d'Elvaux at a relatively high speed (as reported), estimated at around 1.5 m/s by the model (visible in the videos available in the appendix). The water level observed near the affected houses is around 50 cm, while the simulated level is slightly lower, at around 30 cm.

For the June 2018 event, the model simulates even more significant overflows, which seems to correspond well with the observations (see Figure 4 10).

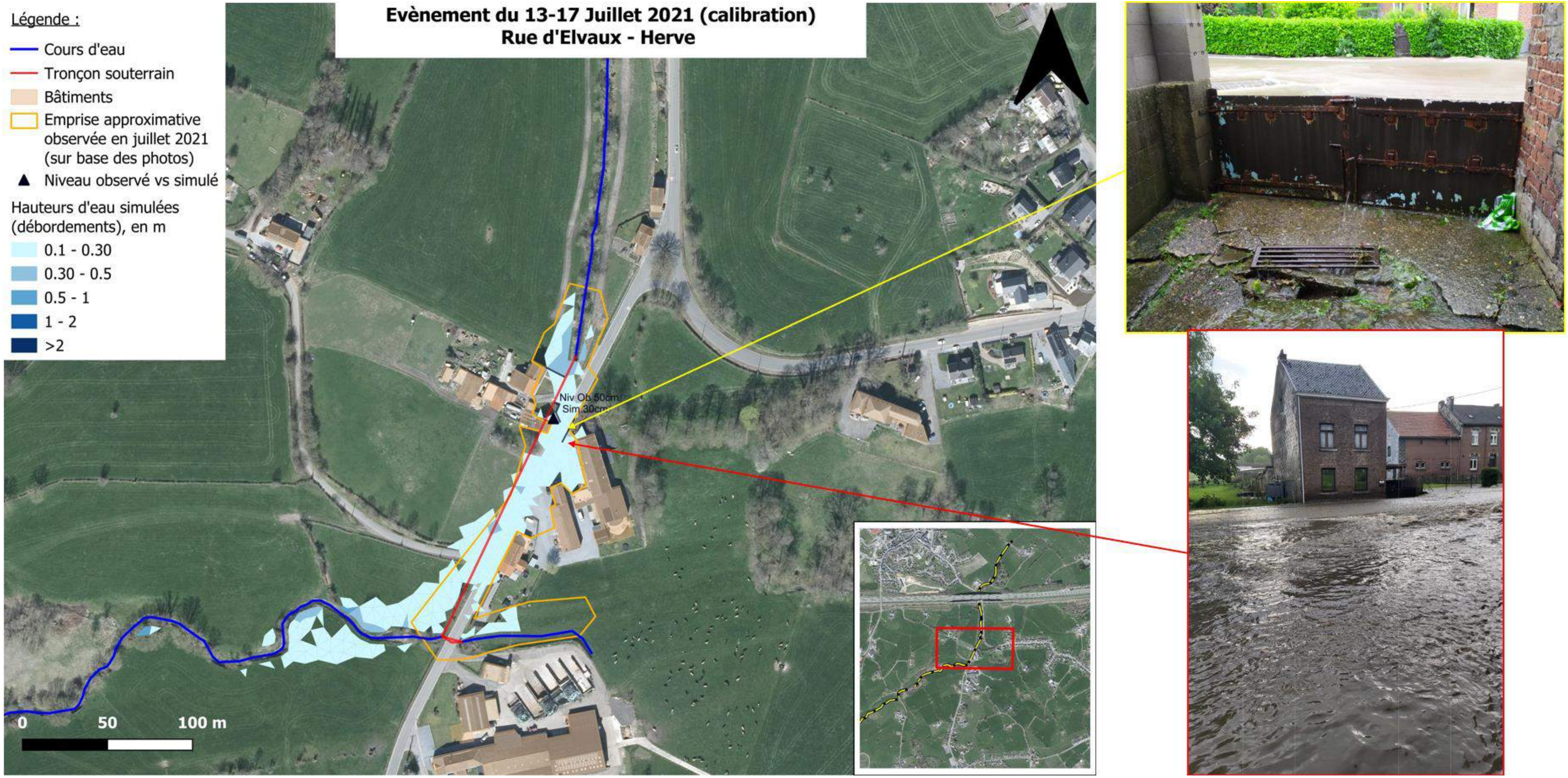

Figure 4-9 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at the level of rue d'Elvaux in Herve.

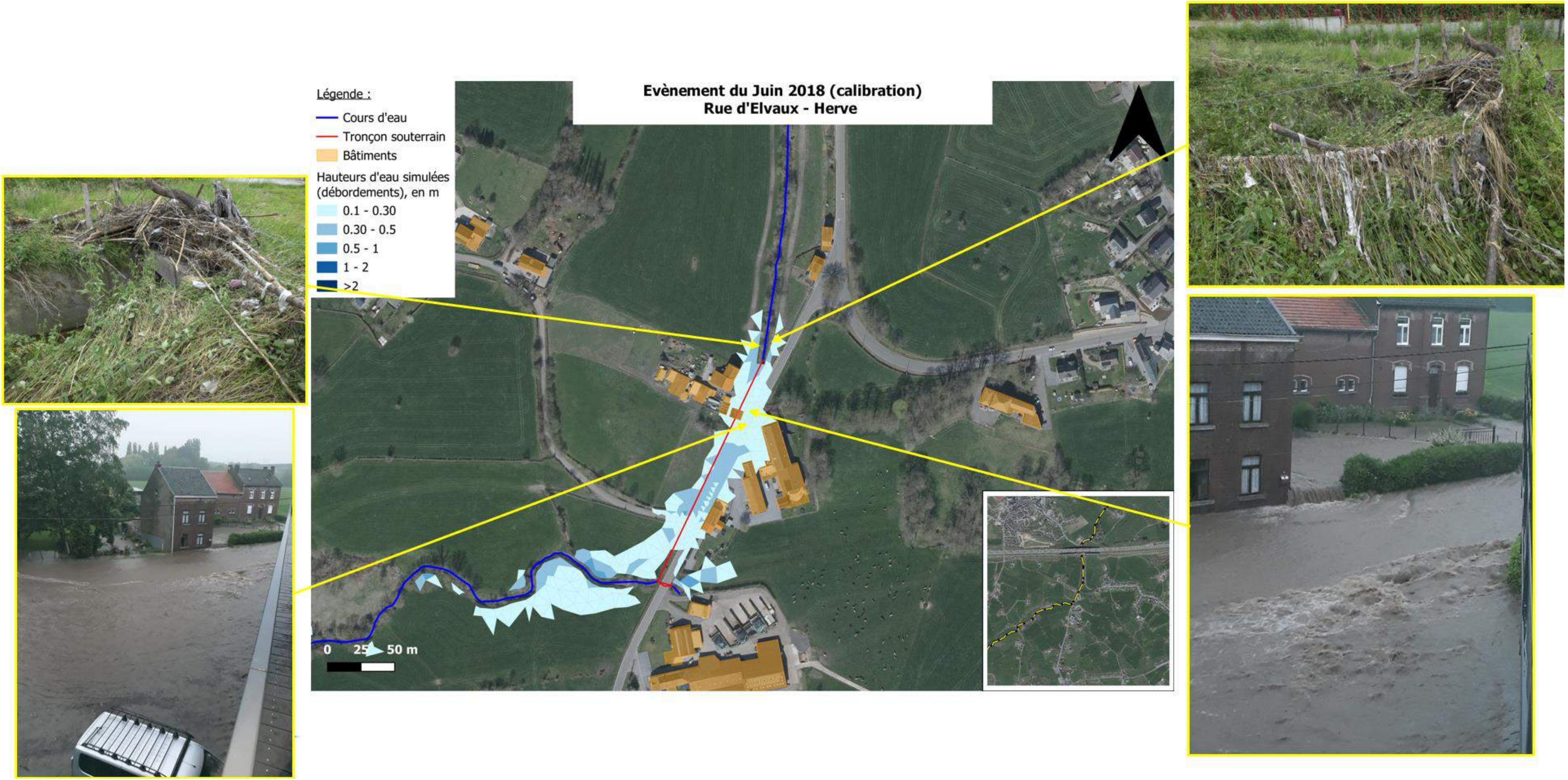

Figure 4-10 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at the level of rue d'Elvaux in Herve.

Zone 03 – Fromagerie du Vieux Moulin

In this critical zone, the model reproduces satisfactorily the overflows that occurred during the July 2021 event. The simulated water level (1.2 m) is close to that observed according to the testimonies gathered. The simulated flood extent is particularly large and could be caused by a number of factors: the configuration of the watercourse (relatively low banks), that of the structure (smaller than the watercourse gauge), and the downstream effect generated by the structure (limiting the flow) crossing the N621 national road.

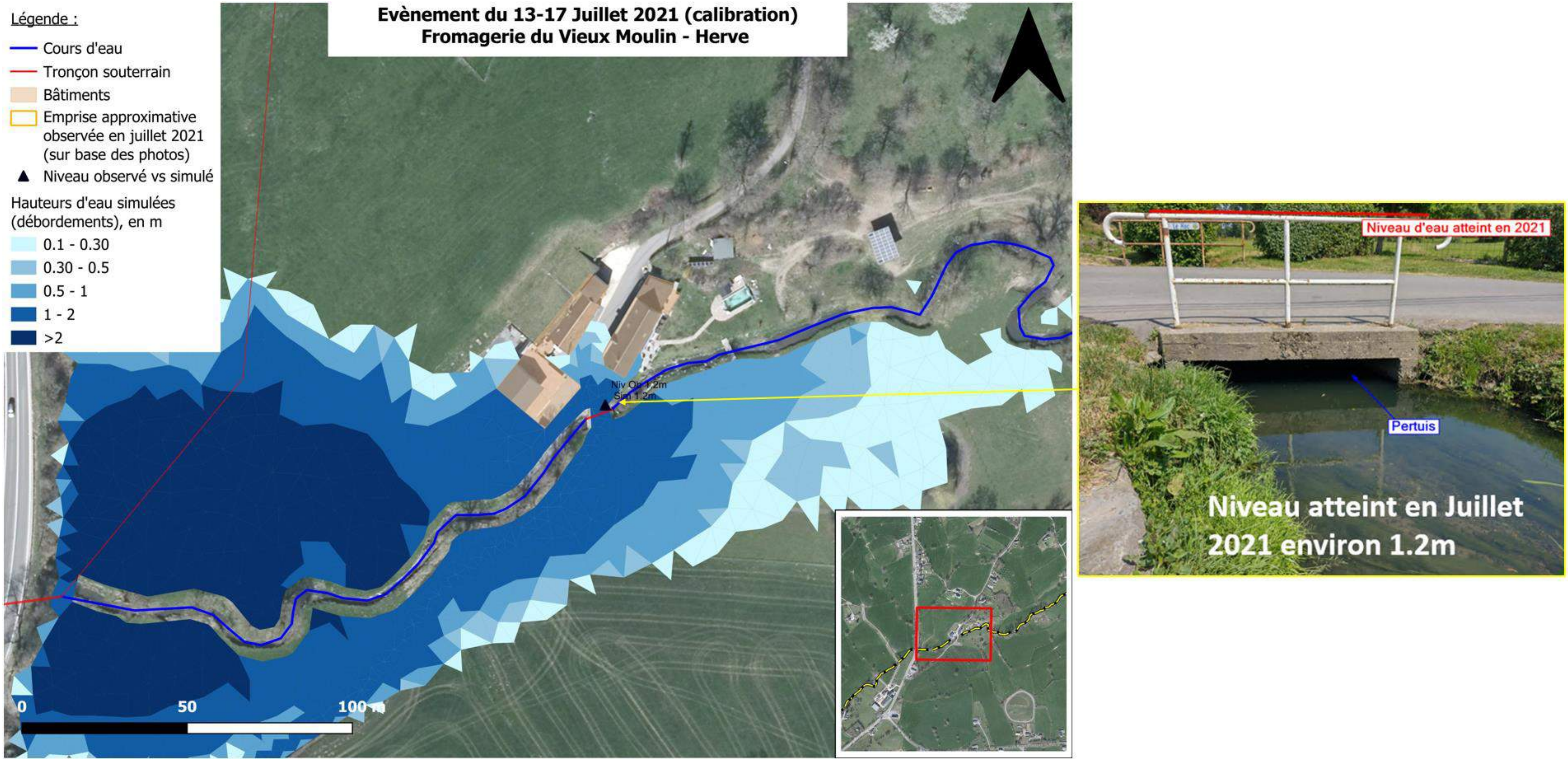

Figure 4-11 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at the Vieux Moulin cheese dairy in Herve.

4.3.2 Soumagne

Zone 04 – Storm water basin, route nationale N621

At the entrance to Soumagne (Figure 4 12), the model simulates overflows upstream and downstream of the structure that crosses the N621 trunk road, but none on the latter, which corresponds to the observations made. The simulated overflows downstream of the structure also seem to reproduce the observations well (in particular the water level reaching the low wall installed on the edge of a garden). With regard to the storm water basin, the testimonies indicate that the basin did not overflow onto the road in July 2021, and the model does not reproduce any overflow onto the road for this event.

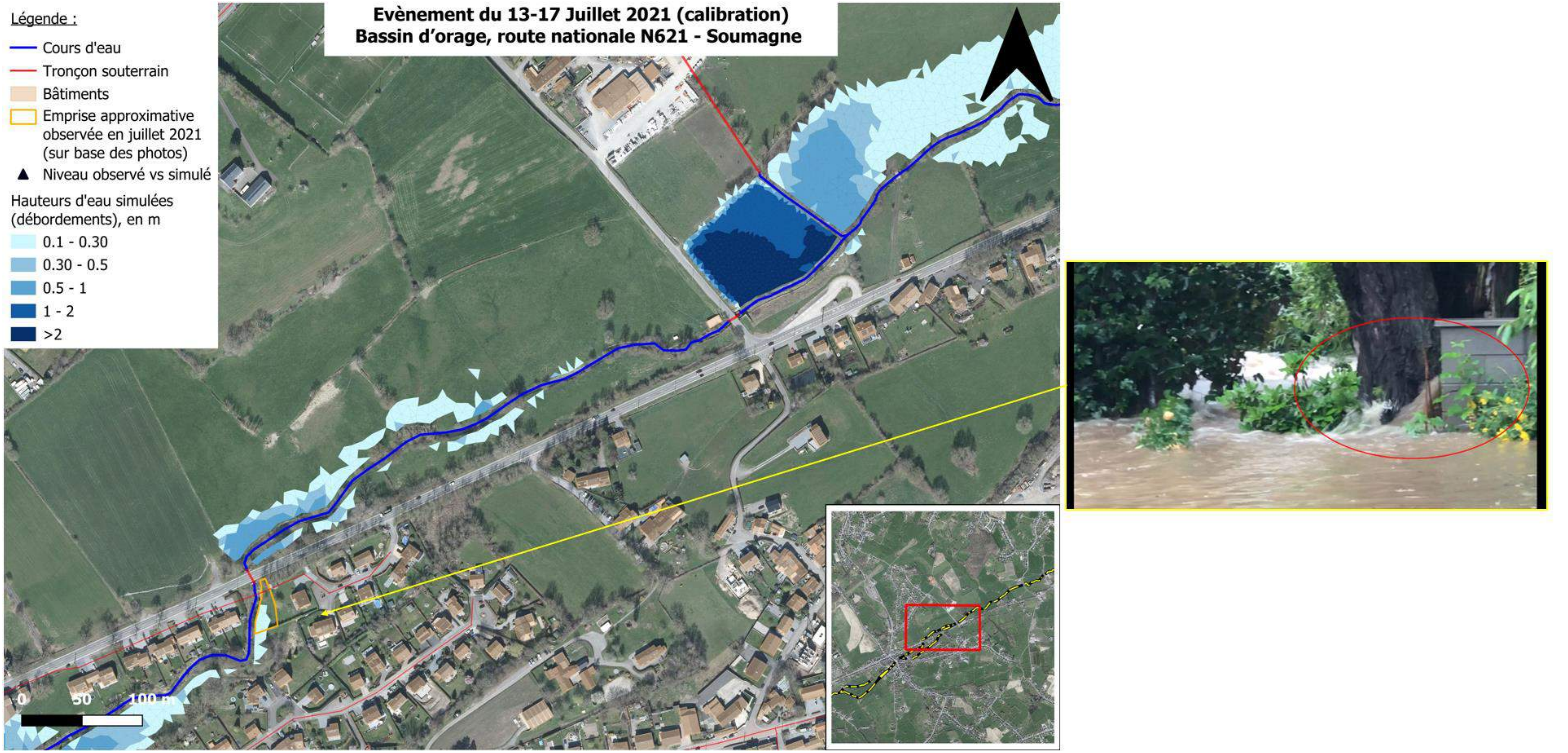

Figure 4-12 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at the level of the storm basin and the N621 national road in Soumagne.

Zone 05 – Soumagne city-centre, Place Ferrer, rue Pierre Curie

The city-centre of Soumagne was affected by extensive flooding, both in terms of the extent and height of the water. In particular, high water levels of around 1.1 metres at the butcher's shop were reported by witnesses and by the University of Liège survey. Figure 4-13 shows the results of the modelling, which appear to correctly reproduce the main areas affected and the water heights observed. For example, the model simulates a water height of around 90 cm at the butcher's shop (slight underestimate).

Overflows from the river Magne occur on the right and left banks upstream of the structure that crosses the main street (Place Ferrer), but are intensified by overflows from the drainage system influenced by the water level in the river Magne. The configuration of the structure (dimensions, shape and orientation) plays a role in the hydraulic capacity of this sector.

Figure 4-13 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event in the Soumagne city-centre, on Place Ferrer and in rue Pierre Curie in Soumagne.

Zone 06 – Nursing home rue Pont Al Plantche

Significant heights of water (over 1 metre) were observed at the nursing home in Rue Pont Al Plantche. This seems to be correctly reproduced by the model (see Figure 4 14). It should be noted that the berm, built a few years ago (see section 3.4) with the aim of reducing the impact of flooding at this location, failed during the July 2021 event, causing overflows that affected the nursing home and surrounding dwellings. Although the model does not incorporate the behaviour of the breached barrier, the flooded areas and simulated water heights seem to correspond relatively well with observations near the nursing home. However, the nursing home, which was affected by the break in the dike, does not appear to be flooded.

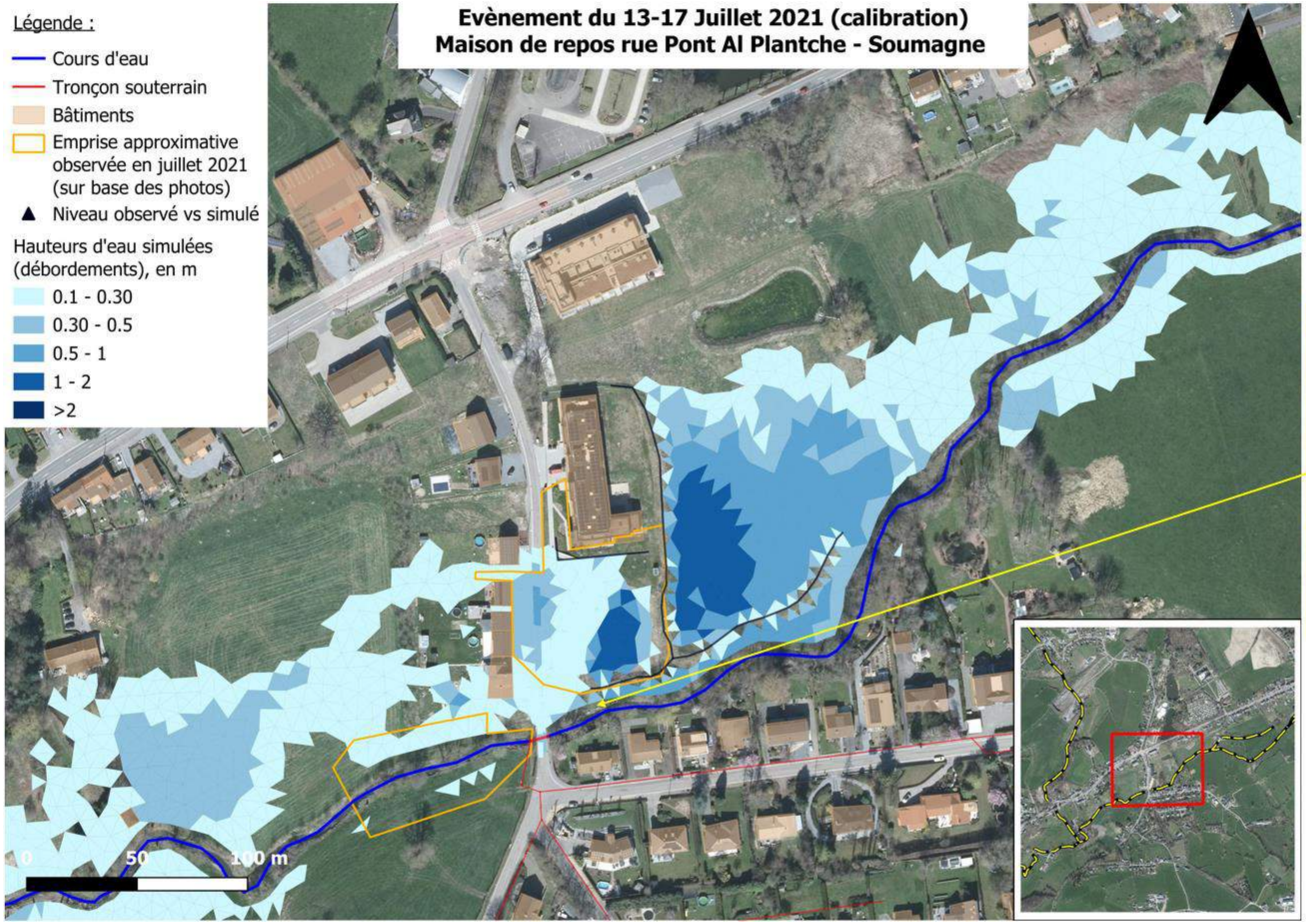

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Figure 4-14 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at the level of the nursing home in Rue Pont Al Plantche in Soumagne.

Zone 07 – Fond des Gottes

In this area, relatively extensive flooding, particularly in terms of water levels, was observed following the overflowing of the 2nd category watercourse, Fond des Gottes. The flooding affected the houses located close to the watercourse, with heights of more than 1 m according to eyewitness accounts. Similar heights are simulated by the model at the homes located near the watercourse (Figure 4 15). The unfavourable configuration of the pipes (see GlobeZenit zoom available in the appendix) passing under the road seems to play a decisive role in these overflows. In fact, the junction between the 2 upstream and downstream pipes is located in a chamber and the alignment between the pipes is not optimal, which can create significant pressure losses. In addition, zooming carried out recently in dry weather shows that one of the pipes is blocked upstream, which significantly reduces its hydraulic capacity. When this passage under the road becomes saturated, the basin fills up to the point where the water can overflow the road. This behaviour is clearly visible in Figure 4 15. Once the water overflows the road, it continues along the right bank to reach the Soumagne wastewater treatment plant.

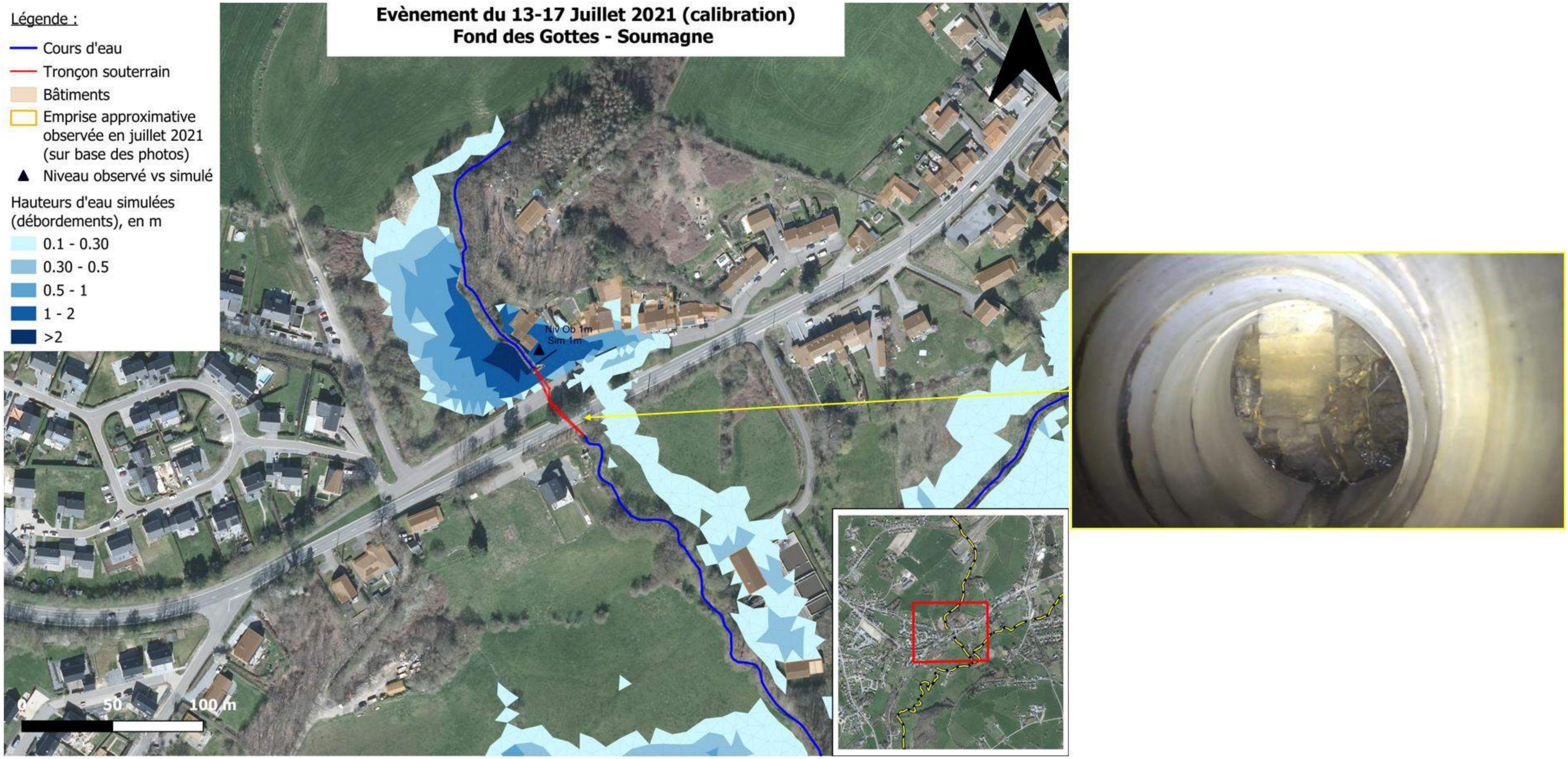


Figure 4-15 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at Fond des Gottes in Soumagne.

4.3.3 Trooz

Zone 08 – Rue Bay Bonnet

Overall, the model reproduces relatively well the flooding observed in the upstream part of rue Bay Bonnet. According to the modelling results (Figure 4 16), the overflows begin at the two structures (concrete footbridges) located upstream, affect the houses located nearby and continue downstream via the street (following the slope of the natural terrain). Other overflows are also simulated at the structure further downstream on rue Bay Bonnet, affecting a nearby house. However, the model seems to underestimate the extent of the overflows observed.

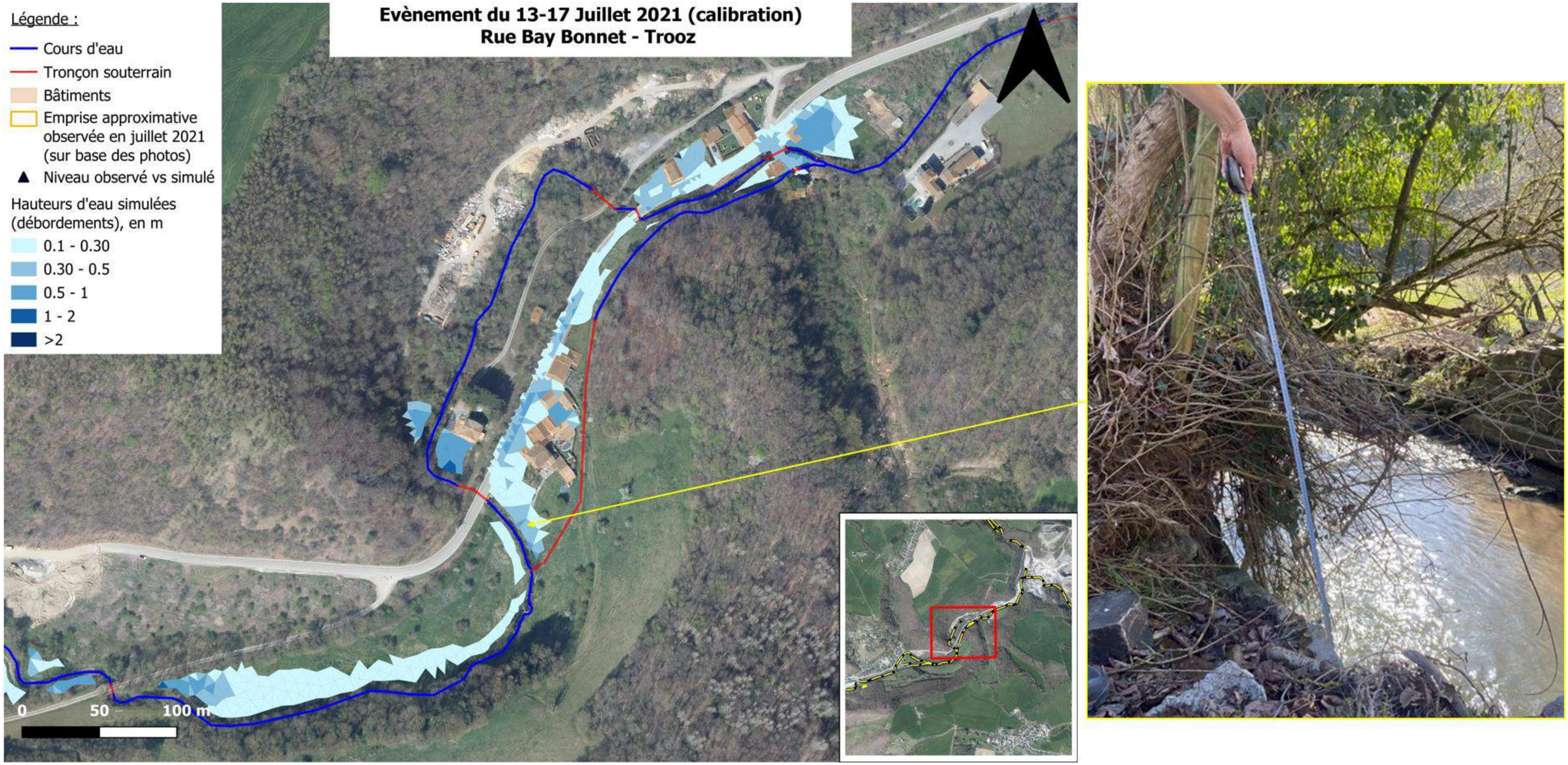


Figure 4-16 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at Fond des Gottes in Trooz.

Zone 09 – Rue Fonds de Forêt

In this area, the model reproduces relatively accurately the flooding observed during the July 2021 event. The modelling results, illustrated in Figure 4-18, show that the first overflows occur on the left bank, at the level of the two structures located to the north of Rue Fonds de Forêt (two concrete footbridges shown in Figure 4-17 below). These overflows then pass through the footbridges on the right-hand side and follow the natural slope of the land, passing through Rue Fonds de Forêt, affecting several dwellings downstream and accumulating in a slight topographical basin, which is consistent with what has been observed. At the level of rue Wiesheid, water heights of 30 cm are simulated at the Maisier Fers & Toles building, which is lower than the heights reported by witnesses (60 cm).

Figure 4-17 : Photo taken at the structures north of Rue Fonds de Forêt, showing the low wall on the right bank

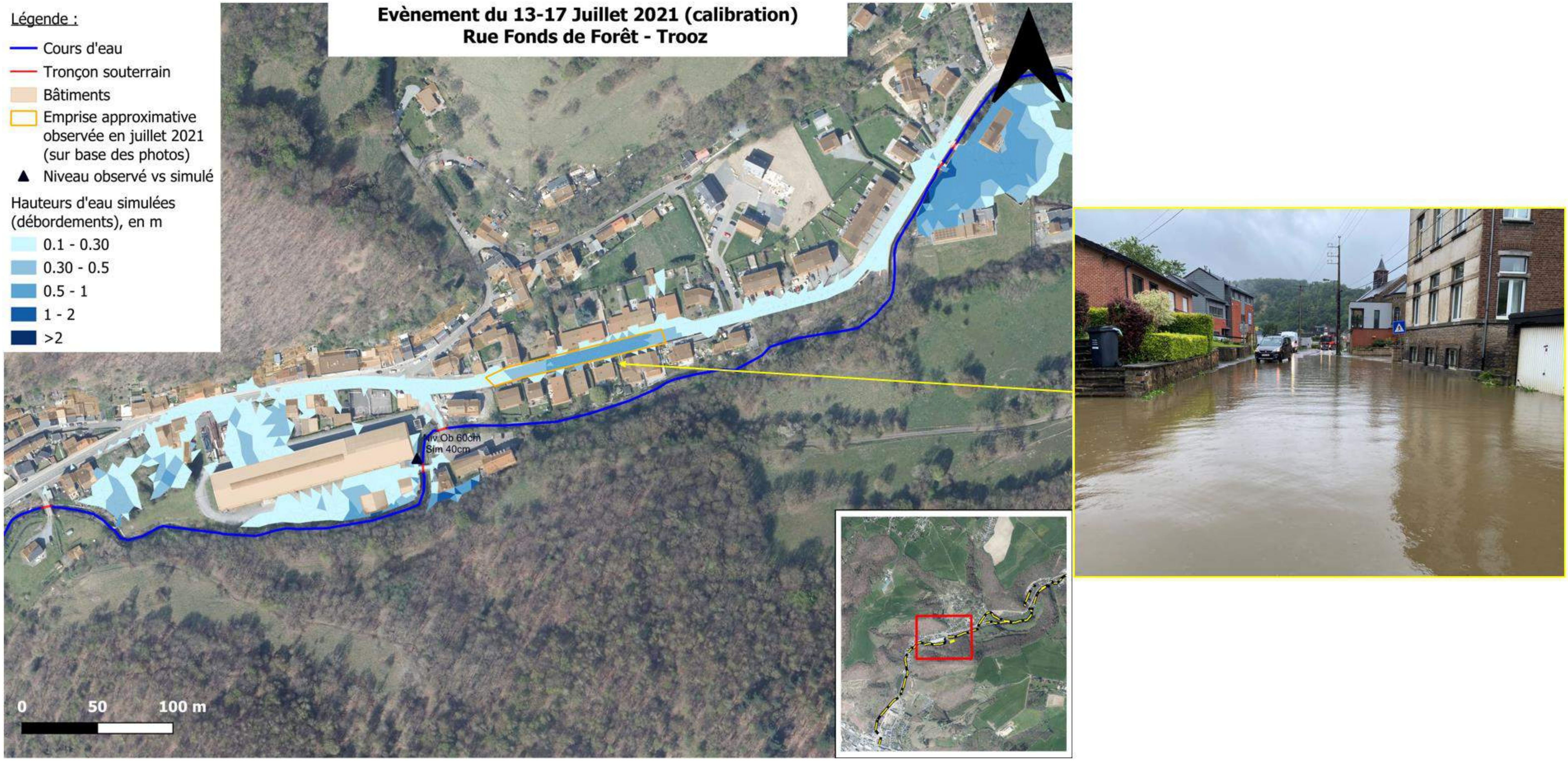


Figure 4-18 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at the level of rue Fonds de Forêt in Trooz.

Zone 10 – Rue Fonds de Forêt, Rue Noirivaux, Rue sur les Biez

In this area, and according to feedback from the municipality of Trooz, some overflows are underestimated by the model, particularly at the level of some dwellings located on the left bank in rue de Biez (upstream part in Figure 4 19). The overflows observed in Rue Noirivaux appear to be better represented, with water heights of between 30 and 50 cm at the homes affected near the bridge. The configuration of the bridge in relation to the watercourse (approach at an angle between the watercourse and the river) may reinforce the overflows upstream of the structure.

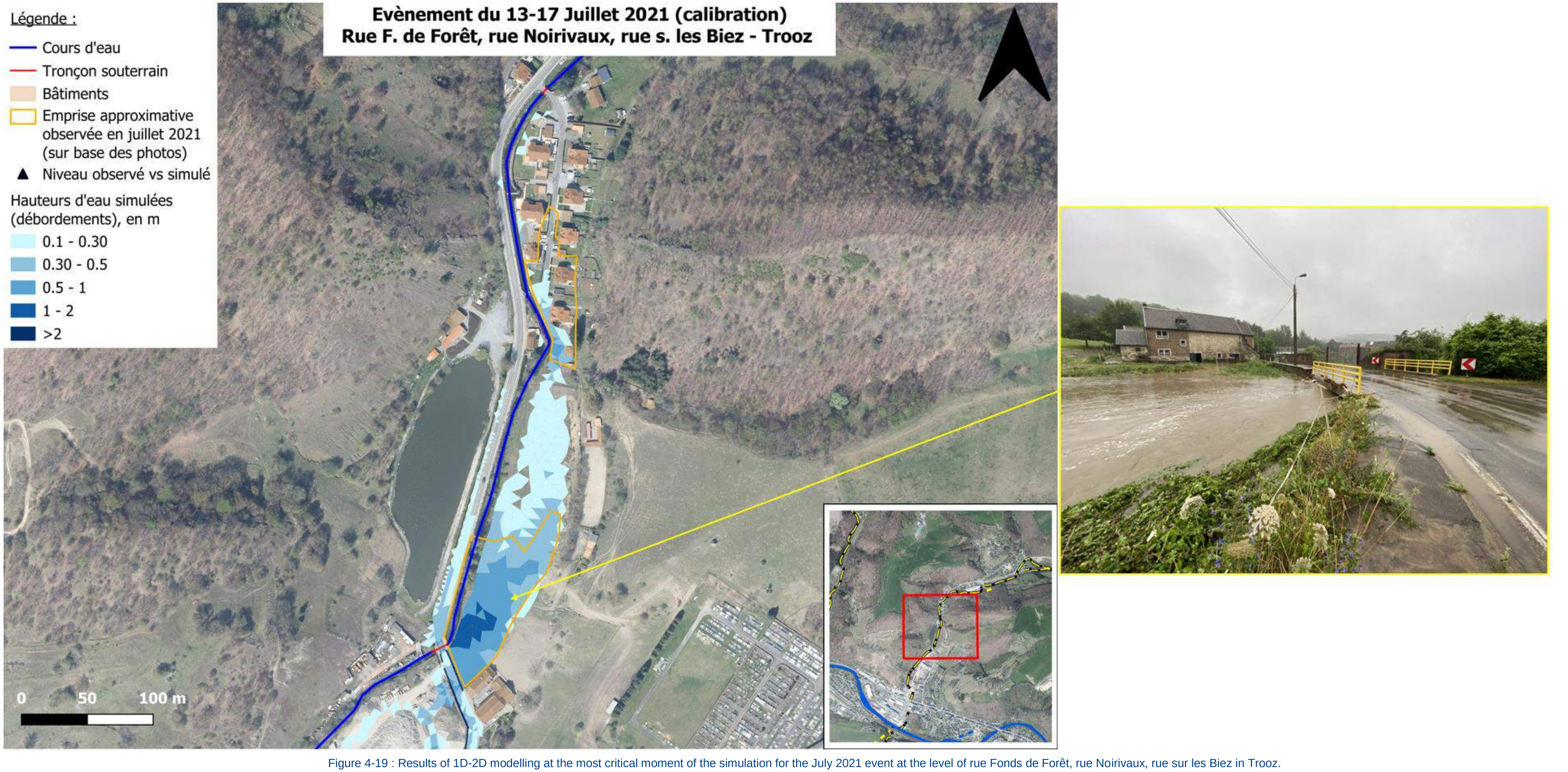


Figure 4-19 : Results of 1D-2D modelling at the most critical moment of the simulation for the July 2021 event at the level of rue Fonds de Forêt, rue Noirivaux, rue sur les Biez in Trooz.

Zone 11 – Confluence with the river Vesdre

Figure 4 20 shows the simulated overflows downstream of Trooz, at the confluence of the river Magne with the river Vesdre. Flooding was obviously particularly critical in July 2021, with very high water levels (reaching around 2.5 metres). The model seems to underestimate the observed water heights (2 m in the simulations). However, the simulated results for this sector need to be qualified, particularly as there are many uncertainties concerning the flow injected upstream at the river Vesdre. In addition, the section relating to the river Vesdre has not been modelled in detail (see section 4.2.5).

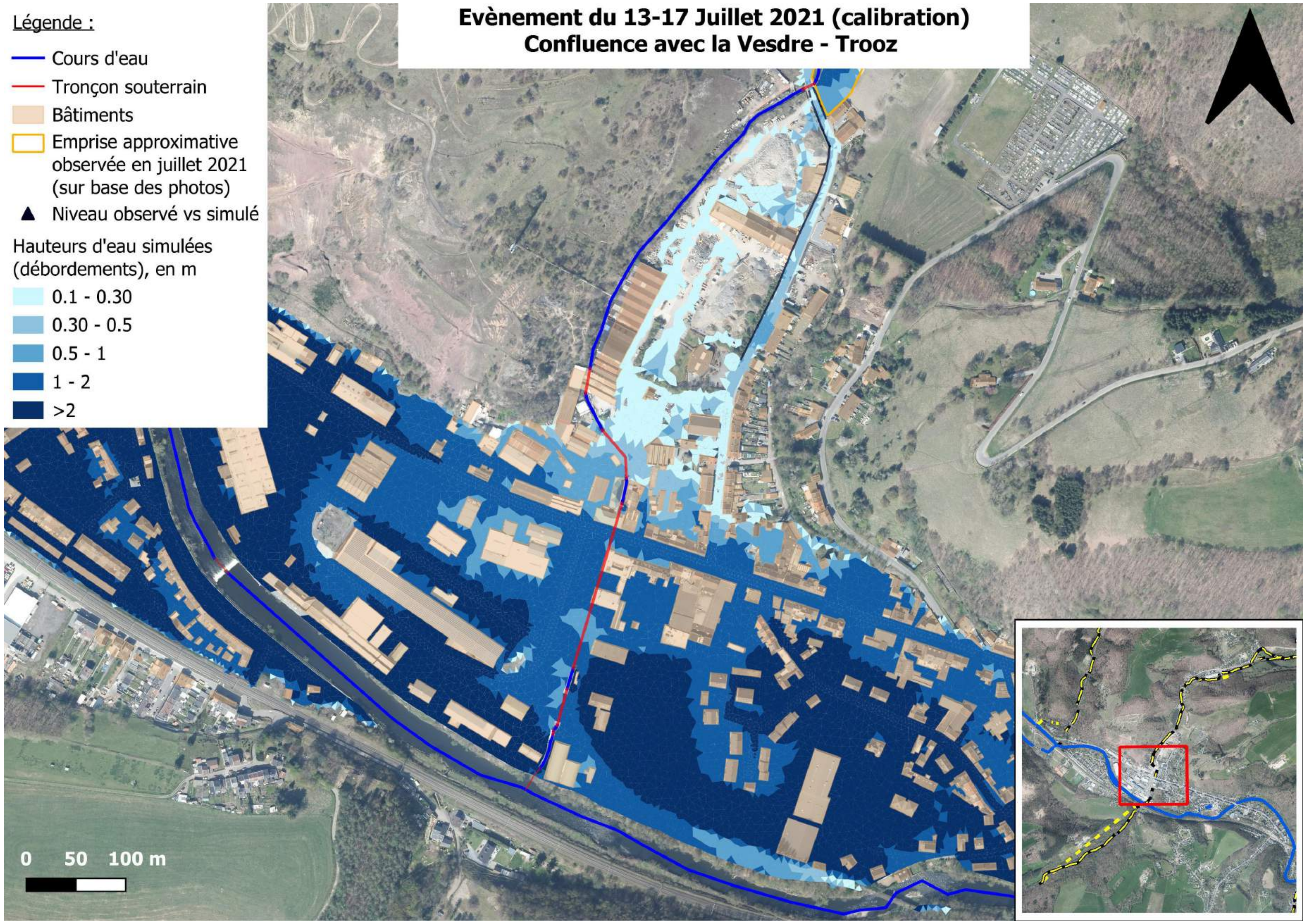


Figure 4-20 : Results of 1D-2D modelling at the most critical time of the simulation for the July 2021 event at the confluence with the river Vesdre in Trooz.

4.3.4 Conclusion on model validation

Overall, the results presented indicate that the model represents the observations relatively accurately, particularly in terms of:

- Behaviour (overflow area and transfer of overflows);
- Water levels
- Flood extent.

Generally speaking, where there are differences with the observations available, the trend seems to be towards an underestimation of overflows. This is particularly the case in some areas of Trooz (rue sur les Biez, rue Fond de Forêt, etc.). There may be a number of reasons for this:

- The model does not take into account jams, which are more frequent during this type of event and can considerably amplify the overflows upstream of certain structures;
- The model only represents flooding linked to overflowing watercourses, and not flooding linked to direct runoff;
- The model is based on a topographical survey of the minor bed in 2023, which has changed since the floods of 2021.

Despite these discrepancies, and in view of the fact that the model is generally representative of the main event, with a large amount of validation data available, the validation of the model is considered satisfactory for carrying out the hydraulic diagnosis and analysing the proposed solutions.

5 Analysis of the existing situation

The hydrological-hydraulic diagnosis for the reference situation (existing state) is carried out on the basis of simulation results with synthetic rainfall for return periods ranging from 5 to 100 years. The aim of this analysis is to provide an overall view of the flooding problem, in particular by analysing the impact of structures on the flow of the watercourse at the most critical points.

The lack of exhaustive rainfall/discharge data (only one rain gauge available in Battice, no reliable discharge data for floods due to the maximum discharge gauged) meant that the production and transfer parameters could only be calibrated for the extreme event of July 2021, for which the critical return period of the rainfall is greater than 200 years. For the calibration of these events, the CN values had to be increased by 10 units to enable a coherent representation of the overflows.

During the diagnostic phase, the CN values were diversified according to the return period, in order to better reflect the frequency of overflows and integrate the impact of the return period on the CN values. It is important to note that this CN diversification applies only to rural catchments. The CN values as a function of the return period are integrated into the model as follows:

- Return period of 5 to 10 years: CN reduced by 10 units
- Return period of 25 to 50 years: CN value unchanged
- 100-year return period: CN increased by 5 units
- 200-year return period: CN increased by 10 units

5.1.1 Diagnosis in Herve

Zone 01 - Water treatment plant

As shown in Figure 5 1, structure OA01_H is not loaded for a return period of 5 years, but it limits the flow, mainly because of the relatively shallow slope of the structure. Overflows are generated mainly on the right bank (Figure 5 2) and then form a water accumulation zone in the natural basin. According to the municipality of Herve, this area was planned as a possible flood expansion zone when the wastewater treatment plant was built. **This area is not particularly critical in terms of the issues affected and should be retained for the overflow of the river Magne. No solution has been proposed to reduce the frequency of flooding in this area.**

Figure 5-1 : Results of 1D-2D modelling at the most critical moment of the simulation, showing the water line profile (in blue) during simulated overflows on the right bank (in green) upstream of structure OA01_H (composite rainfall with a 5-year return period).

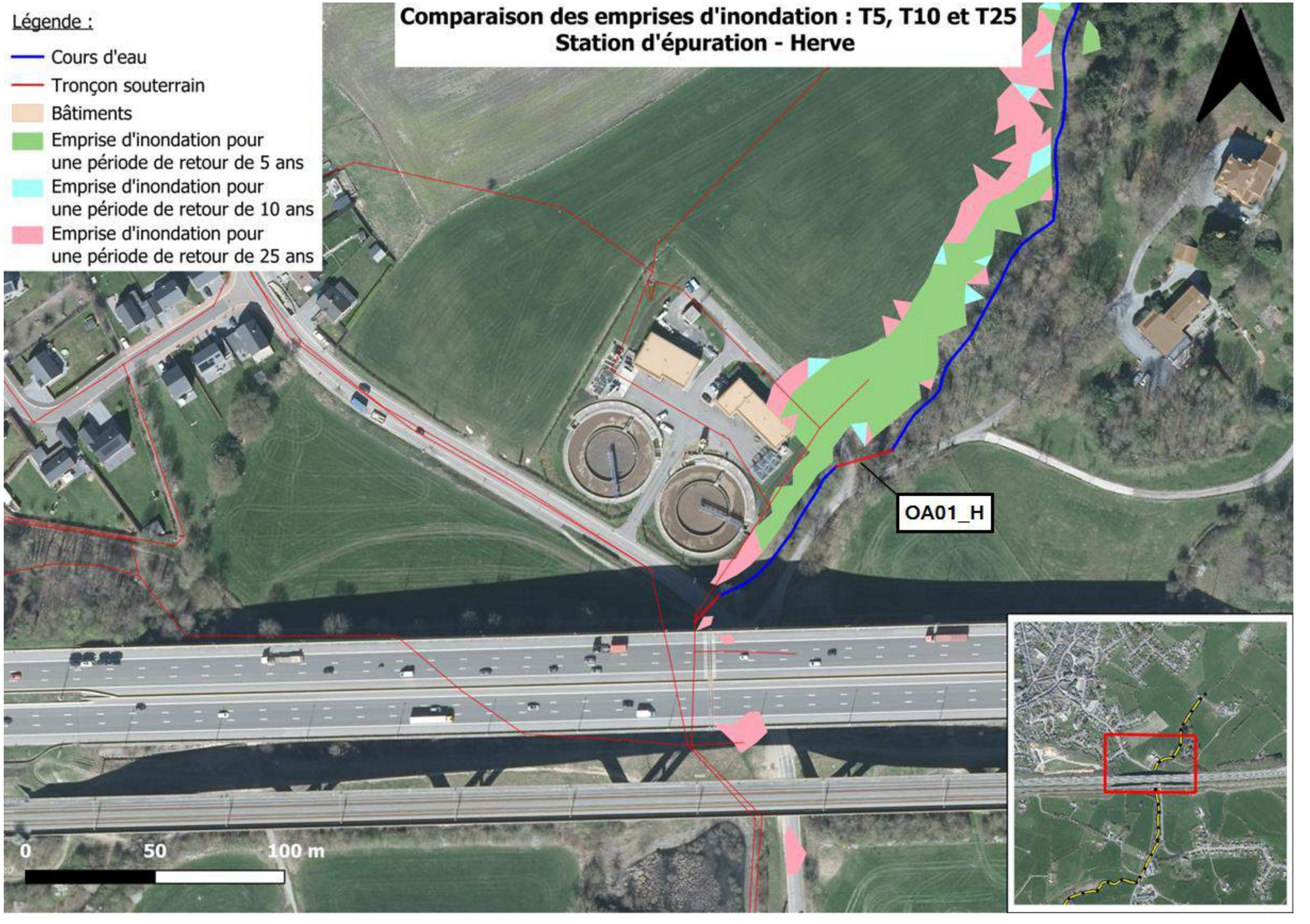


Figure 5-2 : Flood plots for 5-, 10- and 25-year return periods at the Herve wastewater treatment plant

Zone 02 - Rue d'Elvaux

Figure 5-3 shows that the OA02_H structure which enables the passage of the watercourse under the road is quite limiting since there are already simulated overflows for a rain return period of 5 years. Inputs upstream of the sector from the upstream basin (Herve and Battice) are substantial in particular because of the many contributing impermeable surfaces. The peak flow for a rain return period of 5 years is already about 8 m³/s while the capacity of the OA02_H structure is estimated at about 2.4 m³/s. In addition, the flow rates are high (greater than 1.5 m/s per T5) in particular because of the slope which can cause additional pressure losses at the entrance of the structure. In case of saturation of the structure, the first overflows occur at the right bank and the deck, then by the left bank (Figure 5 4). When overflowing, the water follows the slope on the road and can flood the houses on the left (n°110 below the road) and on the right (n°105). All flows converge *in fine* towards the confluence with the stream of Manaihan, as illustrated in Figure 5 5.

As it stands, some localised micro-topography alterations have already been implemented to reduce the effect of flooding once the sluice is saturated: border placement to redirect flows, personal protection (#110). The field visits carried out show the interest of being able to further strengthen the modification of the surface relief to facilitate the flow of water on the surface while protecting the houses.

The hydraulic diagnosis in this sector therefore shows:

- The presence of a limiting structure for a small return period of 5 years
- The importance of surface microtopography on flows after saturation of the sluice

Figure 5-3 : 1D-2D modelling results at the most critical moment of the simulation presenting the profile of the water line (in blue) during the simulated overflows on the right bank (in green) and left bank (in red) upstream of the OA02_H structure (5-year return period composite rain)

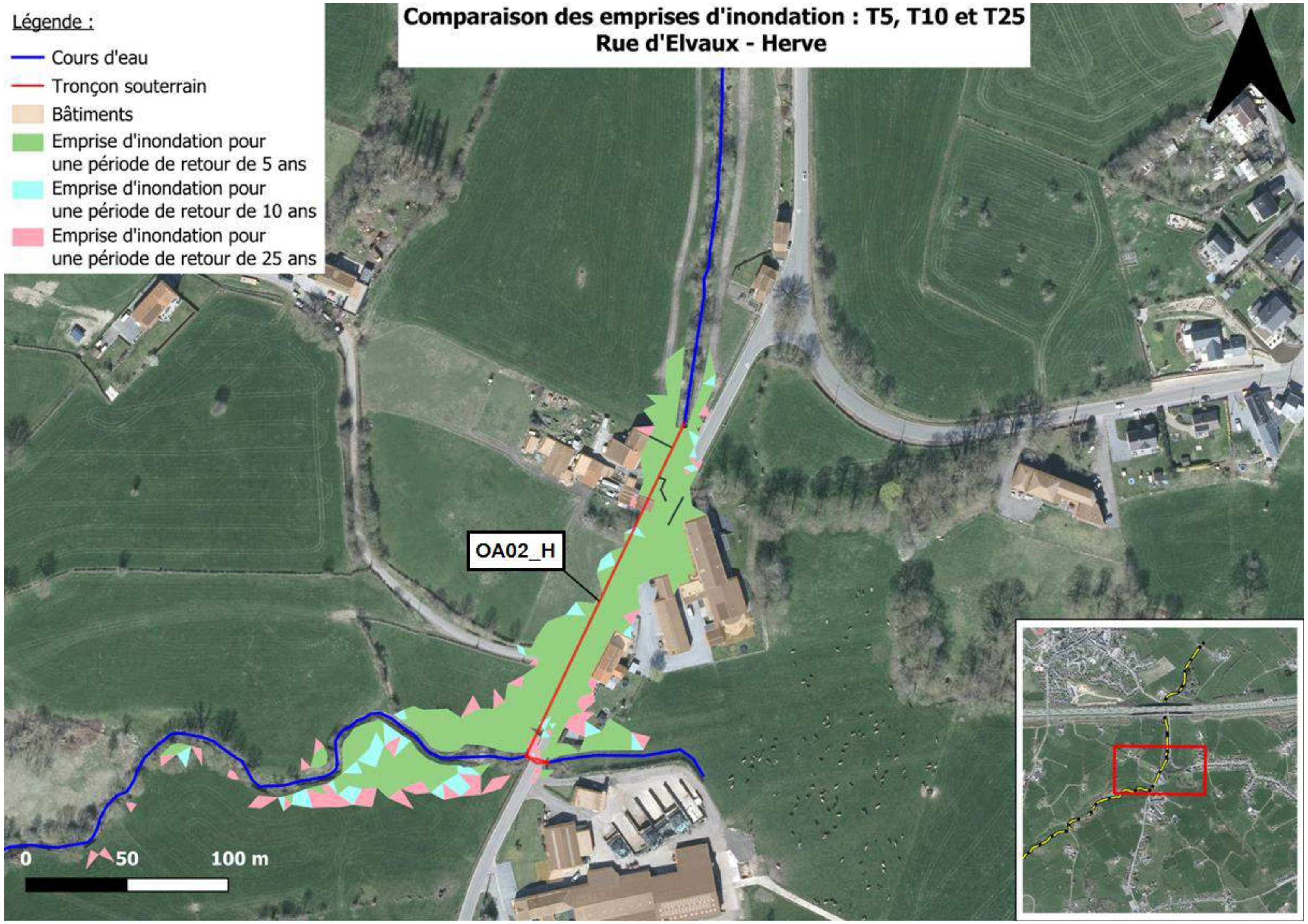


Figure 5-4 : Flood plots for return periods 5, 10, and 25 years at the wastewater treatment plant in Herve.

Séquence 1 : Premiers débordements touchant les habitations à proximité

Séquence 2 : L'écoulement suit la rue vers l'aval formant une zone d'accumulation d'eau dans la prairie

Figure 5-5 : Sequence showing the dynamics of overflows in rue d'Elvaux (5-year return period composite rain)

Zone 03 – Fromagerie du Vieux Moulin

The OA03_H structure allowing passage under the road is limiting for a rain return period of 5 years, as shown in Figure 5-6. Because of its relatively small dimensions in relation to the gauge of the watercourse, overflows occur at the level of the structure, mainly on the left bank side where the topography is more favourable. For return periods between 5 and 10 years, overflows on the right bank slightly reach nearby buildings (Figure 5-9). Downstream of this zone, a water accumulation is formed in the meadow upstream of the OA04_H crossing under the national road N621. This area of grassland is a natural overflow zone reinforced by a slope break of the stream clearly visible on the long profile in Figure 5-6. Overflows at the level of the issue area also become influenced by the downstream for return periods more important as shown in Figure 5-7.

In addition to the aspect related to OA03_H, the field visits and the analysis of the stream overflow sequence (Figure 5-10) show that the overflow on the left bank should be reinforced by a modification of the microtopography (significant modification of the minor bed section, addition of curb on the right bank, modification of slopes in the major bed on the right bank to ward off flooding from houses). There are also elements that can locally slow the flow of water such as a hedge on the left bank directly next to the structure or a shrub in the minor bed upstream of the structure (Figure 5-8). Removing these elements would further reduce a slowdown in flows in the major bed on the left side.

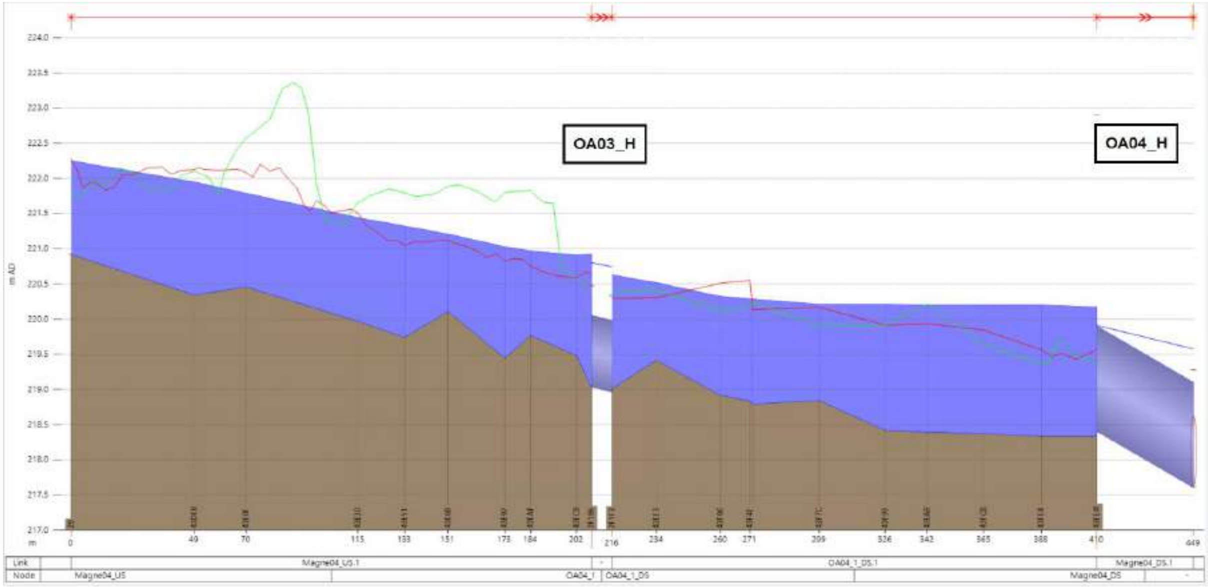


Figure 5-6 : 1D-2D modeling results at the most critical moment of the simulation presenting the profile of the water line (blue) during the simulated overflows on the right bank (green) and left bank (red) upstream of OA03_H and OA04_H (5 year return period composite rain).

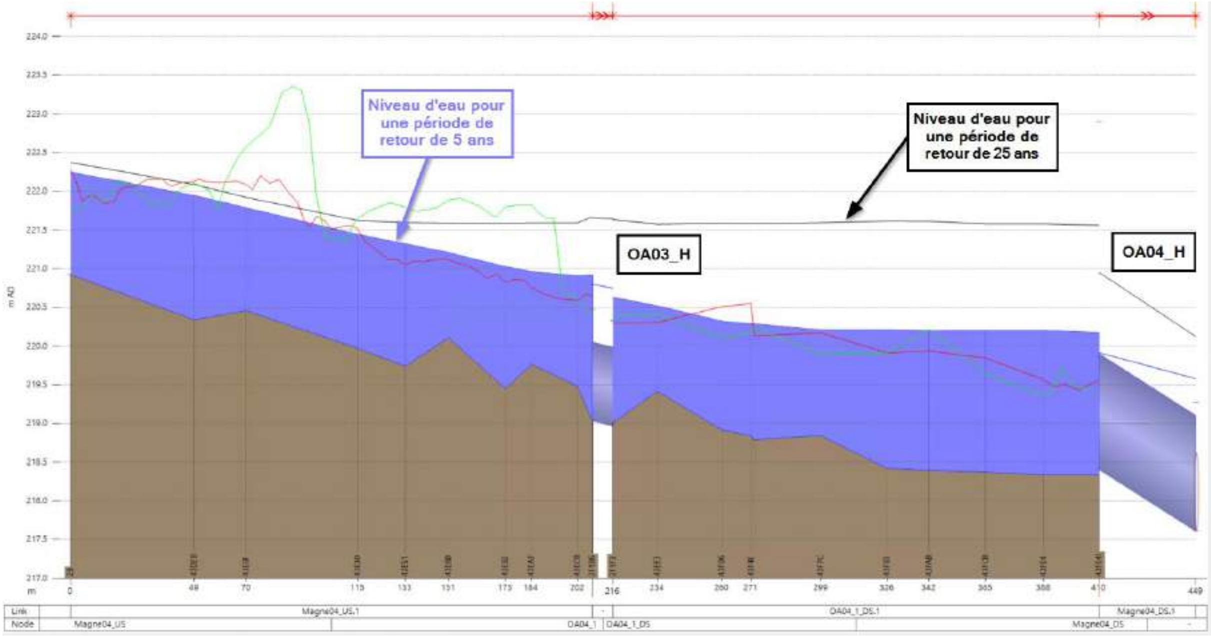


Figure 5-7 : 1D-2D modelling results at the most critical time comparing the profile of the water line for a 5-year return period composite rain (in blue) and for a 25-year return period composite rain (in black).

Figure 5-8 : Photo showing the location of the hedge on the left bank of the river.

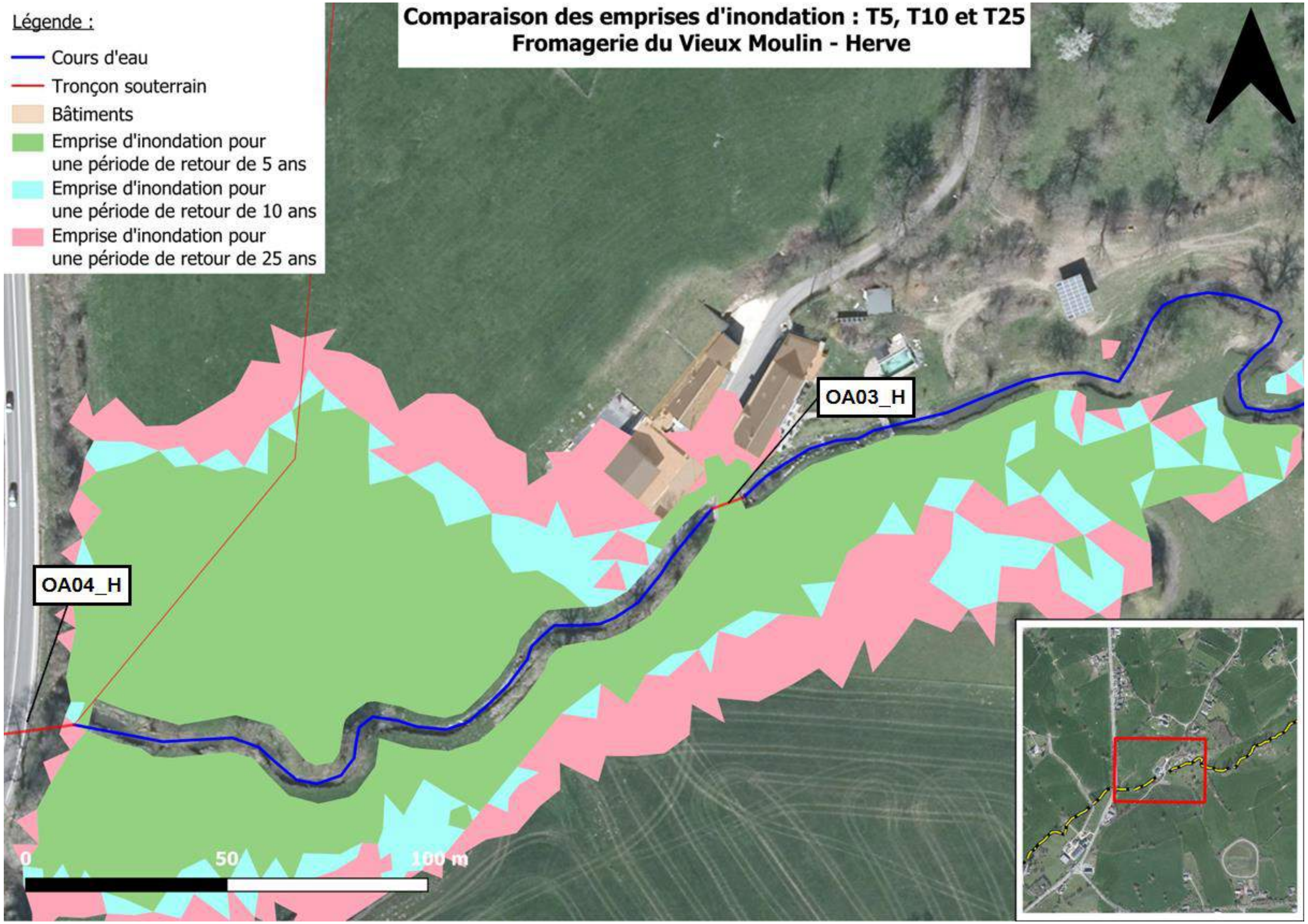


Figure 5-9 : Flood plots for return periods 5, 10, and 25 years at Fromagerie du Vieux Moulin in Herve

Séquence 1 : Premiers débordements au niveau de l'ouvrage côté Fromagerie (Tablier et berge gauche)

Séquence 2 : Accumulation d'eau au niveau de l'ouvrage sous la N621 créant un effet aval au niveau de la Fromagerie

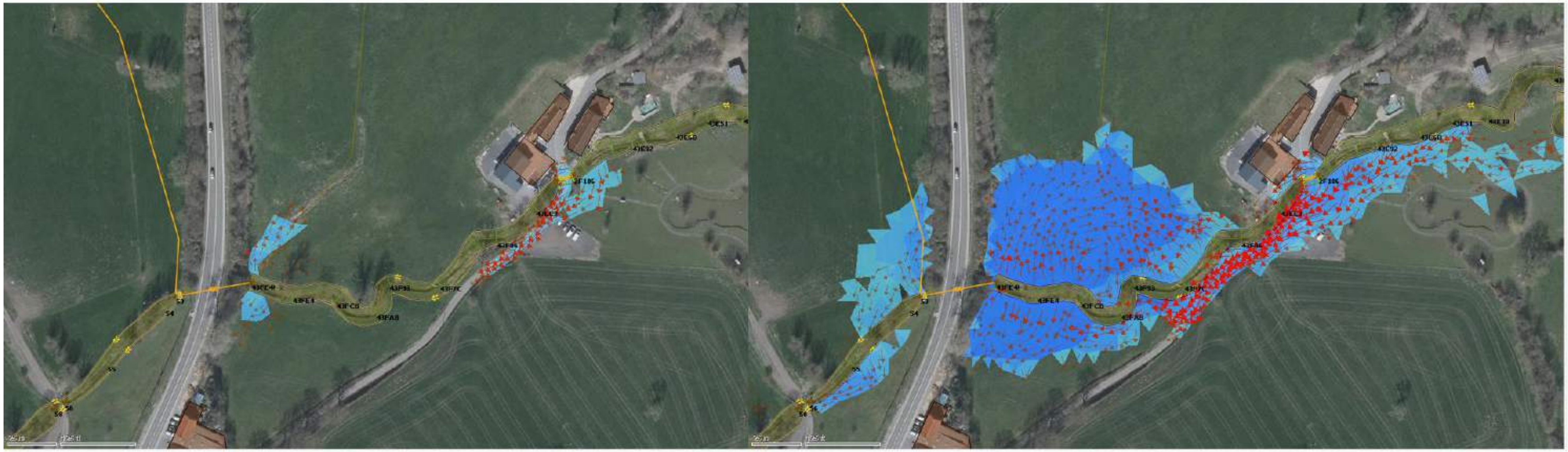


Figure 5-10 : Sequence showing the dynamics of overflows at the Fromagerie du Vieux Moulin (25-year return period composite rain)

5.1.2 Diagnosis in Soumagne

Zone 04 - Storm water basin, route nationale N621

The Soumagne storm water basin (SWB), designed to protect the town downstream from flooding, regulates the flow downstream via a gate. The diagnostic analysis considers the current configuration of the basin, not the future configuration, which involves raising the level of the spillway. The latter configuration will be analysed later in this report.

The gate regulating the basin flow currently limits the flow to a maximum value of around 11.9 m³/s. Analysis of the synthetic simulations shows that there is no significant retention for a return period of 5 years, and the water level in the basin is lower than the upper part of the valve. The leakage rate at the outlet of the structure for this 5-year return period is around 6.5 m³/s and the retention volume is estimated at around 2,600 m³. For higher return periods, retention in the basin increases (see table below). The current reservoir is not capable of fully containing a 25-year return period rainfall, since the reservoir weir is activated and the simulated peak flow at the reservoir outlet is 12.4 m³/s (higher than the maximum regulation value of 11.9 m³/s). For a return period of 25 years, storage in the basin is estimated at around 14,800 m³. The hydraulic diagnosis shows an increase in storage as a function of the return period, but the reservoir is still.

Table 5-1 : Summary of volumes stored in the Soumagne reservoir for each return period studied.

Return period	Volume (m³)	Peak flow (m³/s)	Weir activation	Water level
T5	2600	6.5	Non	200.2
T10	4600	7.9	Non	200.5
T25	14800	12.4	Oui	201.6
T50	19200	14.7	Oui	201.8
T100	27200	19.4	Oui	202.2

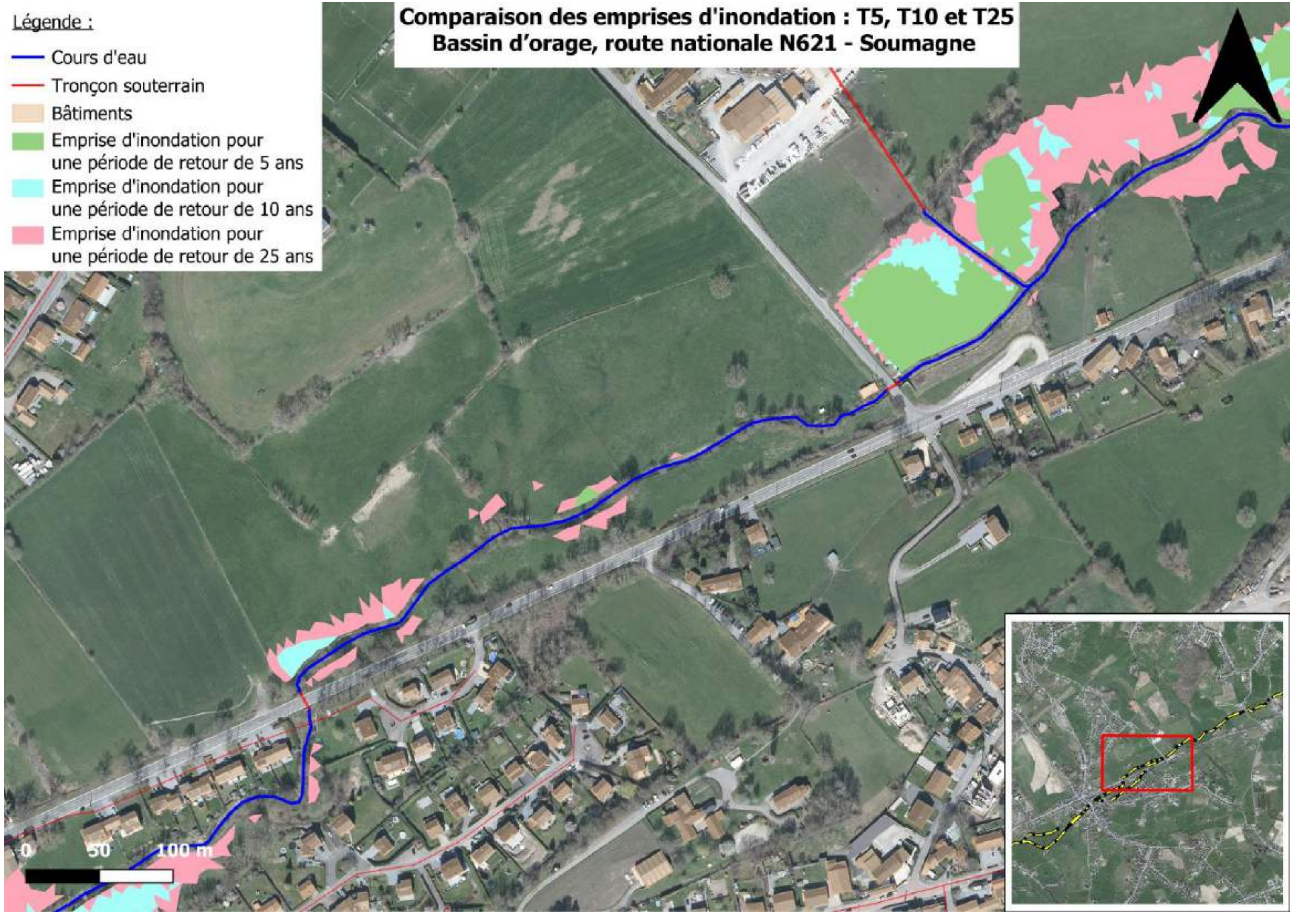


Figure 5-11 : Flood plains for return periods of 5, 10 and 25 years at the Soumagne storm water basin

Zone 05 - Soumagne : Soumagne city-centre, Place Ferrer, rue Pierre Curie

The centre of Soumagne is a particularly critical area in terms of the issues affected. As shown in Figure 5-13, no overflow at river level is observed for rainfall with a return period of 5 years. The overflows that are simulated are more related to the effect of the water level in the river Magne downstream of the crossing structure, which then has repercussions on the 3rd category tributary, the Fond Leroy stream, and on the upstream drainage network at the level of Place Mattéot, Rue Célestin Demblon and Chaussée de Wégimont.

The main double-arch structure OA05_S, located under Place Ferrer, reaches its full capacity for a return period of 10 years (Figure 5-12), with some overflow upstream, in the gardens of nearby dwellings. The admissible capacity of this structure, comprising 2 arch-shaped pipes in its upstream section, is estimated at around 5.8 m³/s. The limiting factors for this structure under the sluice are the angle of inclination between the watercourse and the entrance to the sluice, the dimensions smaller than the upstream gauge of the watercourse, creating a contraction effect, and the transition between a double-arch pipe and a low-arch pipe downstream, which may cause head losses at the junction. These factors contribute to increasing the hydraulic stresses in this area. When the structure is saturated, the head of water upstream increases and then overflows onto the road, as was the case in July 2021. The overflow sequence is shown in Figure 5-14.

The hydraulic diagnosis of this sector therefore shows:

- The presence of a limiting structure for a small return period of 10 years
- The impact of the water level in the watercourse on the Fond Leroy tributary and on the upstream drainage network

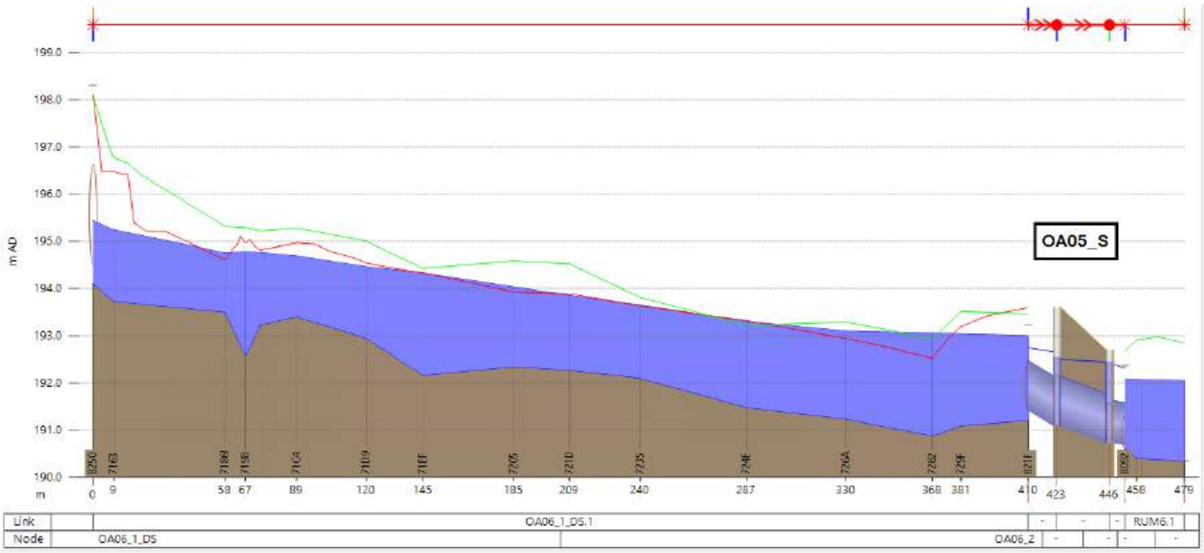


Figure 5-12 : Results of 1D-2D modelling at the most critical moment of the simulation, showing the water line profile (in blue) during simulated overflows on the right bank (in green) and left bank (in red) upstream of structure OA05_S (composite rainfall with a 10-year return period).

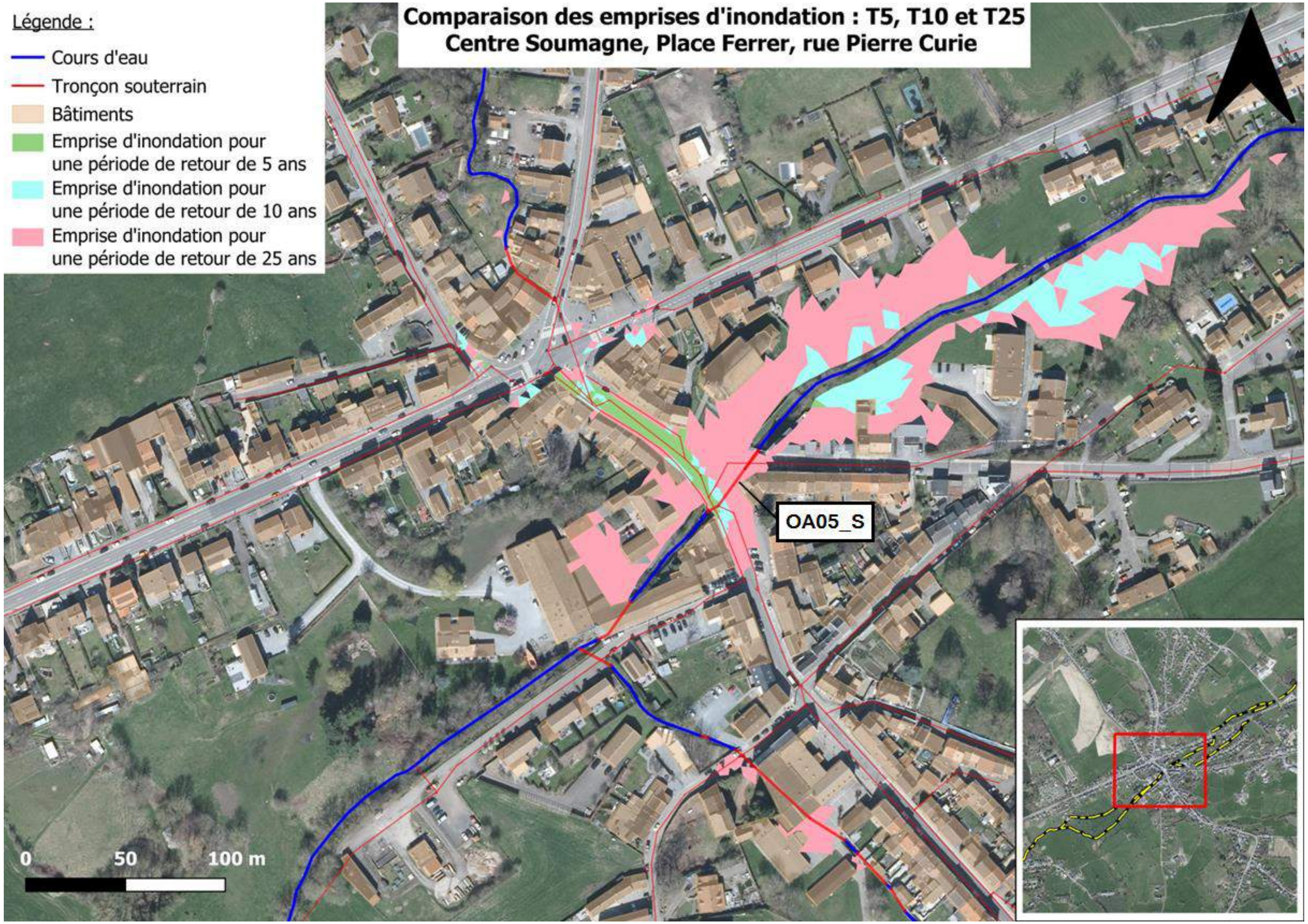


Figure 5-13 : Flood plots for 5-, 10- and 25-year return periods in the centre of Soumagne.

Séquence 1 : Premiers débordements en amont de l'ouvrage, touchant les maisons/jardins à proximité

Séquence 2 : Débordements sur la Place Ferrer via l'ouvrage, et accumulation d'eau (cuvette naturelle) touchant plusieurs bâtiments.

Figure 5-14 : Sequence showing the dynamics of overflows at the level of Place Ferrer in Soumagne (composite rainfall with a 25-year return period).

Zone 06 - Soumagne : Nursing home rue Pont Al Plantche

An analysis of the existing situation at the level of the nursing home shows that structure OA06_S is only limiting after a return period of 25 years (see figure below). The topographical levels of the banks and the major bed in this sector allow overflow primarily into the major bed on the right-hand side upstream of the structure. The barrier and a low wall near the nursing home protect the nursing home from flooding. However, it has been reported that the barrier gave way in July 2021, causing significant flooding, which highlights the risk associated with the failure of such a structure for extreme return periods. For return periods of 25 years, the overflow on the right bank is already affecting the houses next to the structure at the bottom of Rue Pont al Plantche. The water in the major bed drains away to the right bank, partly via the houses and gardens that are present in the area.

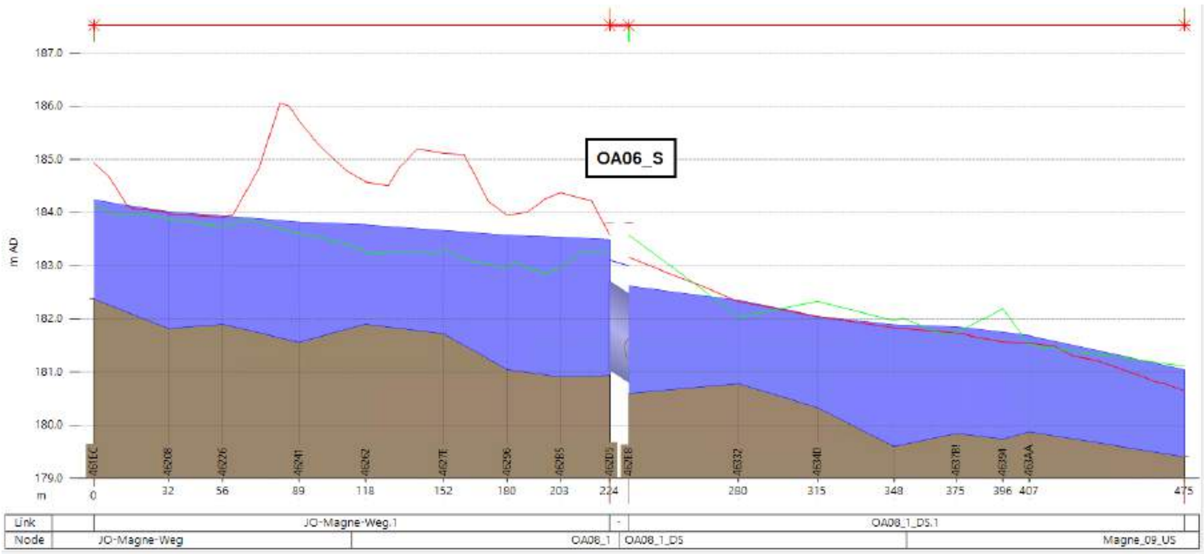


Figure 5-15 : Results of 1D-2D modelling at the most critical moment of the simulation, showing the profile of the water line (in blue) during simulated overflows on the right bank (in green) and left bank (in red) upstream of structure OA06_S (composite rainfall with a 25-year return period).

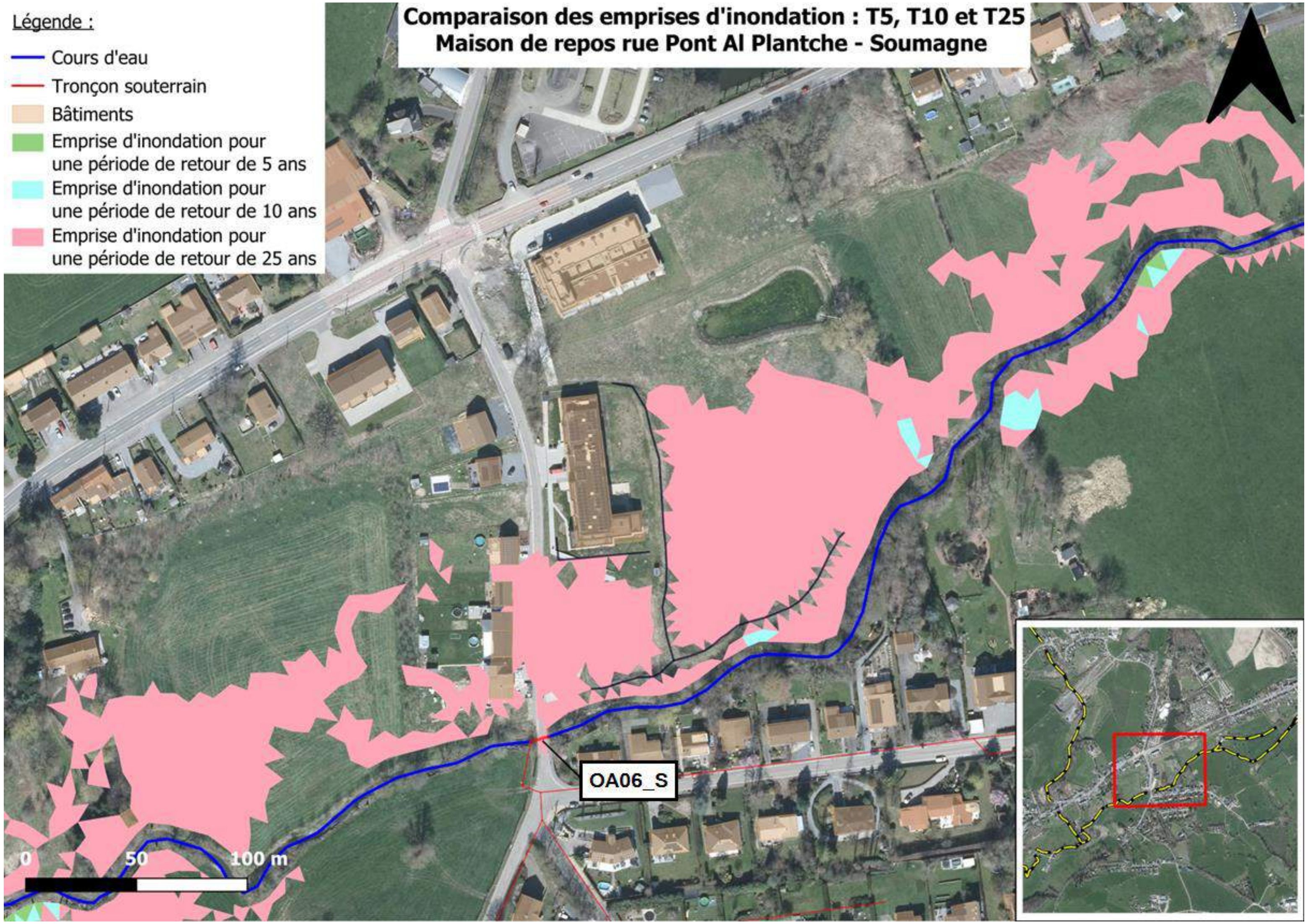


Figure 5-16 : Flood plains for return periods of 5, 10 and 25 years at the level of the nursing home in rue Pont Al Plantche.

Zone 07 - Soumagne : Fond des Gottes

As shown in Figure 5-17, the two D1000 diameter pipes have an unfavourable configuration. GlobeZenit zoomed in on the pipes, revealing a significant reduction in their capacity due to misalignment at the internal junctions between the upstream and downstream pipes, as well as partial blockage of the right-hand pipe. These factors are responsible for a significant reduction in hydraulic crossing capacity.

Simulation results for rainfall with return periods of 5 to 25 years show that the two pipes modelled as they stand do not restrict the flow of the watercourse and do not cause overflow upstream. However, for more extreme return periods, from 50 years upwards, the two pipes in their current configuration limit the flow and cause major overflows affecting neighbouring homes, as illustrated in Figure 5-18 and Figure 5-19.

Once the structure is saturated, the water level upstream increases. As shown in the sequence of overflows in Figure 5-20, water accumulates in this basin area until the road level is reached in the vicinity of numbers 212, 214 and 216. The activation of overflows at this point determines the level currently reached upstream of the road.

The hydraulic diagnosis of this sector therefore shows the importance of reviewing the current configuration of the sluice, which is not conducive to flow and could also encourage the creation of blockages, thereby limiting hydraulic capacity. Improving the flow through the crossing would reduce the flooding that has been observed on Ruisseau des Gottes in this sector.

Figure 5-17 : A photo taken from the zoom showing the state of the pipe structure on Fond des Gottes.

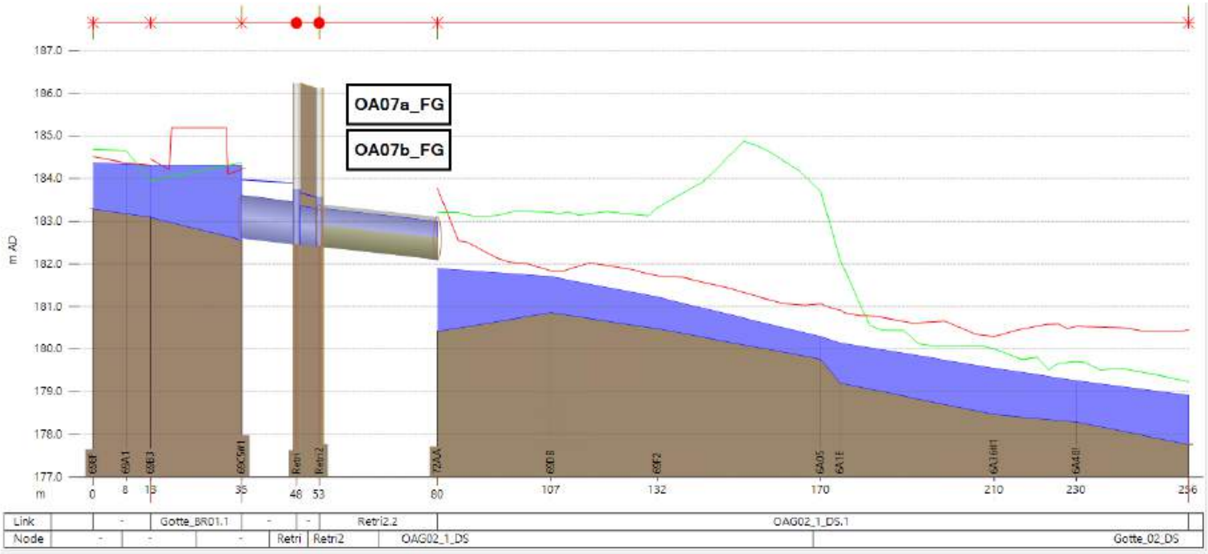


Figure 5-18 : Results of 1D-2D modelling at the most critical moment of the simulation, showing the water line profile (in blue) during simulated overflows on the right bank (in green) and left bank (in red) upstream of structures OA07a_FG and OA07b_FG. The right pipe was modelled in a partially blocked situation (brown). (Composite rainfall with a 50-year return period).

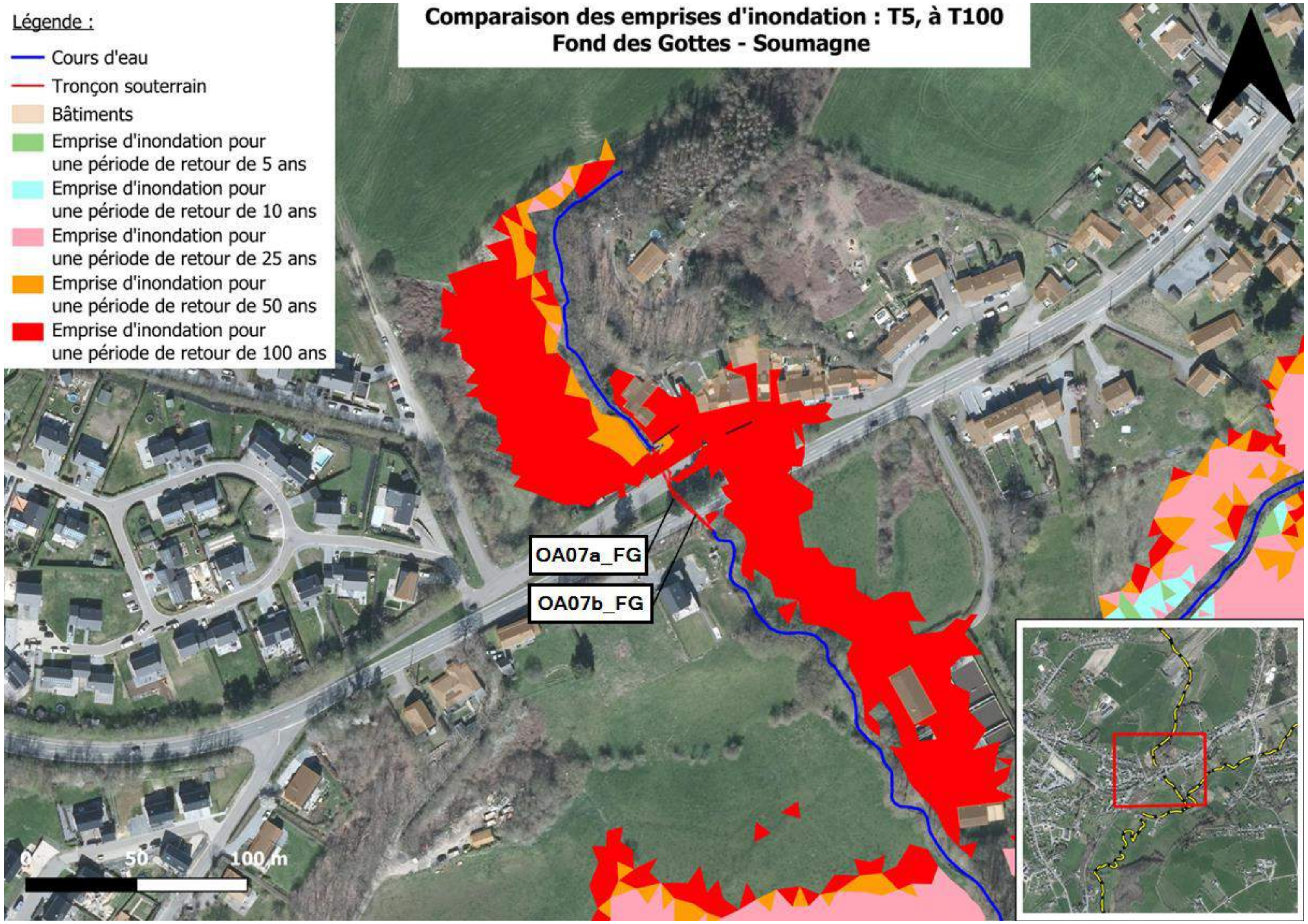


Figure 5-19 : Flood plains for return periods of 5, 10 and 25 years at the level of Fond des Gottes

Séquence 1 : Premiers débordements par la berge droite en amont des deux conduites

Séquence 2 : Les inondations s'intensifient et atteignent les maisons à proximité par la berge gauche. Les écoulements passent ensuite vers l'aval en traversant la route N621.

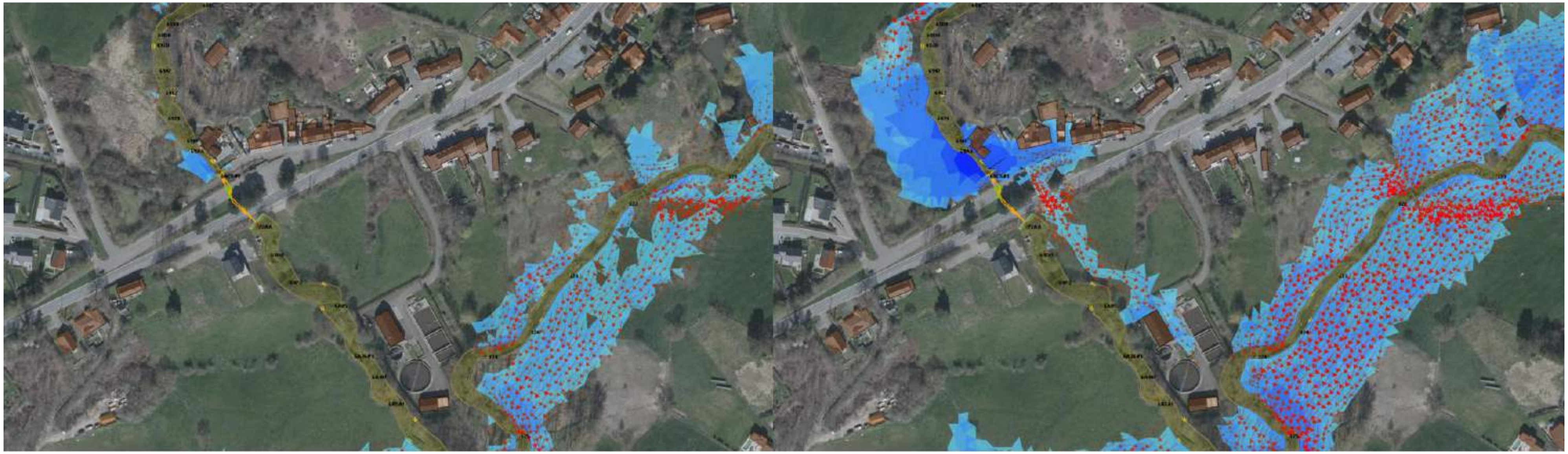


Figure 5-20 : Sequence showing the dynamics of overflows at the level of Fond des Gottes (composite rainfall with a 100-year return period)

5.1.3 Diagnosis in Trooz

Zone 08 - Trooz : Rue Bay Bonnet

At the upper end of rue Bay Bonnet after the quarry, the watercourse splits into 2 reaches. On the main watercourse is structure OA08_T, which is directly beside the road (Figure 5-24). On the other side, there is structure OA09_T on the left reach. The main flow takes place in the right-hand reach via OA08_T. Flow to the right reach is allowed by a weir located upstream of OA08_T.

As shown in Figure 5-21, structure OA08_T (also shown in Figure 5-23), located near the road, is already under pressure for a 5-year return period, but does not cause overflows. It becomes critical for a 25-year return period with subsequent overflow onto the road. The acceptable capacity of this structure is approximately 6.5 m³/s. The orientation of the watercourse at this point, in particular the change in flow direction, encourages overflow towards the road in the event of saturation of the structure. The water overflowing onto the road at this point would follow the natural gradient and impact the houses further downstream (in particular Nos. 2, 6 and 8 rue Bay Bonnet). The sequence of overflow and transfer onto the road is shown in Figure 5-25.

Structure OA09_T, located on the left reach (see also an image in Figure 5-23), has an admissible capacity of 3.7 m³/s less than structure OA08_T. Structure OA09_T is limiting for a return period of 10 years. During floods, most of the flow passes through the main reach and not through the left reach.

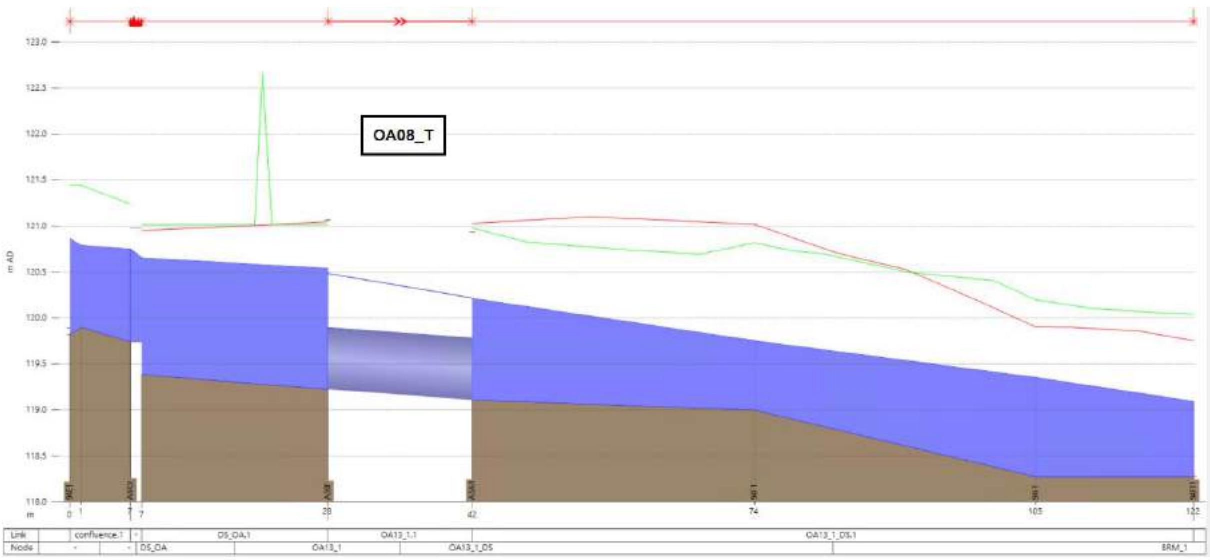


Figure 5-21 : Results of 1D-2D modelling at the most critical moment of the simulation, showing the water line profile (in blue) upstream of structure OA08_T (composite rainfall with a 5-year return period).

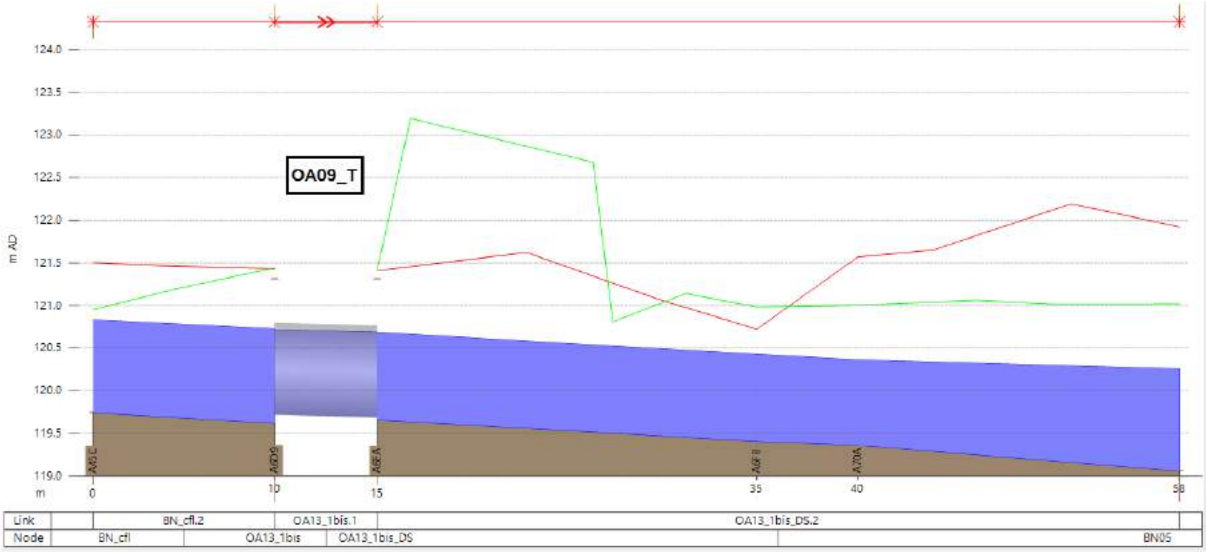


Figure 5-22 : Results of 1D-2D modelling at the most critical moment of the simulation, showing the water line profile (in blue) upstream of structure OA09_T (composite rainfall with a 5-year return period).

Figure 5-23 : Photos showing the upstream end of structures OA08_T and OA09_T

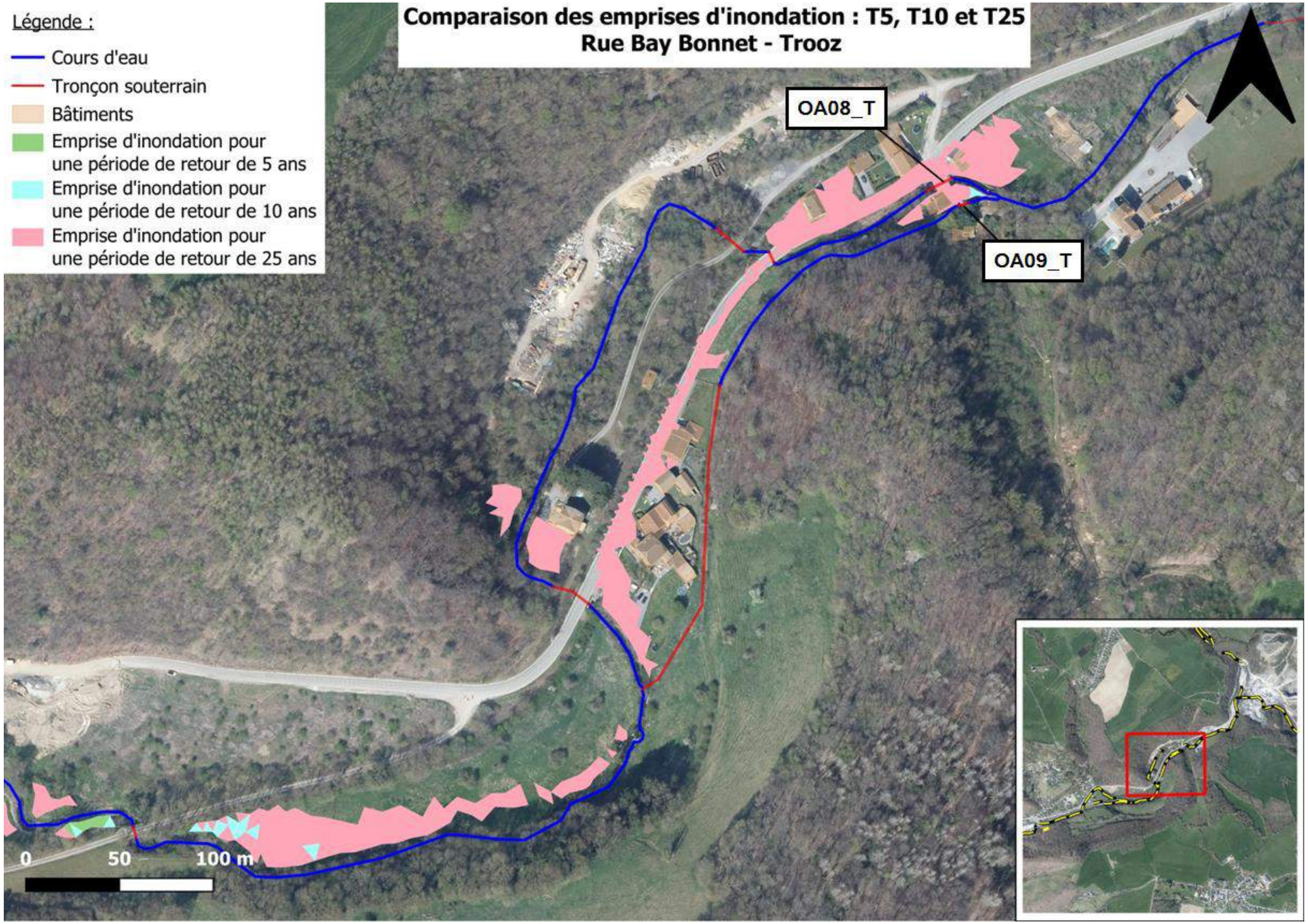


Figure 5-24 : Flood plains for return periods of 5, 10 and 25 years at the level of rue Bay Bonnet in Trooz.

Séquence 1 : Premiers débordements par la berge droite en amont des ouvrages OA08_T et OA09_T

Séquence 2 : Les écoulements suivent la rue Bay Bonnet vers l'aval et touchent les habitations à proximité.

Figure 5-25 : Sequence showing the dynamics of overflows in Rue Bay Bonnet (composite rainfall with a 25-year return period)

Zone 09 - Trooz : Rue Fonds de Forêt

In this sector, the diagnosis shows an initial area of overflow on the upper part of Rue Fonds de Forêt around no. 52. At present, there is a low wall on the right bank, which sends the water back to the left bank if the watercourse overflows. The low wall has recently been renovated and is continuous over the section preventing overflow onto the road. Structures OA10_T and OA11_T are the two structures at this location (see photos in Figure 5-26). Structure OA11_T has an apron, which prevents overflow, but it is not the case for structure OA10_T, which is located just upstream. Water can therefore reach the road at this point in the event of saturation. This sequence is simulated by the model, as can be seen in Figure 5-29, which shows the overflow sequence at this point for a return period of 25 years. In fact, overflows in this sector are reflected further downstream in Rue Fonds de Forêt. As shown in Figure 5-27, structures OA10_T and OA11_T are limiting for a 25-year return period. The admissible capacity of these structures is estimated at around 11 m³/s.

Structures OA12_T and OA13_T are located downstream of this zone, near No. 24 of Rue Wiesheid and the warehouse. Structure OA12_T (see photo in Figure 5-27) has a large capacity, but this is not the case for structure OA13_T, which is loaded for a return period of 5 years and has a maximum admissible capacity of around 10.5 m²/s. It is also located just downstream of a change in the direction of the watercourse. The first overflows will therefore occur on the right bank and may then affect the building just downstream.

Figure 5-26 : Photos showing the location of structures OA10_T and OA11_T

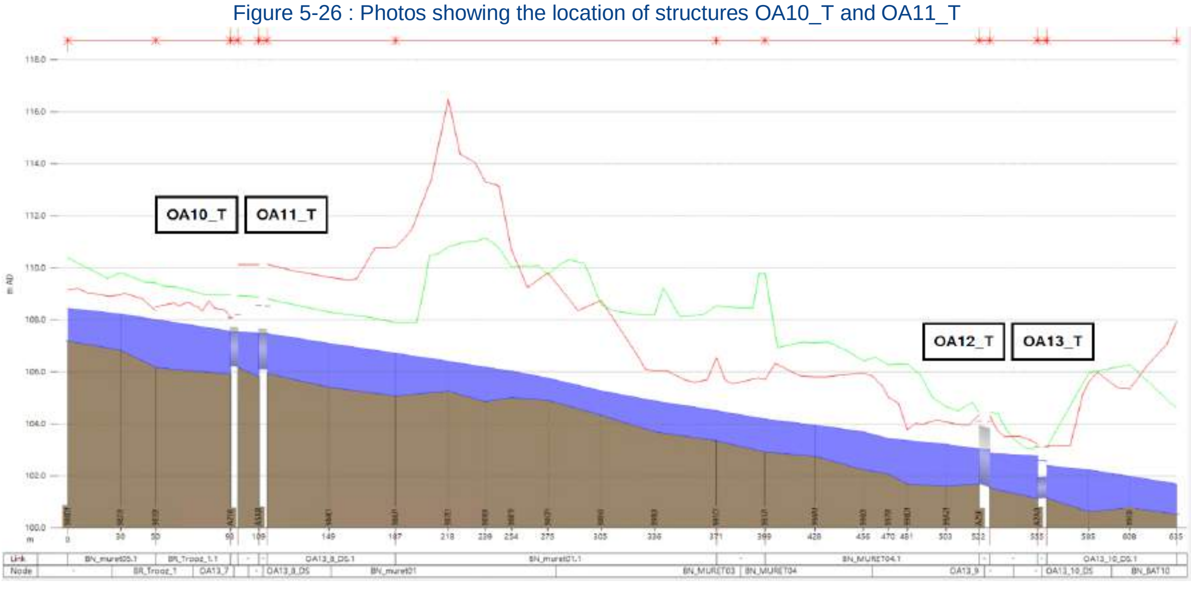


Figure 5-27 : Results of 1D-2D modelling at the most critical point in the simulation, showing the water line profile (in blue) upstream of structures OA10_T, OA11_T, OA12_T and OA13_T (composite rainfall with a 5-year return period).

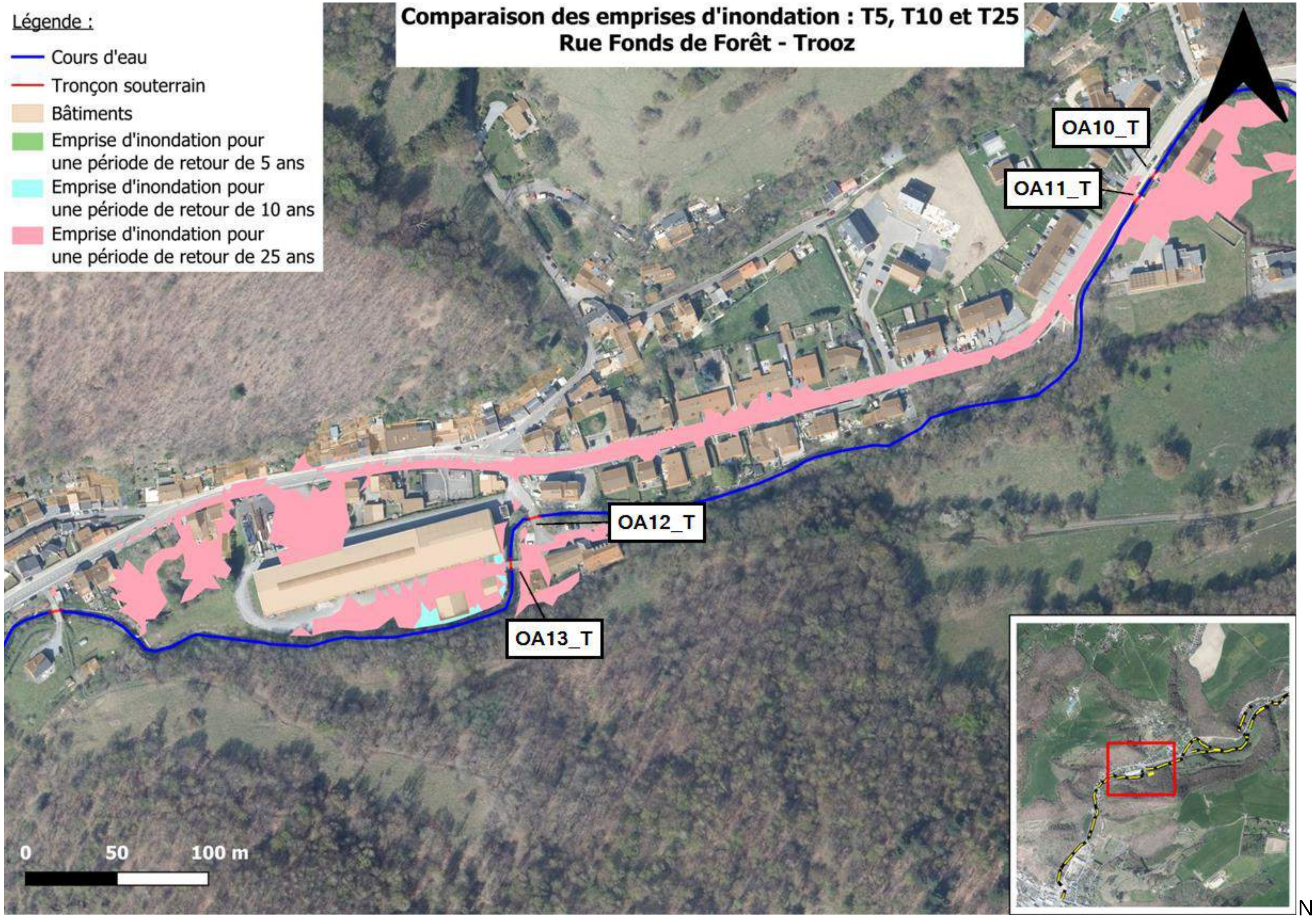


Figure 5-28 : Flood plains for return periods of 5, 10 and 25 years at the level of rue Fonds de Forêt in Trooz.

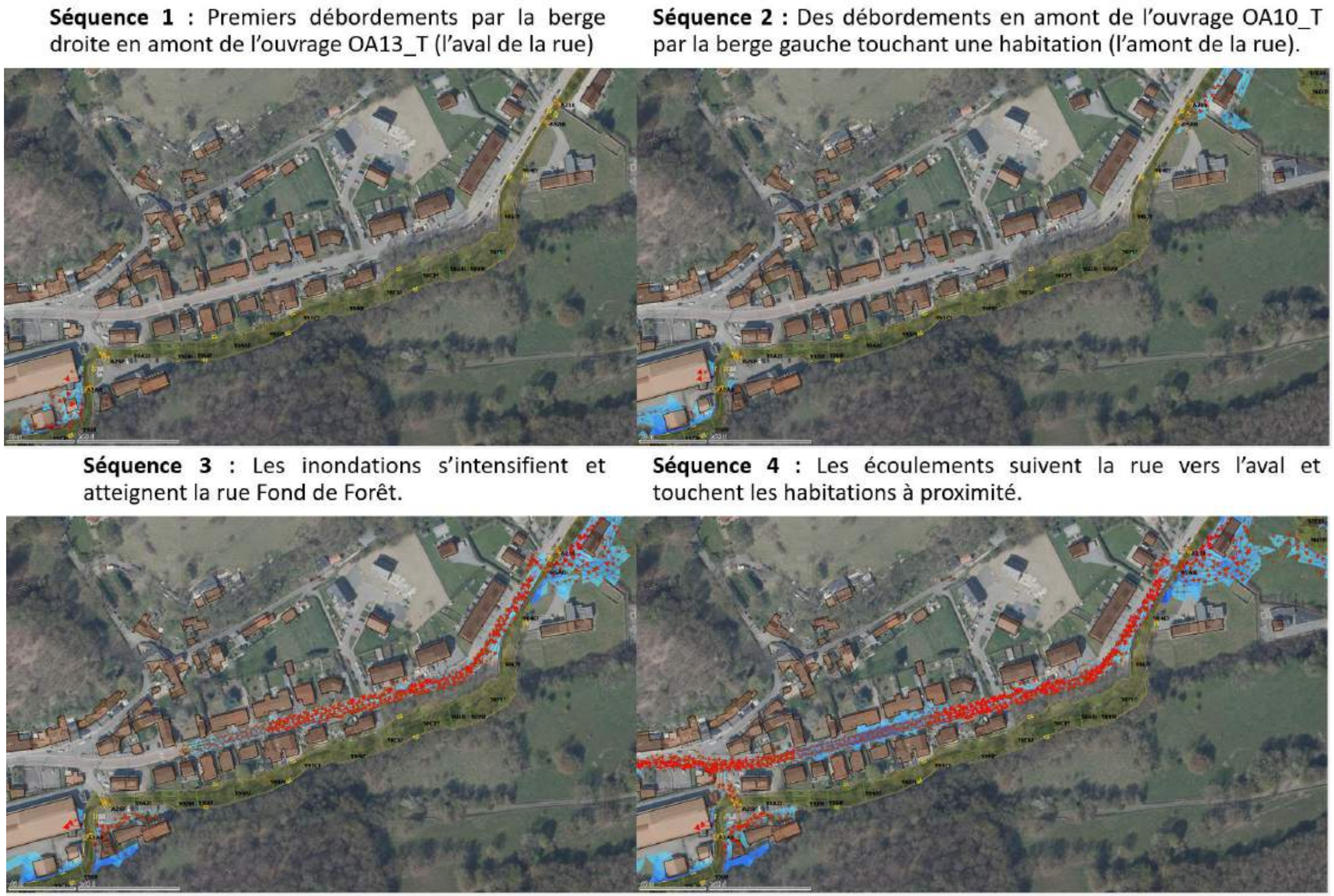


Figure 5-29 : Sequence showing the dynamics of overflows in Rue Fond de Forêt (composite rainfall with a 25-year return period).

Zone 10 - Trooz : Rue Fonds de Forêt, Rue Noirivaux, rue sur les Biez

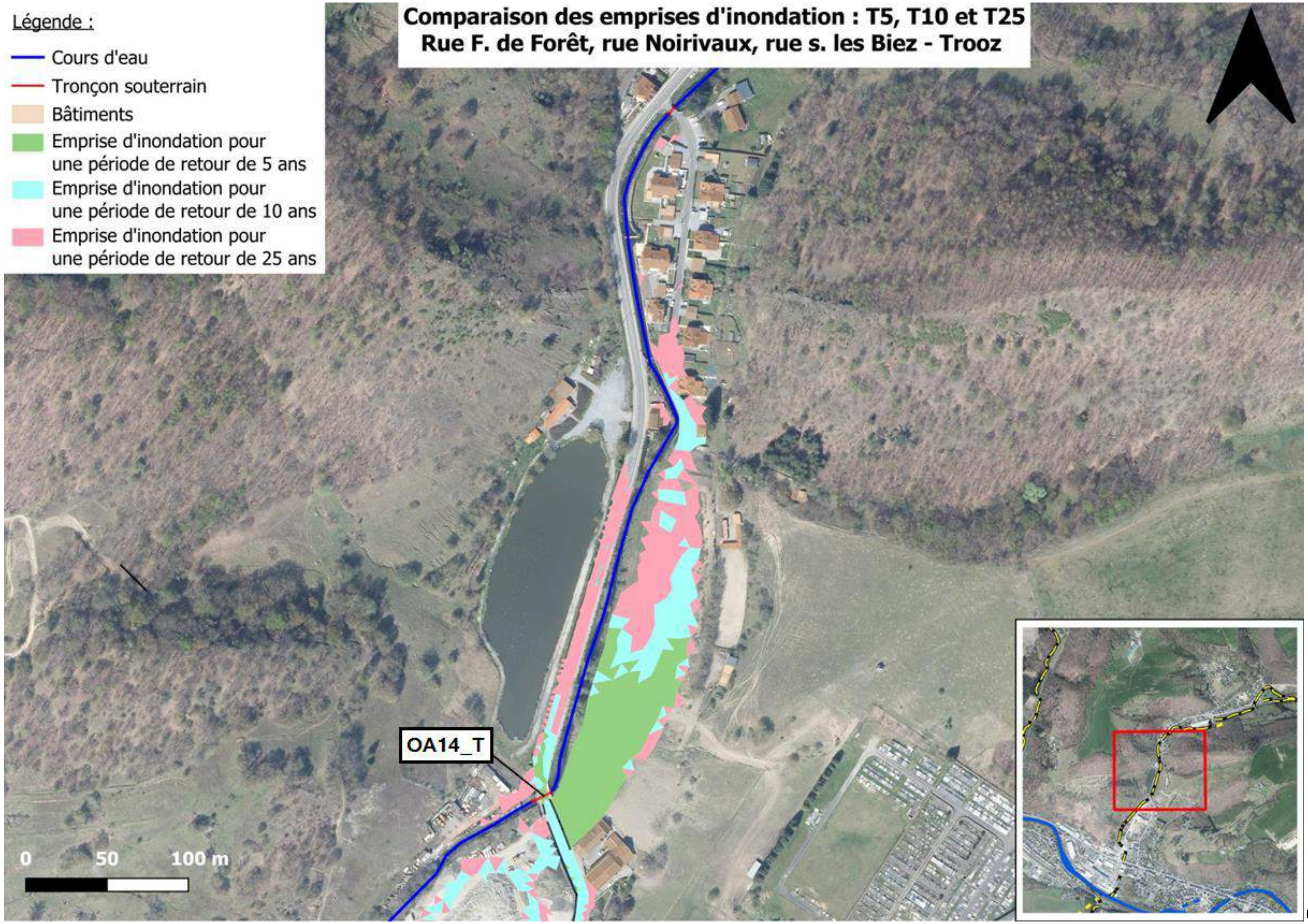
The main critical structure in this sector is structure OA14_T at the level of Rue Noirivaux, crossing the N673 trunk road. The hydraulic operating sequence for a 25-year return period is shown in Figure 5-32.

Structure OA14_T is limiting for a 5-year return period. Its maximum capacity is reached, as shown in Figure 5-30, generating overflows on the left bank, affecting the nearby dwelling.

As shown in Figure 5-31 and based on the overflow sequence in Figure 5-32, from a 10-year return period rainfall onwards, a water accumulation zone forms upstream of structure OA14_T. Overflows can pass over the N673 and reach the downstream side of the road following the slope of the land, affecting a house (rue Noirivaux no. 44), as illustrated in Figure 5-31 (the house affected is shown in Figure 5-34 in Zone 11 - Confluence with the river Vesdre). Once overflowing onto the road, flooding can also affect the car park of the Chêne S.A. company and affect nearby buildings. In addition, overflows have been observed on the left bank of the watercourse at the level of Rue sur les Biez, affecting a dwelling. For a rainfall with a 25-year return period, Figure 5-31 shows greater overflow on the right bank of the watercourse, passing over the N673 road.

The overflow area upstream of structure OA14_T was mentioned as a potential area for retention. The analysis of this proposal is detailed later in this report.

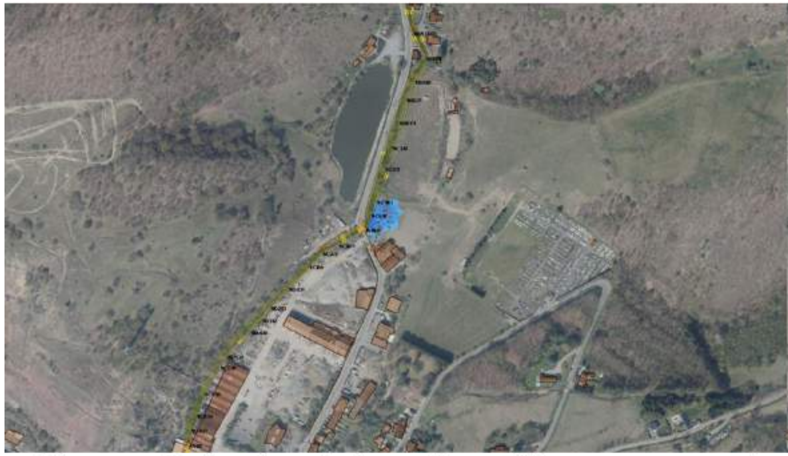
Figure 5-30 : Results of 1D-2D modelling at the most critical moment of the simulation, showing the profile of the water line (in blue) during simulated overflows on the left bank (in red) upstream of structure OA14_T (5-year return period rainfall).



OA

Figure 5-31 : Flood plots for 5-, 10- and 25-year return periods at the level of rue Fonds de Forêt in Trooz

Séquence 1 : Premiers débordements par la berge gauche en amont de l'ouvrage OA14_T



Séquence 2 : Des débordements générés également en amont, au niveau de la rue sur les Biez par la berge gauche touchant une habitation

Séquence 3 : Les inondations s'intensifient, passent sur la route N673 via le muret à côté de l'habitation n°46 et suivent la pente du terrain vers l'aval

Séquence 4 : Les débordements passent sur la route N673 par la berge droite du cours d'eau, et atteint les bâtiments de Chêne S.A. via l'entrée des véhicules situé à côté de l'ouvrage OA14_T

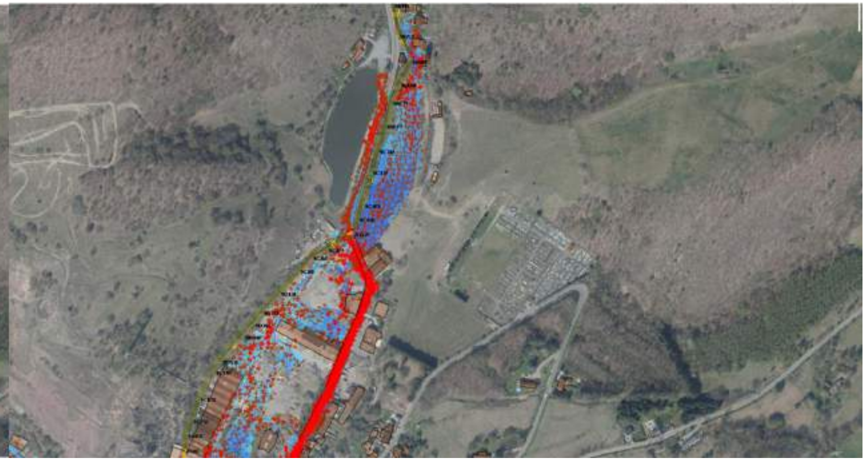


Figure 5-32 : Sequence showing the dynamics of overflows in Rue Noirivaux and Rue sur les Biez (composite rainfall with a 25-year return period)

Zone 11 – Confluence with the river Vesdre

The hydraulic analysis of this downstream section of the river Magne was carried out without applying a high boundary condition to the river Vesdre. The aim is therefore to analyse the behaviour of this sector under the basic flow conditions of the river Vesdre.

As illustrated in Figure 5-33, the analysis shows that the capacity of the various structures under the openings in this downstream section is capable of withstanding return periods greater than T25, which is acceptable compared with other critical areas in the study zone. The flooding areas shown in Figure 5-34 are essentially the result of overflows from structure OA14_T in Rue Noirivaux.

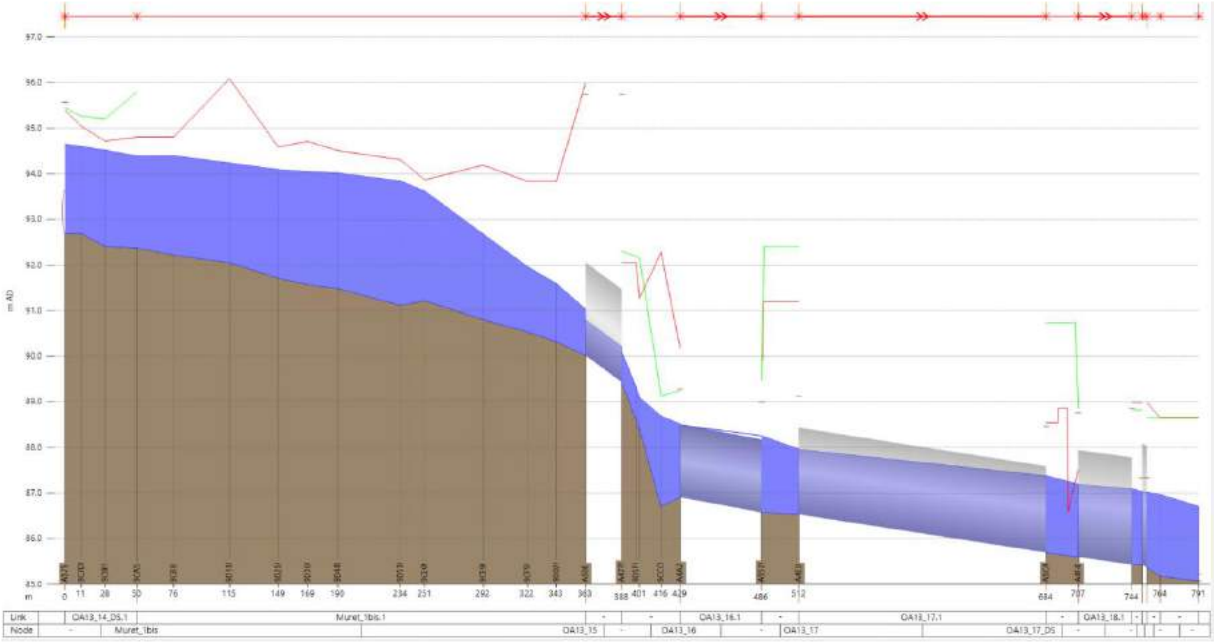


Figure 5-33 : Results of 1D-2D modelling at the most critical moment of the simulation, showing the water line profile (in blue) in the downstream part of Trooz (composite rainfall with a 25-year return period).

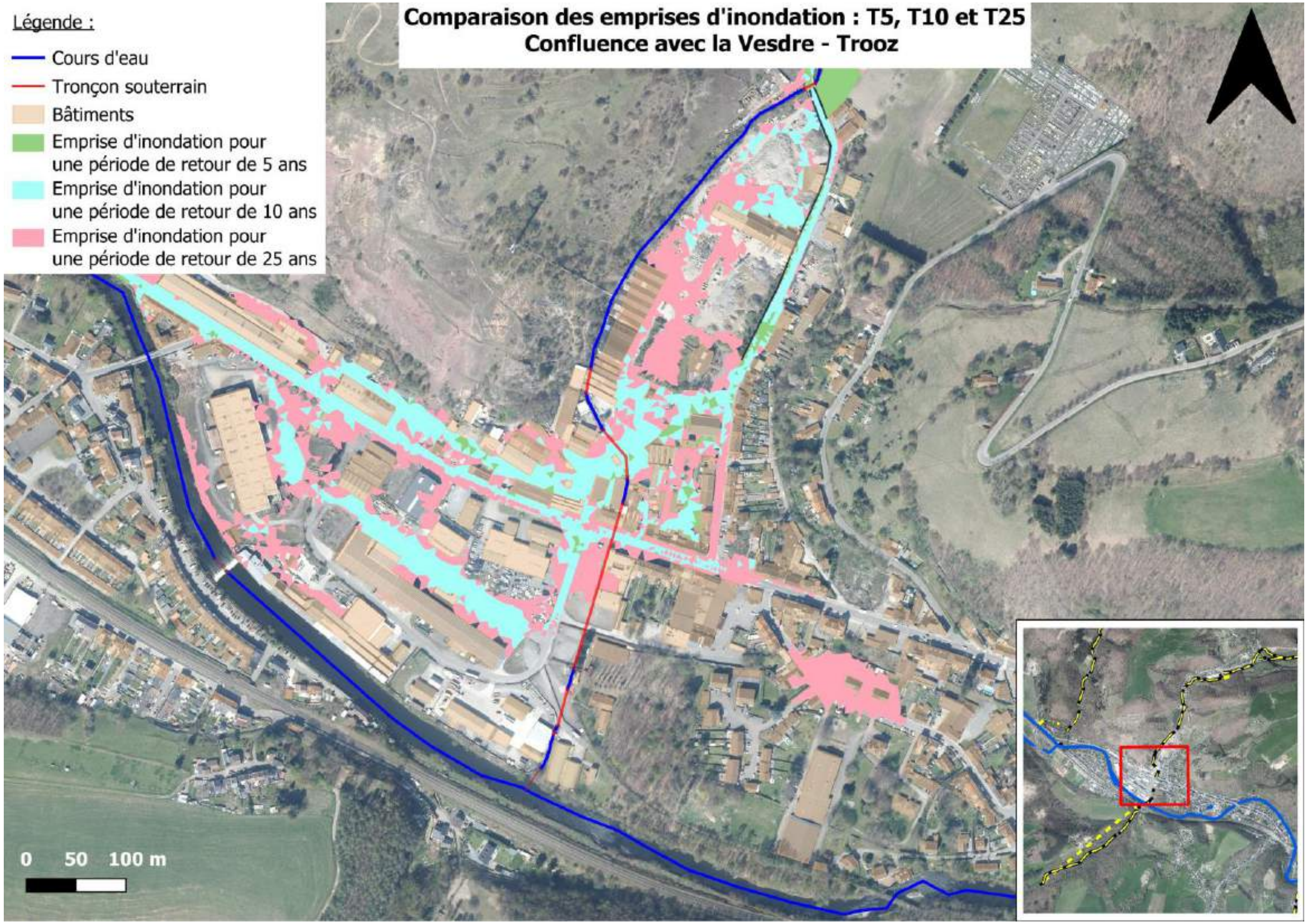


Figure 5-34 : Flood plains for return periods of 5, 10 and 25 years downstream of Trooz

5.1.4 Conclusion on the diagnosis of the existing situation

The hydraulic analysis enabled us to analyse the most likely causes of the overflows observed, highlighting certain critical areas, even for small return periods, such as in Herve in rue d'Elvaux (critical situation for a return period of 5 years). This is an example of the historical modification of the watercourse, which has been constrained in certain sectors by being placed under an orifice when it was naturally free surface. These hydraulic bottlenecks have a major impact on flooding by overflowing watercourses. In other situations, the overflowing of the watercourse occurs for more significant return periods of 25 years or more extreme and must be relativized with regard to the natural phenomenon of overflowing of watercourse (natural overflow in the major bed which can in theory occur frequently for small return periods of 5 years). However, the events of June 2018 and July 2021 were extreme in scale and therefore had a major impact on the areas analysed as part of the hydraulic analysis presented above.

An analysis of the existing situation in the most critical areas of the catchment reveals a number of facts:

- A number of structures are particularly critical on the Magne stream and are responsible for overflows affecting nearby homes. The characteristics of these structures, including their permissible flows and critical return periods, are detailed in Appendix 8.4. The most critical structures in the study area in terms of their impact on sensitive areas are:
    - o Under-passage in rue d'Elvaux in Herve, limiting by T5
    - o Under aperture in Soumagne, limiting by T10
- The analysis showed the value of improving hydraulic configurations such as the Fond des Gottes stream in Soumagne. The structure is not limiting for small return periods, but the configuration of the area in the face of extreme events leads directly to significant damage to the few houses upstream. The available data, in particular the zoom under the road, show the interest of studying a scenario to improve the hydraulics in this sector.
- There are therefore opportunities to improve the hydraulic capacity of certain structures or to adjust their configuration, particularly in terms of slope, position in relation to the watercourse and proximity to other structures. There is also an opportunity to modify these structures by opening up the watercourse. A scenario along these lines will be studied in Rue d'Elvaux.
- The analysis also highlighted the importance of the microtopography and structuring elements in the major bed: borders or low walls, or even barriers, have a significant impact on flows once the watercourse overflows. The overflowing nature of certain sectors can also be indirectly linked to overflows upstream, as is the case in Trooz with overflows in rue Bay Bonnet or Fonds de Forêt, which affect neighbourhoods further downstream through subsequent runoff onto the road.
- Areas of water accumulation form naturally in topographical basins in certain sectors of the major bed, and could be exploited as Temporary Immersion Zones (ZIT) to reinforce their floodable nature. In addition, certain sectors have also been mentioned as being of interest by the municipalities and the Province, and their potential will be analysed.

6 Identification and/or optimisation of relevant solutions

Based on a hydraulic diagnosis of the existing situation, improvement solutions were identified for the most critical areas. Various individual scenarios were tested in the model to assess their impact on overflows. At this stage of the analysis, 5 scenarios have been analysed:

- The creation of TIZs upstream of rue d'Elvaux near the Herve wastewater treatment plant
- Modification of the existing sluiceway in rue d'Elvaux, opening up a section of the watercourse
- The effect of raising the weir of the Soumagne storm water basin on the areas to be protected
- Modification of the existing opening in the Gottes stream at Soumagne
- The creation of a TIZ in rue Noirivaux in Trooz

6.1 Solutions in Herve

6.1.1 Scenario 1 : two TIZs in a row near the wastewater treatment plant

Concept of the scenario

According to the previous analysis of the existing situation, the most critical area in Herve is Rue d'Elvaux. Quite frequent overflows, already for rainfall with a 5-year return period, occur at the level of the sluice which takes the watercourse upstream from the street, thus affecting nearby homes. To mitigate these recurrent overflows, one of the solutions being considered is to set up Temporary Immersion Zones upstream of the site. This would have the effect of smoothing the flood hydrograph by reducing the peak flow and spreading the flood, thus allowing the water to flow more favourably through the central conduit of rue d'Elvaux.

Location and available storage volume

The most suitable location upstream of the critical area in rue d'Elvaux is the meadows surrounding the watercourse upstream of the treatment plant. An analysis of the topography of the area could lead to the installation of 2 structures in a row. The plot areas of these TIZs are shown in Figure 6-1 below, and their location in the catchment area can be seen more generally in Figure 6-3. At this stage of the analysis, a number of assumptions have been made to determine the feasibility of installing these structures on the watercourses. Table 6-1 summarises the main characteristics of the TIZs. The static volume available for each structure as a function of the planned height of the embankment is estimated on the basis of the DTM. The analysis indicates that TIA01 could release a static volume of around 23,000 m³ and TIA02 a static volume of 7,500 m³.

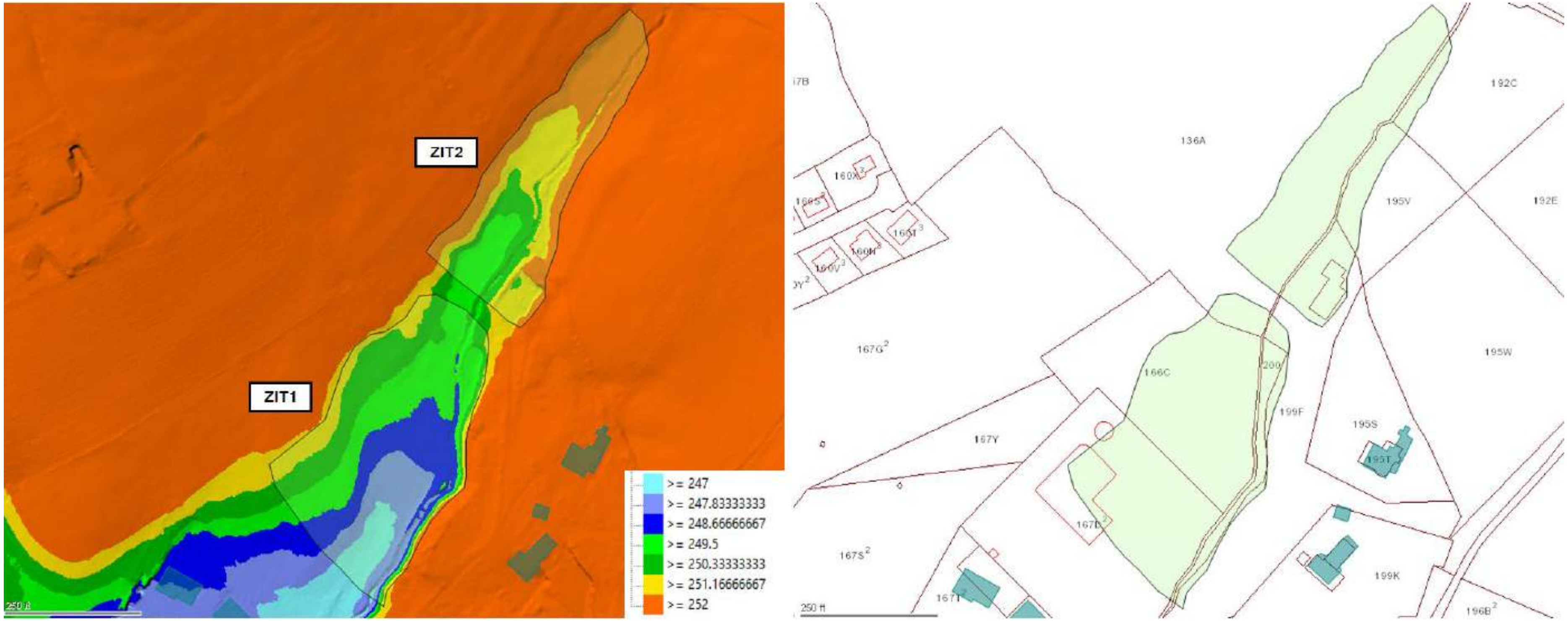


Figure 6-1 : Approximate location of the TIZs in relation to the digital terrain model and the cadastral map

Table 6-1 : Main characteristics of the TIZs in Herve

Characteristics	TIZ 1	TIZ 2
Flood plot (ha)	1.04	0.8
Max. dam height (m)	4	3
Max dam length (m)	89	68
Volume before spillage (m³)	23100	7500

Estimated volume to be stored

In the first instance, the estimate of the permissible flow rate at the outlet of the structures is based on the permissible flow rate to be respected downstream in line with the area to be protected. In addition, a safety coefficient should be applied to the permitted flow at the outlet of the TIZ if the retention structure is not located directly upstream of the area at stake and if additional intermediate contributions not controlled by the structure may occur, which is the case in the configuration discussed since approximately 60% of the surface area of the catchment is uncontrolled.

According to the hydraulic analysis, the permissible flow at the level of Rue d'Elvaux is approximately 2.4 m^3/s to avoid flooding. The table below shows the volumes that would have to be stored if a structure were placed directly upstream of the floodgate (i.e. directly at the level of Rue d'Elvaux) to ensure that this flow rate was respected for return periods of 5 years, 10 years and 25 years. It can be seen that the volumes to be stored are substantial and that there is no directly suitable place to store them elsewhere.

Table 6-2 : Volume to be stored (m^3) in function of leakage flow for return periods T5, T10 and T25 years, if a structure were to be positioned just upstream of Rue d'Elvaux

.

Coefficient security	Leakage rate (m^3/s)	Total volume T5 (m^3)	Total volume T10 (m^3)	Total volume T25 (m^3)
1.00	2.40	15648	22072	38724
0.80	1.92	19484	26821	44991
0.60	1.44	24882	33295	55536
0.40	0.96	32339	43033	68226

The location of the TIZs in the catchment shows that only around 40% of the catchment would be controlled by the structures, with the other 60% coming from Herve with its many urban areas. Analysis of the flows passing through each part of the catchment for a 5-year return period (see Figure 6-2) shows that the planned TIZs would never enable the 2.4 m³/s permissible flow to be complied with, since the flood hydrograph for the additional intermediate inflows would already reach more than 6 m³/s for this 5-year return period. **In other words, even if all the inflows from the eastern part of the catchment area controlled by the TIZs were stored for a 5-year return period and the flow from this part of the catchment area were zero, there would still be overflows at the level of Rue d'Elvaux.**

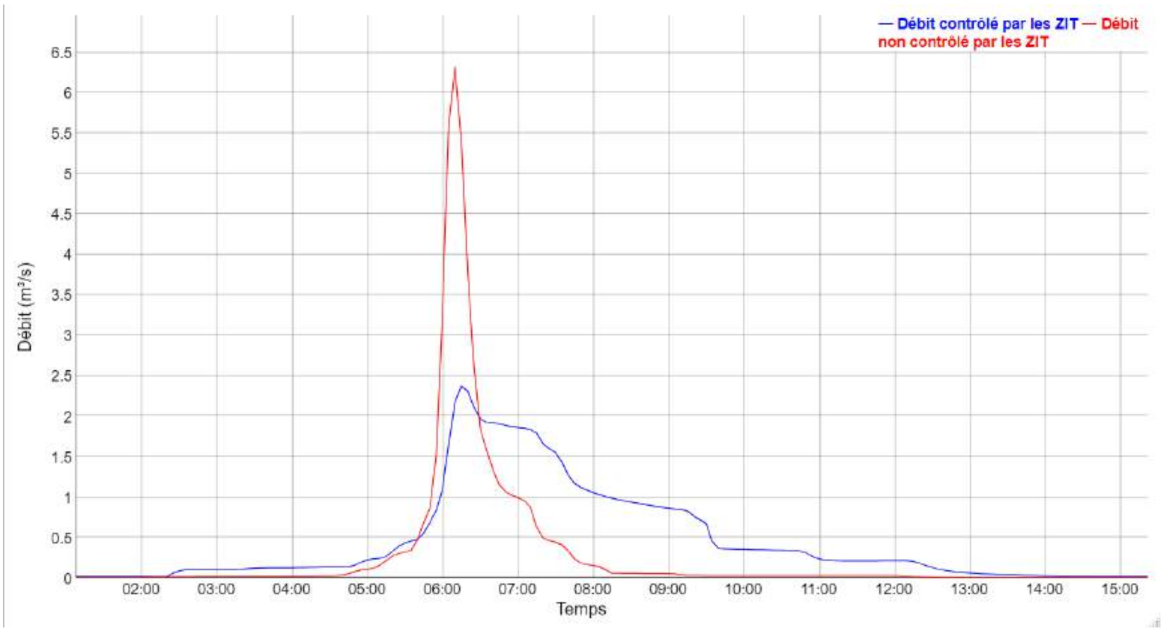


Figure 6-2 : Comparison of flood hydrographs simulated by the 1D-2 hydrological-hydraulic model upstream of the TIAs (in blue) and upstream of Rue d'Elvaux (in red) (composite rainfall with a 5-year return period)

Despite this observation, which clearly shows that these TIZs would not make it possible to avoid a flooding problem in Rue d'Elvaux due to a high peak flow, we have estimated a potential volume to be retained in the TIZs by taking a variable leakage flow at the outlet of the structure of between 1 and 0.4 m³/s. The table below shows the volumes to be retained at the future TIZs in function of the return period and the variation in the leakage rate. It appears that around 27,500 m³ would be needed to retain a 25-year return period rainfall in this sector, assuming a leakage rate of 0.4 m³/s.

Table 6-3 : Volume to be stored (m³) as a function of leakage rate for return periods T5, T10, T25, T50 and T100 years

Coefficient security	Leakage rate (m³/s)	Total volume T5 (m³)	Total volume T10 (m³)	Total volume T25 (m³)	Total volume T50 (m³)	Total volume T100 (m³)
1.00	1.00	5415	7700	13437	16851	23595
0.80	0.80	7385	10077	17635	21715	28738
0.60	0.60	9908	13329	22454	27259	34858
0.40	0.40	12667	16927	27491	33107	41866

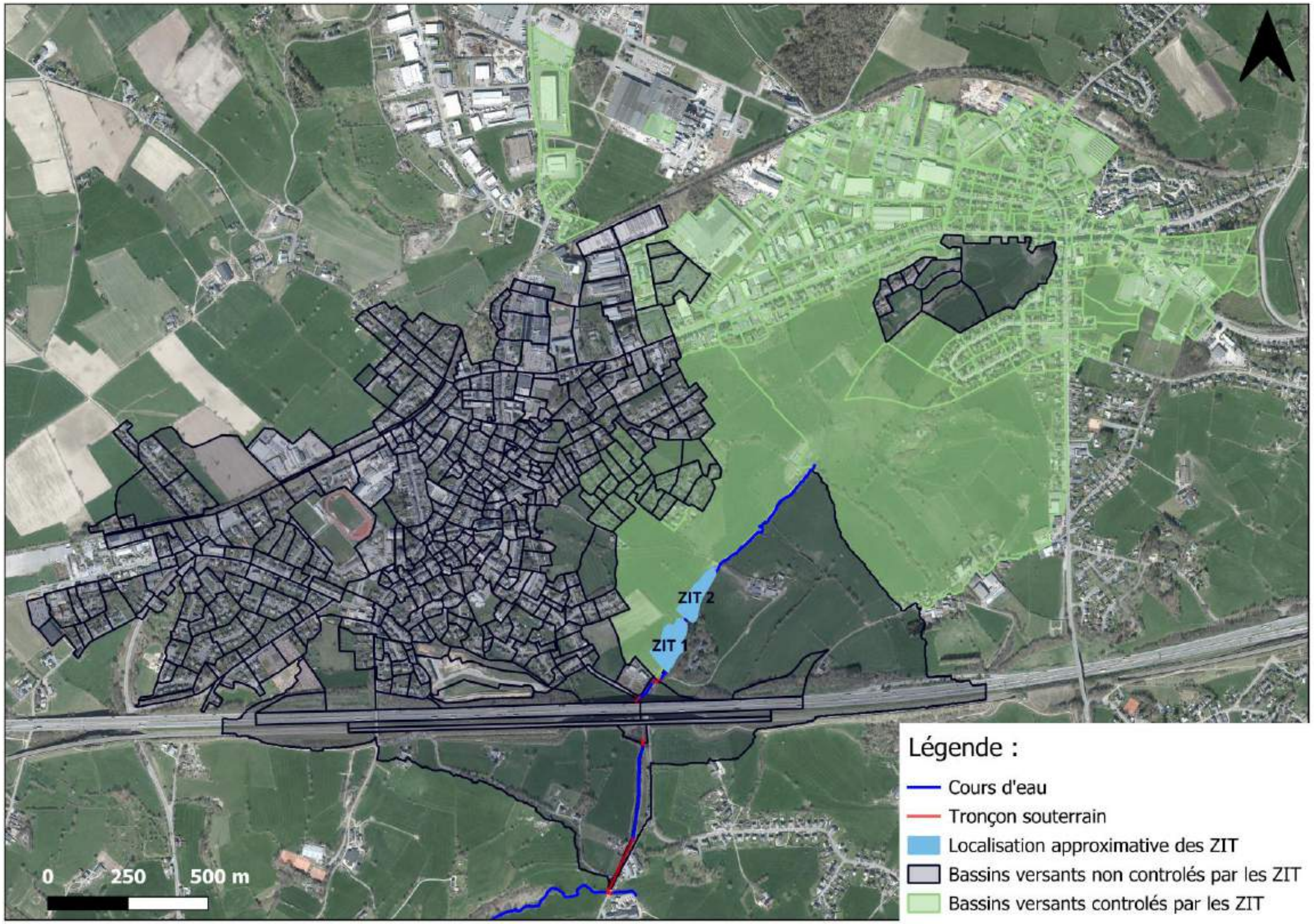


Figure 6-3 : Mapping of the sub-catchments controlled by the Herve TIZs

Conclusions on the benefits of TIZs in Herve

The analyses presented above show that:

- The percentage of the catchment area controlled by the structures is too low (only 40% of the catchment area). The peak flow coming from the other part of the catchment is very high and exceeds the capacity of the opening at the level of Rue d'Elvaux, even for a return period of 5 years. Installing this type of structure upstream of the area to be protected is therefore not enough to solve the flooding problem. Other solutions will have to be found, in particular increasing the admissible capacity of the area to be protected.

- In the event that the inflows from the rest of the catchment area were better controlled in the future by the installation of other control structures, for example, and that the peak flow in the uncontrolled part of the catchment area were close to 2 m^3/s for up to 25 years, the possibility of installing TIZs in the meadows near the treatment plant would make it possible to recover a return period of **25 years by considering a leakage flow of 0. 6 m^3/s when comparing the volume of storage available with the volume required**, which is considered potentially **satisfactory**. However, this scenario has not been analysed and needs to be the subject of a more global vision of the catchment area, including work on upstream urban inputs

6.1.2 Scenario 2: modification of the opening in rue d'Elvaux and opening up of a section of the watercourse

Concept of scénario

Analysis of the first scenario revealed a negligible impact from the implementation of two TIZs in the meadows surrounding the Herve wastewater treatment plant, due to uncontrolled inputs from around 60% of upstream catchments (both rural and urban). A second scenario is being studied to protect Rue d'Elvaux, involving modifying the sluiceway and opening up a section of the watercourse. This would not only increase the hydraulic capacity of the structure, but also take advantage of this modification to return the watercourse to an open surface, which was its historical configuration (see also Figure 6-4) and offers advantages such as reducing the risk of clogging and renaturation of the watercourse.

The main changes compared with the existing situation would be (see also overview showing the main elements selected in Figure 6-5):

- Opening of the roadway and replacement of the existing opening;
- On the upstream section, a larger opening is designed to increase hydraulic capacity;
- On the downstream section, the existing opening will be replaced by an open watercourse. The free-flowing section will initially run parallel to the road and will then be gradually moved away from it to change the location and orientation of the current confluence between the river Magne and its tributary. A passage under the roadway must be preserved in order to reach Rue du Château;
- New modifications to the existing microtopography on the surface to facilitate downstream flow in the event of saturation of the channel.

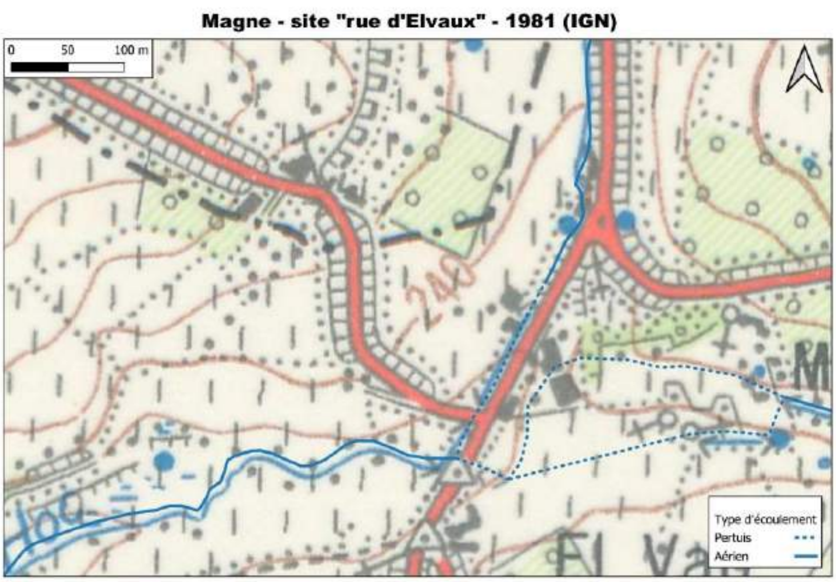


Figure 6-4 : Situation in 1981 of the river Magne in the open along the roadside from downstream of the houses in rue d'Elvaux (the watercourse passes under rue du Château)

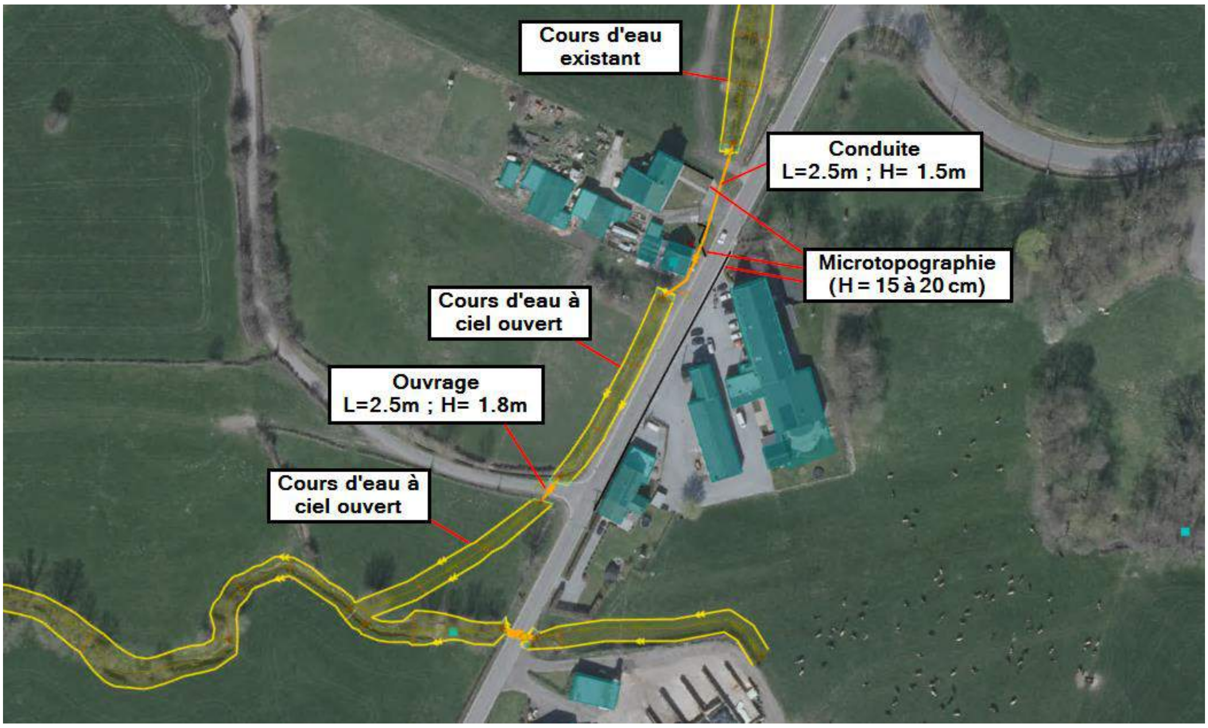


Figure 6-5 : 1D-2D modelling of scenario 2

Sizing of the sluiceway taking in the river Magne

In order to determine the new dimensions of the pipe in Rue d'Elvaux, an analysis based on the upstream flow was carried out, taking into account a slope of 0.02 m/m. A width of 2.5 m was set on the basis of the existing watercourse gauge, and the height was adjusted on the basis of the upstream flow for return periods of 5 to 100 years. Table 6-4 below summarises the different heights of the new pipe as a function of the return period. The dimensions adopted for the opening at this stage are ultimately 2.5 m wide by 1.5 m high, allowing a 50-year return period flood to pass through theoretically. The future passage area will therefore be 3.75 m² instead of 2 m² in the existing situation.

Tableau 6-4 : Determination of the dimensions of the pipe in rue d'Elvaux according to the upstream flow for each return period between 5 (T5) and 100 years (T100).

Return period	Upstream flow (m^3/s)	Fixed width (m)	Height of the opening (m)
T5	9	2.5	1.1
T10	11	2.5	1.3
T25	13	2.5	1.4
T50	14	2.5	1.5
T100	15	2.5	1.6

Reopening of the river Magne at the level of rue d'Elvaux

Based on discussions with the Stream&River Consult consultancy firm, the river Magne could be opened up again from downstream of house no. 110, in conjunction with the upstream pipe, which would reduce the risk of flooding in the area.

This would require the following modifications:

- Digging a new drainage channel between the road (rue d'Elvaux) and the meadow on the right bank.
- Passage of this channel under Rue du Château. The dimensions of the passage under the road are:
  o Width = 2.5m ;
  o Height = 1.8m;
- Extension of the new channel in the meadow downstream of Rue du Château;
- Development of the confluence point with the existing watercourse.

Figure 6-5 illustrates this development scenario as reproduced in the model.

In addition to the flooding benefits, this scenario offers advantages from a biological point of view. A number of practical recommendations should be considered and are set out below.

- **Longitudinal ecological continuity**

Generally speaking, the reduction in the length of the channel (from 175 m to 59 m) will be favourable to the free movement of fish. To optimise this benefit, a number of points need to be considered:

- No waterfall at the downstream junction with the preserved channel;

- Depth of water and average flow velocities at low water compatible with the swimming capacity of fish (target species: fario trout);

- Passage under Rue du Château: the optimum configuration is a rectangular passage, maintaining the continuity of the natural stony bottom of the channel under the structure. If a concrete slab is unavoidable, care should be taken to maintain a sufficiently deep-water gap during low-water flows, as well as a rough surface (fixed deflectors) to both diversify the flow and concentrate the flow of water during low-water flows. Avoid any falls downstream of the structure;

- When redesigning the existing upstream opening, it is essential to ensure that the depth and average water velocities meet the same criteria for fish passage. If necessary, it is possible to add roughness to the bottom of the structure, but this must be done in such a way as not to compromise the hydraulic capacity of the structure. The aim is to create a balance between protecting aquatic fauna and maintaining the hydraulic performance of the structure.

- **New channel**

Given the local configuration and constraints, the route of the new channel would be straight from the outlet of the sluice to the meadow at the level of the Rue du Château, then it would curve and meander to ensure the downstream junction with the existing watercourse.

About the specifications :

- The width of the channel: will be calculated in such a way as to guarantee a depth and flow speeds in line with the ecological requirements of fish, in particular the target species which is the brown trout;

- The bottom of the channel: would be made of stony materials, chosen according to a geological composition compatible with the site, with a grain size adapted to the flow conditions to ensure its stability. Fixed boulders could be placed at random along the bed to diversify the flow.

- Cross-sectional profiles: given the slope, the straight part of the new channel will be of the "invert" type (shallow, turbulent rapid flow), while a deeper zone ("anchorage") may be created in the downstream bend.

The preliminary dimensions of the channel are:

  - Base width = 2.5 m;
  - Total width = 6.5 m;
  - Depth = between 1.1 and 1.6 m.

- **Protecting banks against erosion**

- Straight part of the channel: the left bank is constrained by the road, and rockfill bank protection will prevent any lateral erosion. On the right bank, a natural bank could be created, with planting (establishment of a tree-lined riparian buffer zone) to provide rapid stabilisation (willow cuttings on the bank slope) and lasting stabilisation (tree planting at the bank crest.

- Downstream meandering section: a string of trees can be planted on both banks, in continuity with the existing trees on the downstream section. Specific protection can be provided in the extrados of the bend: live willow fascines at the foot of the bank (see figure below), combined with willow cuttings (+ coir geotextile) on the embankment.

- At the confluence with the existing watercourse: bank protection will be reinforced at the confluence of the two watercourses to prevent the risk of erosion (fascine on the left bank + planting).

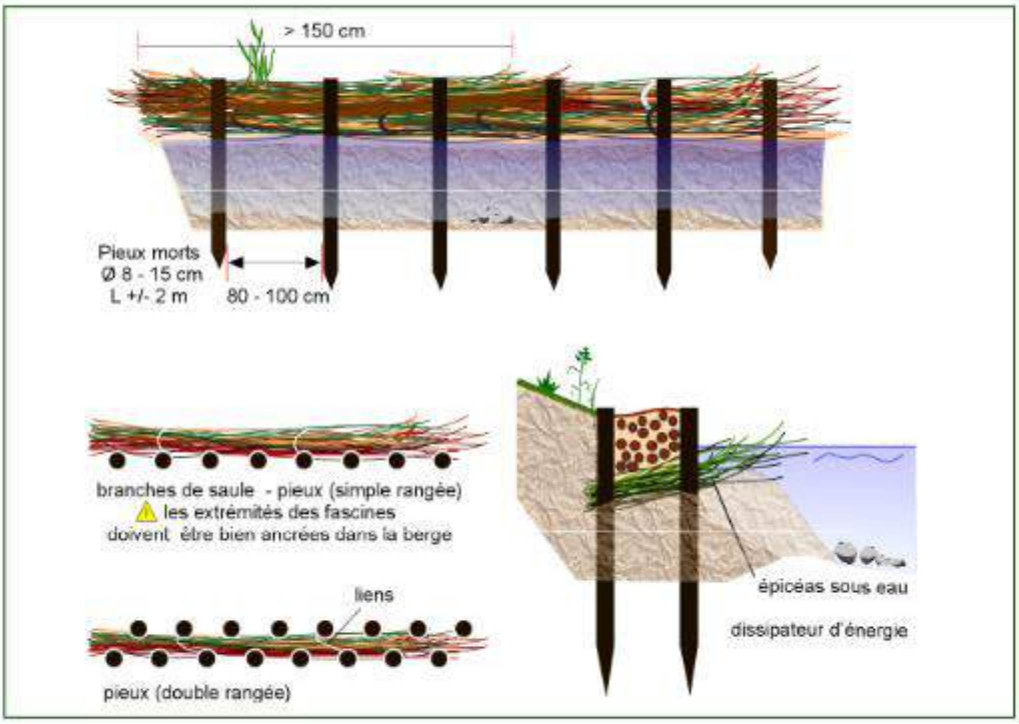


Figure 6-6 : Protection of the foot of the bank by gabion.

Impact on flooding in rue d'Elvaux

The various elements are integrated into the modelling of the existing situation as shown in Figure 6-5.

The results of the scenario modelling, including the various structural elements mentioned above, show a positive impact compared with the current situation, as illustrated in Figure 6-7. The scenario significantly reduces overflows in Rue d'Elvaux. For a 5-year return period, there is no longer any overflow in Rue d'Elvaux, significantly reducing the flooded area and the issues affected. For a return period of 10 years, slight overflows are observed on the street without, however, affecting the dwellings. The overflow caused by T10 is linked to head losses upstream of the structure due to high velocities, as the pipe itself is not at full capacity. For more extreme rainfall events, such as those with a 25-year return period, only house n°110 is slightly affected by overflow, with a simulated water height of around 5 cm at the level of the house. This represents a significant improvement on the current situation, where the simulated water level reaches 30 cm for a return period of 5 years.

As shown in Figure 6-7, overflows upstream of structure OA02_H are less significant than in the existing situation. Thanks to the additional modification of the microtopography on the left side of the road downstream (height above ground of around 15 to 20 cm), at the level of building no. 101J, the overflows which follow the slope of the land from upstream to downstream do not affect any dwellings. What is more, the new channel was essentially designed to overflow on the right bank in order to exploit the neighbouring meadows without affecting nearby buildings. No overflow on the left bank, on the road, has been observed for the 25-year return period.

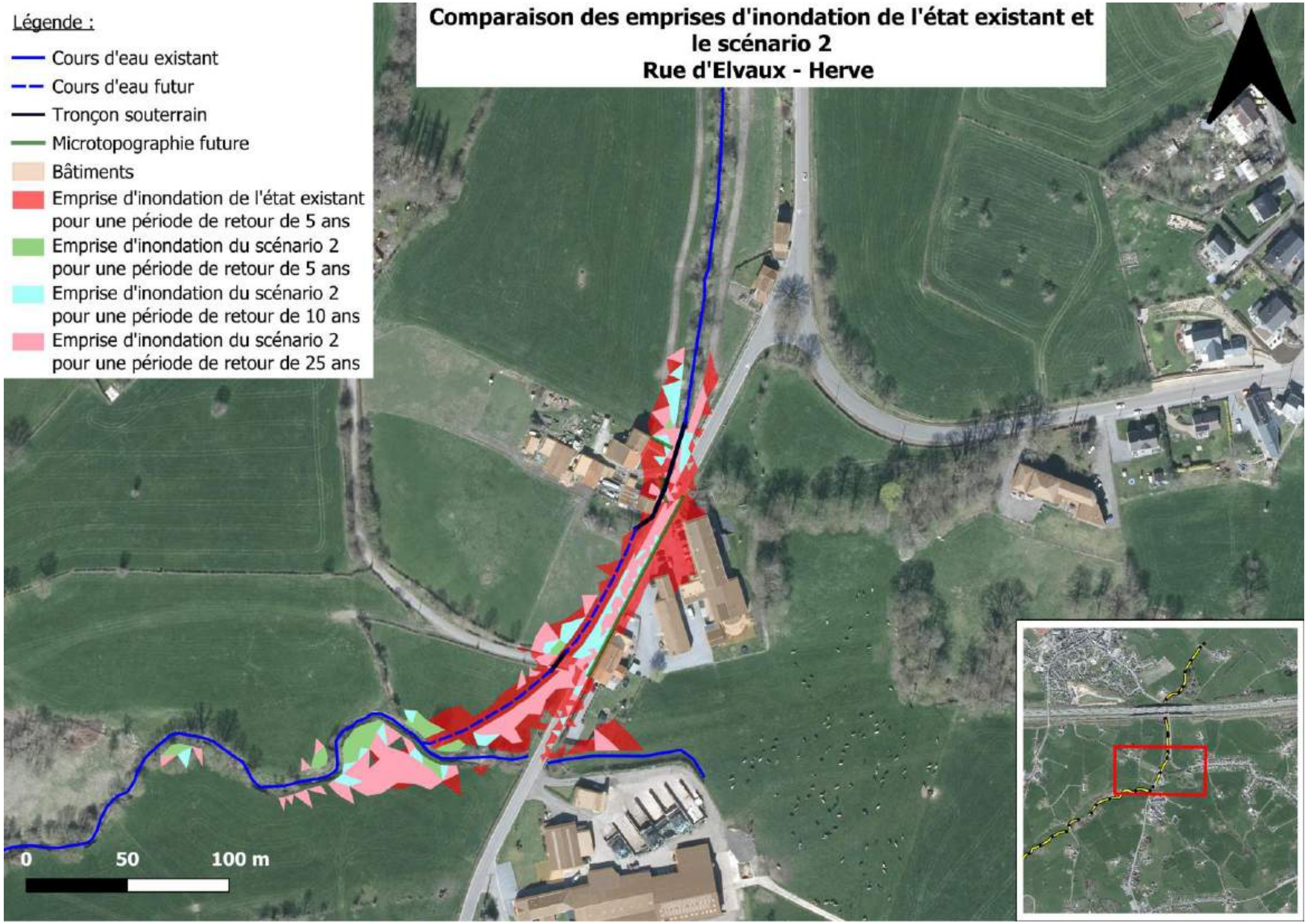


Figure 6-7 : Comparison of the flooding areas of the existing situation (composite rainfall with a return period of 5 years) and scenario 2 (composite rainfall with a return period of between 5 and 25 years)

Conclusions on the benefits of improvements to Rue d'Elvaux

Analysis of a scenario in Rue d'Elvaux has shown the benefits of modifying the hydraulic capacity in this sector. The gains in terms of flood reduction and environmental enhancement are significant for return periods of more than 10 years. Because of the high flow velocities in the area, overflows may still occur even though the sluiceway is not saturated. It is therefore necessary to provide the necessary microtopography on the surface to guide runoff downstream and down Rue d'Elvaux. This will provide effective protection for some homes. Lastly, individual protection measures can further enhance the level of protection in certain areas by protecting the entrances to key zones.

6.2 Solutions in Soumagne

6.2.1 Scenario 3 : Raising the weir of the Soumagne storm water basin

Concept of the scenario

The spillway is to be raised to increase the retention capacity of the Soumagne storm water basin. The planned raising will bring the current spillway level of 201.43 mDNG to a level of 202.03 mDNG, i.e. a rise of around 60 cm. The aim of this scenario is to assess the effectiveness of the modification compared with the existing situation. It is assumed at this stage that there is no change in the level at which the gate is opened compared with the existing situation.

Analysis of the effect of modifying the level of the basin weir at the structure

The results of the simulations indicate that the planned modifications have effectively improved storage in the storm water basin. Table 6-5 shows that the new configuration of the basin does not activate the spillway at T50, which is greater than the existing situation. The additional storage volume is relatively small per T25 and reaches up to 9100 m³ for a return period of 100 years (it should be noted that the storage volume includes the storage volume on the direct flood plot of the basin but also the storage on the meadows upstream which are also affected by the regulation of the basin).

The relatively small difference in storage between the existing and future situations is also reflected in the hydrograph at the outlet of the structure, as shown in Figure 6-8. The main reason is linked to the fact that a constant regulation flow is not maintained as a function of the increase in the hydraulic load in the basin. As a result, despite the increase in the level of the weir in the future state, the increase in the head of water in the basin generates a potentially greater leakage flow through the control valve. The overall leakage flow from the structure between the existing and future situations is therefore little changed.

Tableau 6-5 : Summary of the volumes stored in the Soumagne reservoir for each return period studied with the leakage flow through the control valve

Return period	Max. volume stored (m³)	Additional volume (compared with existing situation)	Peak flow downstream scenario (m³/s)	Weir activation scenario	Water level scenario
T5	2600	0	6.5	Non	200.2
T10	4600	0	7.9	Non	200.5
T25	15200	440	12.3	Non	201.6
T50	23400	4300	13.9	Non	202.05
T100	36200	9100	18.3	Oui	202.5

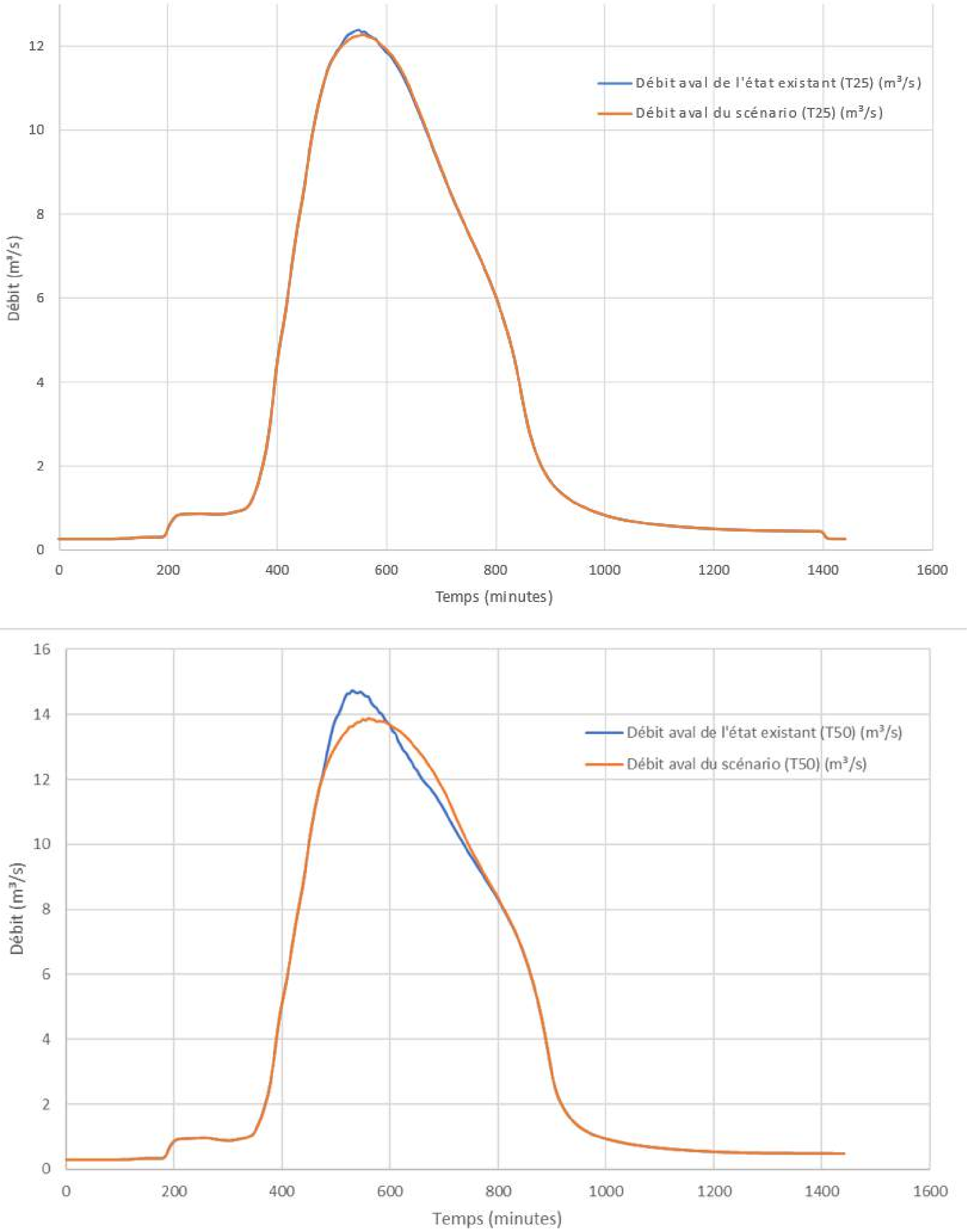


Figure 6-8 : Hydrographs downstream of the structure for T25 and T50.

Analysis of the effect of modifying the level of the Soumagne basin weir

In the centre of Soumagne, at the level of Place Ferrer, the new configuration of the storm water basin does not seem to improve the situation in terms of overflows upstream of structure OA05_S, which is consistent with the small difference observed directly downstream of the structure. Consequently, it would be interesting to study the effect of reducing the level of the control gate on overflows for return periods ranging from 25 years to 100 years. It also seems important to consider a variation in the level of the gate in function of the hydraulic load in an attempt to maintain a more constant value for the leakage flow when the water level in the basin rises.

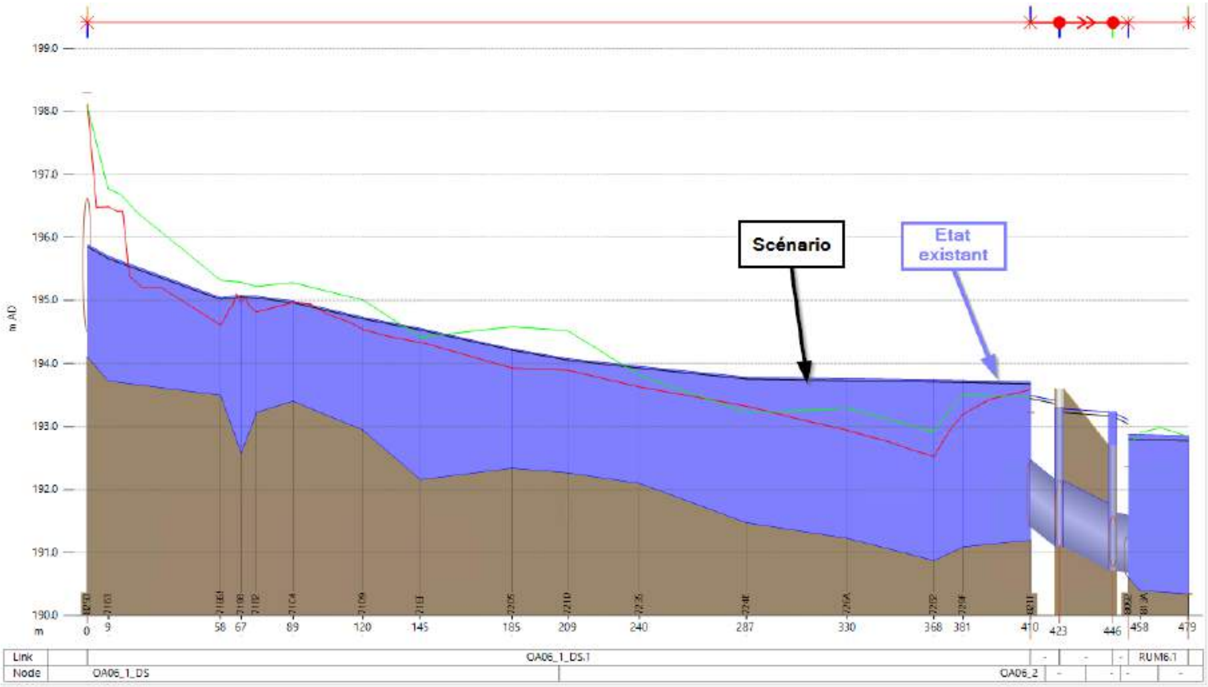


Figure 6-9 : Results of 1D-2D modelling at the most critical time comparing the water line profile of the existing situation (in blue) and the future scenario (in black) for a composite rainfall with a 50-year return period.

Conclusions on the modification of the level of the weir of the Soumagne storm water basin

The increase in storage in the storm water basin is relatively limited and does not result in a sufficient change in the flood hydrograph before and after modification. The main reason for this is that the flow through the valve increases as the level in the basin rises. It would therefore be advisable to analyse in more detail:

- The effect of reducing the level of the sluice gate on the flow in Soumagne
- The advantage of maintaining a constant leakage flow at the outlet of the structure so as not to increase the outlet flow when the water level in the basin rises.

6.2.2 Scenario 4: modification of the existing opening on the Gottes stream in Soumagne

Fond des Gottes, a tributary of the river Magne, was the cause of significant overflow during the July 2021 event, affecting neighbouring homes. According to the hydraulic assessment (see section 5.1.2), the main cause of the overflows observed at this site was the highly restrictive configuration of the two 1000 mm diameter pipes that run under the N621 road (chaussée de Wégimont). The diagnosis revealed that there is a misalignment at the internal junctions between the upstream and downstream pipes in the current situation, which could lead to overflows after a return period of 50 years. The aim of this scenario is to propose a better configuration of the two pipes to improve the flow during major floods.

Approach 1: Improving the current configuration of the two pipes

The first approach tested in the model consists of removing the current misalignment and installing two pipes in parallel, while maintaining a diameter of 1000 mm for each.

The modelling results, illustrated in Figure 6-10, show that this first approach improves the situation in terms of overflows upstream of the pipes. Laying the two 1000 mm diameter pipes in the correct alignment facilitates flow transfer. With this new configuration, overflow occurs mainly on the right bank of the watercourse for a return period of 100 years, without affecting neighbouring dwellings. For a rainfall with a return period of 200 years, significant overflow is nevertheless observed upstream of the pipes, affecting neighbouring houses. There is therefore overflow onto the road and flooding of this basin area for T200 with two D1000 pipes.

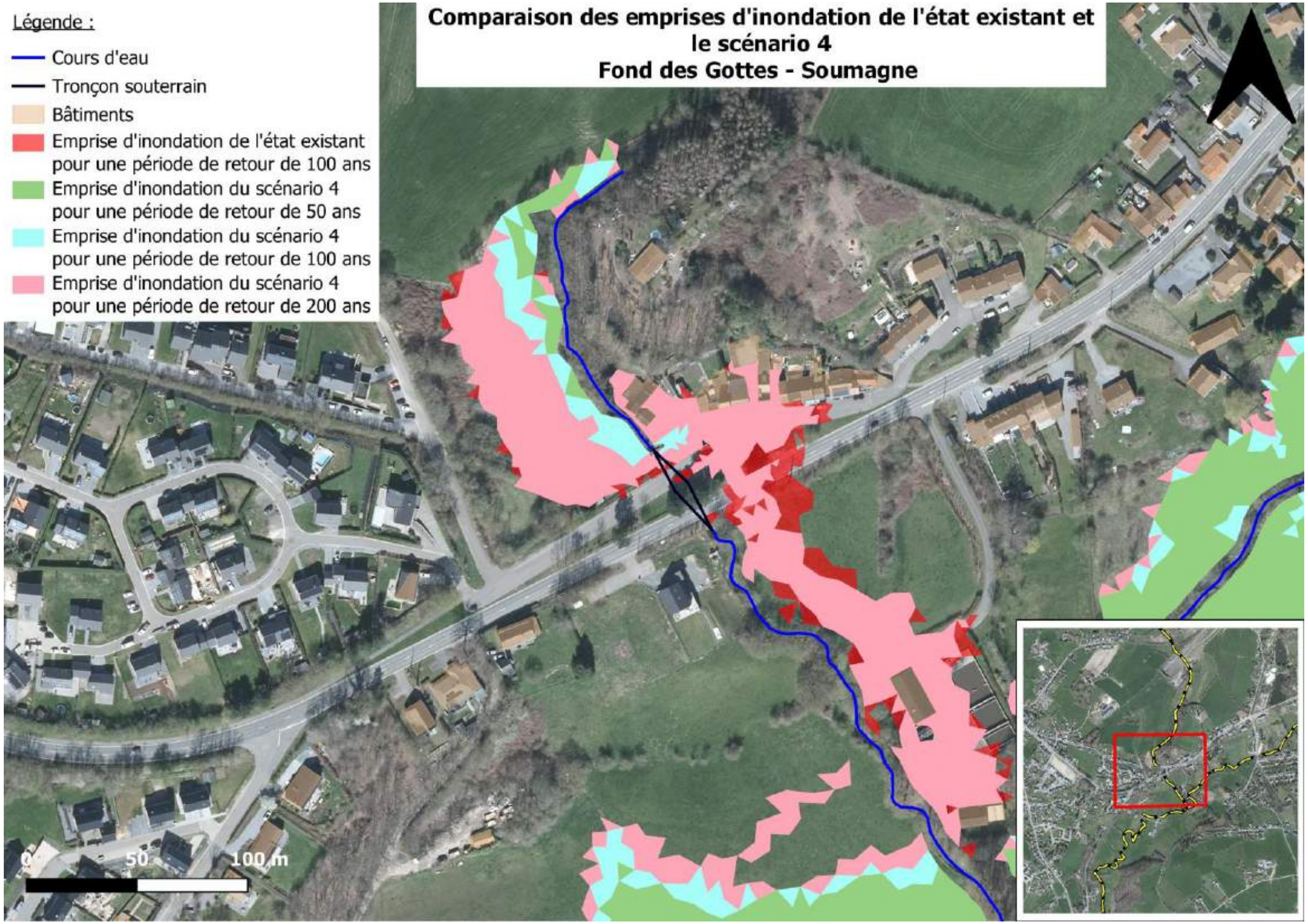


Figure 6-10 : Comparison of the flooding areas of the existing situation (composite rainfall with a return period of 100 years) and scenario 4 (approach 1) (composite rainfall with a return period of between 50 and 200 years)

Approach 2: Installation of a single rectangular pipe

A second approach was tested as part of this scenario, consisting of replacing the two 1000 mm diameter pipes with a single rectangular pipe running from upstream to downstream. The aim is to obtain a structure offering greater hydraulic capacity with fewer head losses.

In order to determine the new dimensions of the rectangular pipe, an analysis based on the upstream flow was carried out using a slope of 0.014 m/m. A width of 4 m was set on the basis of the existing stream gauge and the height was adjusted on the basis of the upstream flow for return periods of 50 to 200 years. The table below summarises the different heights of the new pipe depending on the return period. The dimensions adopted for the opening at this stage are ultimately 4 m wide by 1 m high, allowing a flood with a return period of 200 years to pass through theoretically. The future passage area will therefore be 4 m² instead of 1.6 m² in the existing situation.

Table 6-6 : Determination of the dimensions of the pipe on the Fond des Gottes stream in function of the upstream flow for each return period between 50 (T50) and 200 years (T200).

Return period	Upstream flow (m^3/s)	Fixed width (m)	Height (m)
T50	4	4	0.6
T100	7.65	4	0.9
T200	9.5	4	1

The modelling results illustrated in Figure 6-11 show that the installation of a rectangular pipe measuring 4 metres by 1 metre considerably improves the situation compared with the existing situation for critical return periods between 50 years and 200 years. Fewer overflows are observed upstream of the structure for both return periods, without affecting neighbouring homes. In addition, this approach generates significantly fewer overflows than the first approach for the two return periods of 50 years to 200 years.

Approach 3: Partial or total opening up of the watercourse

Taking into account the modelling results of the second approach, a third approach involving the partial or total opening up of the watercourse could be tested. This approach would make it possible to assess both the hydraulic impact of the development in terms of evacuating water during floods, and the ecological impact in terms of improving fish passage.

Conclusions regarding the modification of the opening on the Gottes stream

The analyses carried out with the model showed:

- A significant reduction in the risk of flooding in this sector thanks to the laying of two correctly aligned D1000 pipes. The first dwellings are affected by T100 in the existing situation, whereas this is simulated for T200 in the future situation.
- A more effective reduction in the risk of flooding is achieved by opting for a single rectangular pipe of 4 metres wide by 1 metre high. No dwellings are affected for all return periods in the future situation.

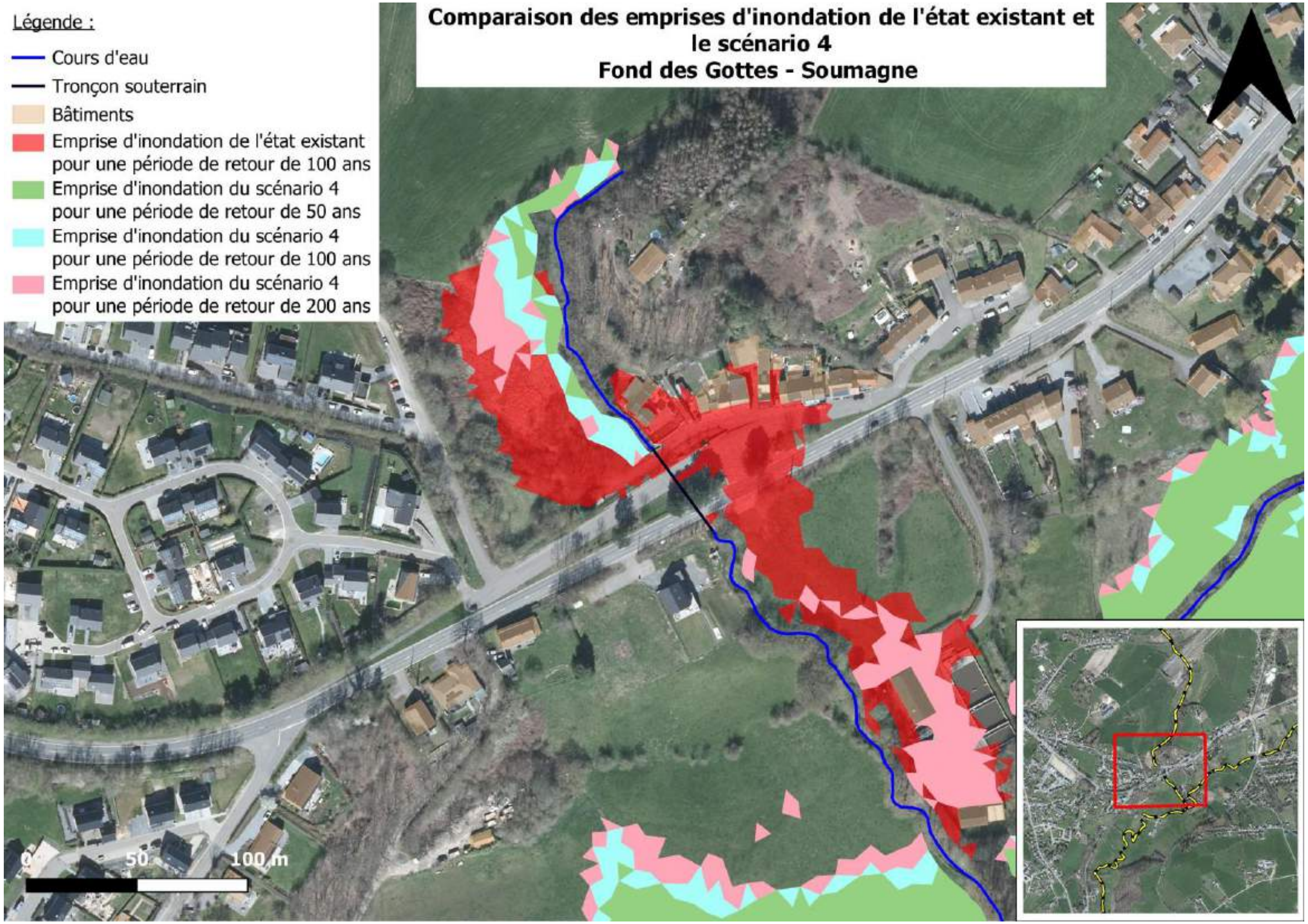


Figure 6-11 : Comparison of the flooding areas of the existing situation (composite rainfall with a return period of 100 years) and scenario 4 (approach 2) (composite rainfall with a return period of between 50 and 200 years)

6.3 Solutions in Trooz

6.3.1 Scenario 5 : TIZ at the level of rue Noirivaux

Concept of the scenario

The problem of flooding downstream of Trooz, not counting the downstream effect of the river Vesdre, is mainly concentrated in Rue Noirivaux, where the watercourse overflows its left bank for a return period of 5 years (see diagnosis 0Zone 10 - Trooz: Rue Fonds de Forêt, Rue Noirivaux, Rue sur les Biez). In order to assess the possibility of mitigating these overflows and the rest of the municipality of Trooz, an area suitable for setting up a TIZ at the level of Rue Noirivaux was identified. This area had been identified as a potential zone in previous urban planning studies.

Location and available storage volume

As shown in Figure 6-13, this site is located along the N673 road upstream of structure OA14_T. Analysis of the topography indicates that it is necessary to build a dike 1.5 metres above road level (around 95 mDNG) along the N673. The aim of this measure is to maximise the storage capacity of the TIZ, effectively manage the large inflows upstream, estimated at around 10 m³/s for a rainfall with a return period of 5 years, and prevent recurrent overflows onto the N673 road on the right bank.

The static volume available in the retention area in function of the planned height of the embankment is estimated on the basis of the DTM. The analysis indicates that the TIZ could release a static volume of around 16,000 m³, which is low. The main characteristics of the TIZ are summarised in Table 6-7.

The installation of this structure also involves other operational issues. Indeed, it is essential to note that the area upstream of the TIZ, located along Rue sur les Biez, has been identified as an area sensitive to overflowing of the watercourse on both its left and right banks (see diagnosis 5.1.3 Zone 10 - Trooz: Rue Fonds de Forêt, Rue Noirivaux, Rue sur les Biez). In order to avoid any negative impact of the downstream effect of the TIZ on this zone, an increase in the level of the banks to between 50 cm and 1 metre must be provided along the section of the watercourse extending from upstream of the TIZ to the downstream part of Rue sur les Biez. This measure will ensure that neighbouring homes are protected against overflows in the event of the effects of the TIZ spreading upstream. In addition, it may be necessary to provide a protective berm for the dwelling near structure OA14_T.

Table 6-7 : Main features of the Trooz TIZ

Features	TIZ Noirivaux
Flood plot (ha)	1.35
Max. dam height (m)	1.5
Length of dyke (m)	225
Volume before spillage (m³)	16000

Estimated volume to be stored

In the first instance, the estimate of the permissible flow at the outlet of the structures is based on the permissible flow to be respected downstream in the area to be protected. In the present case, this is the admissible flow rate of structure OA14_T, estimated at around 10.6 m³/s in the diagnostic phase. The table below shows the volumes to be retained at the future TIZ in function of the return period based on the variable flow varying between 10.6 m³/s and the factors for reducing this flow. The table shows that:

- The TIZ could barely withstand a 10-year return period, since the volume to be retained would be around 17,000 m³ and the volume available would be around 16,000 m³.
- The TIZ would not be able to cope with a flood with a return period of 25 years, as the volume to be retained would be around 119,000 m³, which is much greater than the volume available.

Table 6-8 : Volume to be stored (m³) as a function of leakage rate for return periods T5, T10, T25, T50 and T100 years.

Coefficient security	Leakage rate (m³/s)	Total volume T5 (m³)	Total volume T10 (m³)	Total volume T25 (m³)	Total volume T50 (m³)	Total volume T100 (m³)
1.00	10.60	777	17001	118967	132259	179539
0.90	9.54	2246	33946	149322	167130	222740
0.80	8.48	10513	52836	181066	203040	266945
0.70	7.42	24828	73629	214070	239632	312065

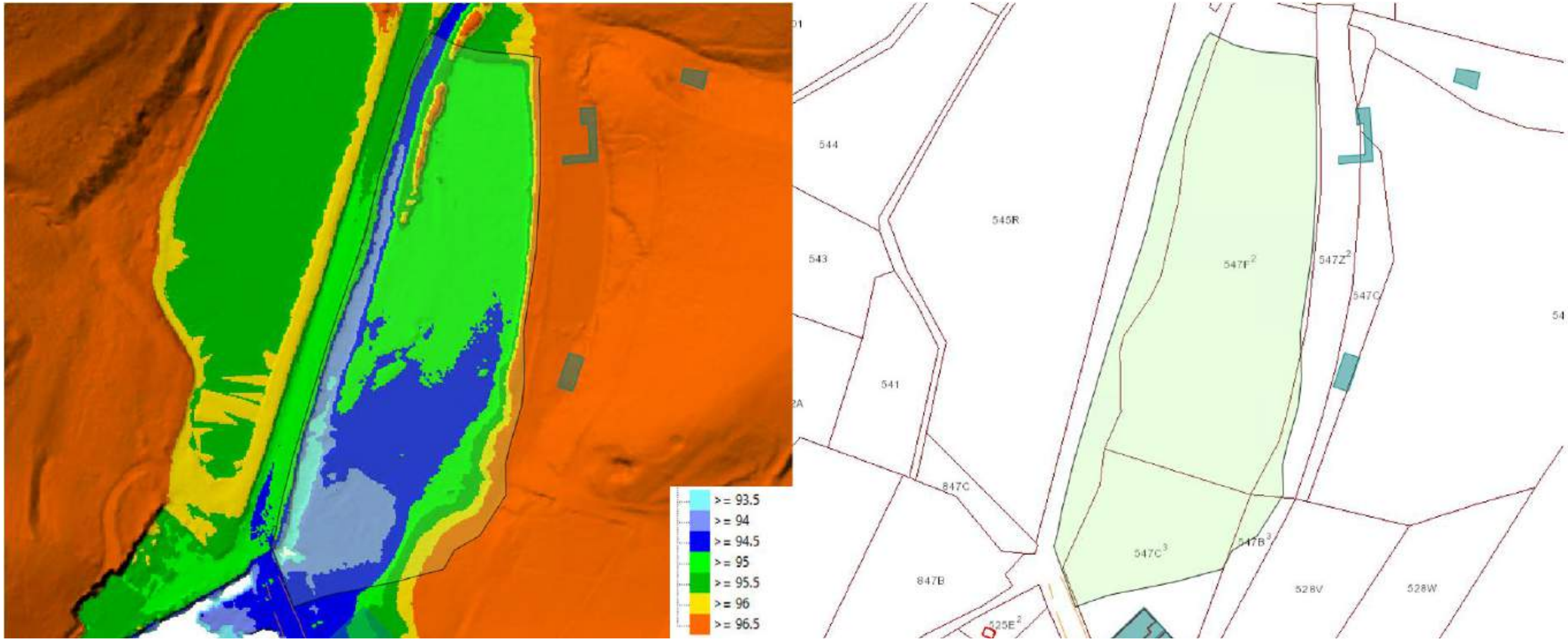


Figure 6-12 : Approximate location of the TIA in relation to the digital terrain model and the cadastral map.

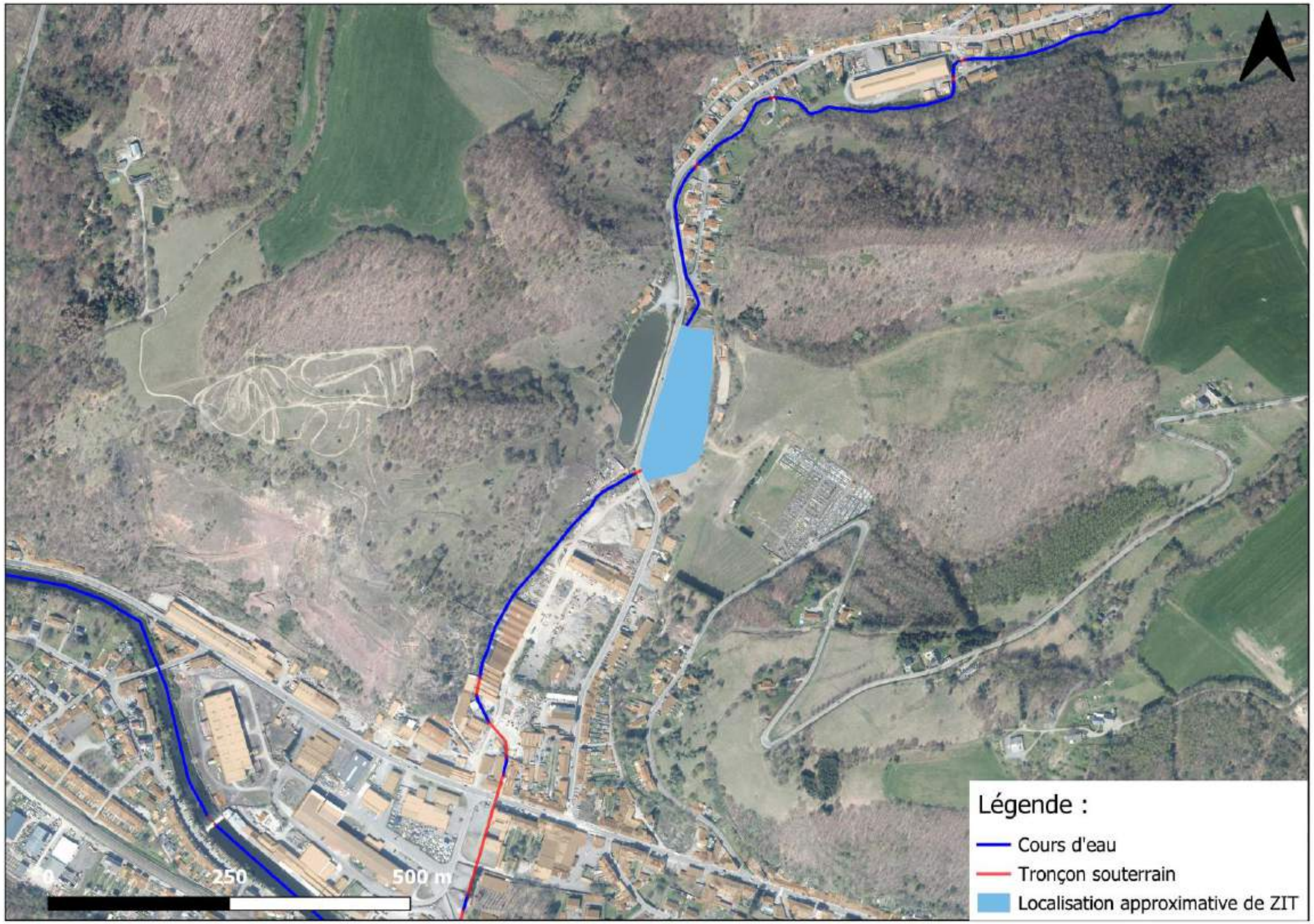


Figure 6-13 : Map of the approximate location of the Trooz TIZ

Analysis of the effect of the TIA in the model

The TIZ is included in the model in the configuration described above, assuming a leakage rate of 10.6 m³/s and a weir level of 96.3 mDNG.

Analysis of the modelling results comparing the existing situation and this scenario, as illustrated in Figure 6-14, reveals that the installation of the TIZ makes it possible to manage floods with a rainfall return period of between 5 and 10 years. No homes are affected on either Rue Noirivaux or Rue sur les Biez. However, for more extreme return periods, from 25 years onwards, when its maximum capacity is exceeded, the TIZ is insufficient to manage the upstream inflow, resulting in overflows onto the N673 road and Rue sur les Biez, affecting nearby homes (Figure 6-15).

On the basis of this analysis, it turns out that the implementation of the TIZ has no significant effect on overflows downstream of Trooz for major return periods, from 25 years upwards. However, its positive effect is limited to lower return periods of between 5 and 10 years.

Conclusions on the benefits of a TIA in Rue Noirivaux

The analyses presented above show that:

- The TIZ has only 16,000 m³ of static storage and is not capable of holding back a flood with a return period of 10 years. This result is not surprising given its location downstream of the river Magne catchment area, which generates substantial inflows given the size of the catchment area.
- This TIZ will not be able to protect Trooz against an event such as July 2021.

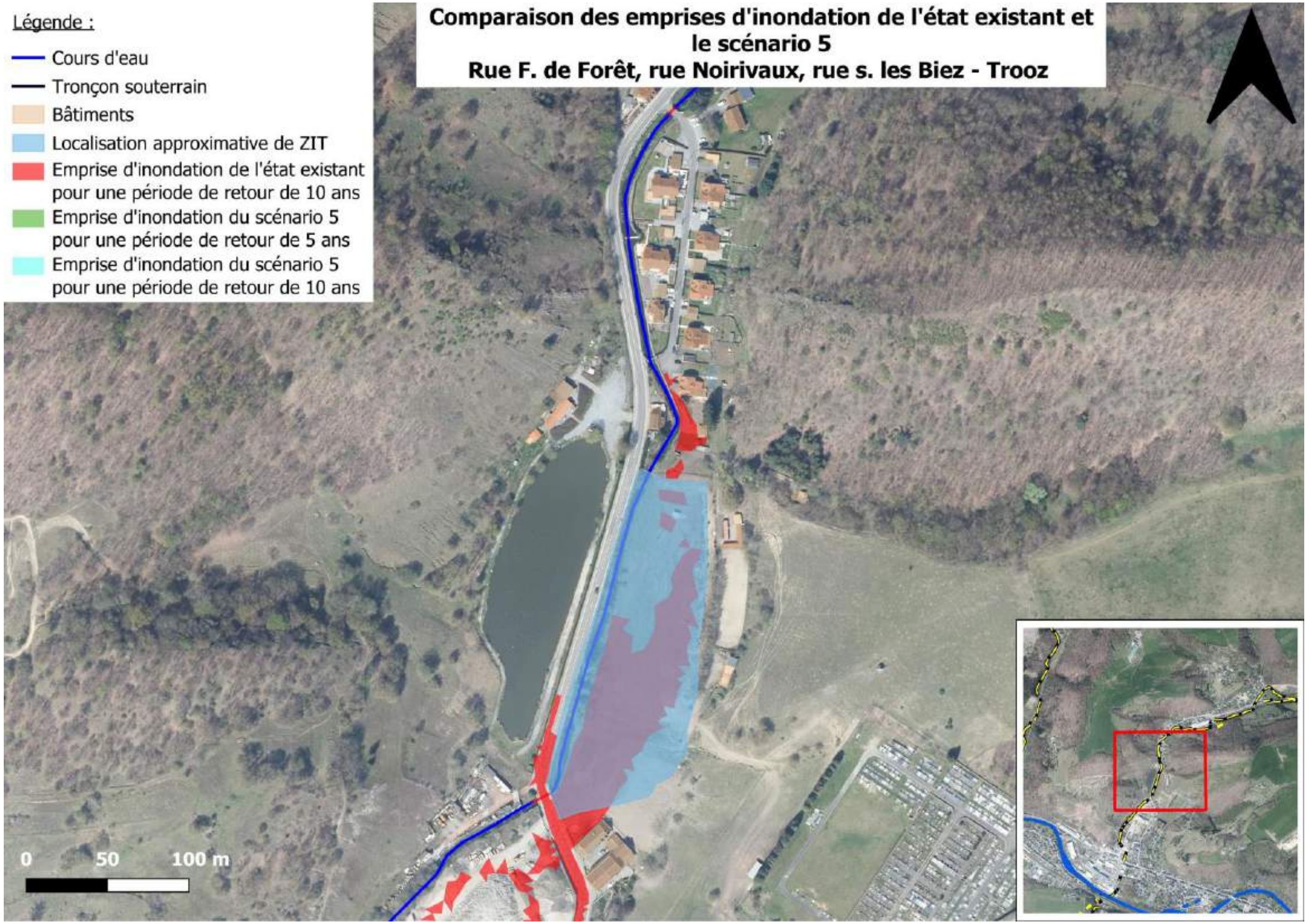


Figure 6-14 : Comparison of the flooding areas of the existing situation (composite rainfall with a return period of 5 years) and scenario 5 (composite rainfall with a return period of between 5 and 10 years)

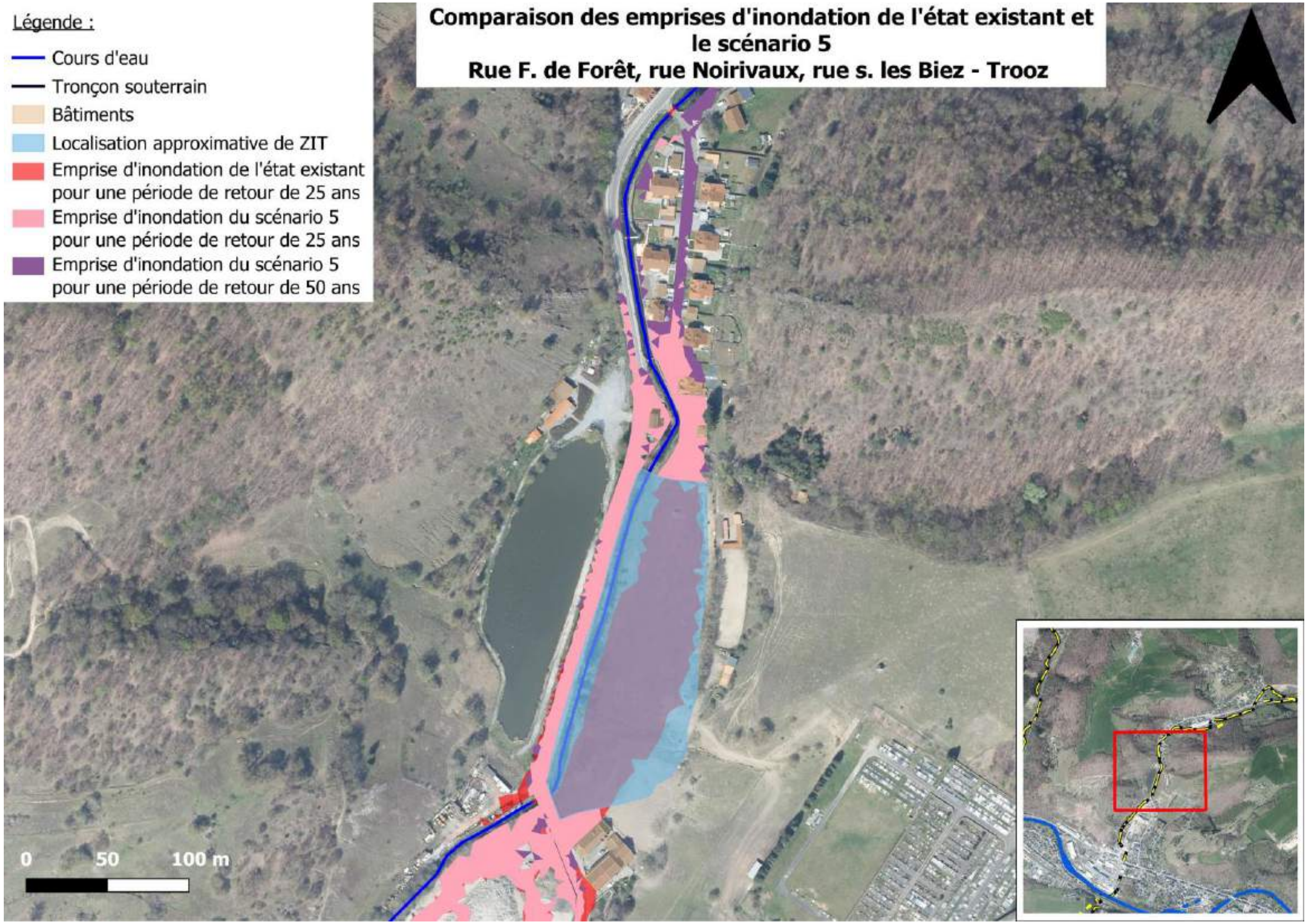


Figure 6-15 : Comparison of the flooding areas of the existing situation (composite rainfall with a return period of 25 years) and scenario 5 (composite rainfall with a return period of between 25 and 50 years)

6.4 Other scenarios to be analysed

This report highlights the pre-feasibility analysis of five scenarios in the study area. However, other scenarios could also be analysed:

- Scenario 6 - Optimisation of the Soumagne storm water basin: this scenario involves testing different positions of the control valve in order to maximise storage in the basin and reduce the water level in the centre of Soumagne.

- Scenario 7 - Reopening of the underpass at the level of Place Ferrer: this scenario will test a structure with greater hydraulic capacity to encourage the transfer of flow from upstream to downstream during floods.

- Scenario 8 - Partial or total opening of the Fond des Gottes watercourse: as mentioned in scenario 4 (section 6.2.2), a partial or total opening of Fond des Gottes at the level of Chaussée de Wégimont (N621) seems appropriate from a hydraulic and ecological point of view.

- Scenario 9 - Use/Optimisation of the merlon at the level of Rue Pont Al Plantche: it would be worthwhile to study the effect of the merlon and the improvement of the flow in order to drain the accumulation area near the nursing home.

- Scenario 10 - Creation of a TIZ in Rue des Deux Tilleuls in Soumagne: a suitable area for the creation of a TIZ in Rue des Deux Tilleuls.

- Scenario 11 - Use of the quarry as a storm basin: this scenario will be tested to assess the feasibility of using the quarry in Olne as a TIZ.

- Scenario 12 - Creation of a TIZ in Rue Neuville: an area suitable for the creation of a TIZ in Rue Neuville in Olne.

- Scenario 13 - Re-meandering the watercourse at the level of the meadows upstream and downstream of the Soumagne storm basin: This scenario should make it possible to test the relevance of re-meandering the river Magne, which would have a positive impact on reducing flow velocity and improving the operation of the storm basin. By adding this approach, hydraulic and ecological considerations to mitigate flooding and strengthen the resilience of the area are taken into account.

- Scenario 14 - Creation of a TIZ in Rue Bay Bonnet: an area suitable for the creation of a TIZ in Rue Bay Bonnet in Trooz.

7 Conclusions

This report highlights the problem of flooding in the river Magne catchment, focusing particularly on the most critical areas, namely Herve, Soumagne and Trooz. The 1D-2D model built for this study was calibrated and validated mainly on the basis of the July 2021 event and feedback from the municipalities concerned. Following this validation, critical areas were identified and subjected to an exhaustive hydraulic diagnosis. The most sensitive areas presented in this report are as follows:

- Zone 01 - Station d'épuration in Herve
- Zone 02 - Rue d'Elvaux in Herve
- Zone 03 - Fromagerie du Vieux Moulin in Herve
- Zone 04 – Storm basin, national road N621 in Soumagne
- Zone 05 - Centre Soumagne, Place Ferrer, rue Pierre Curie
- Zone 06 – Nursing home rue Pont Al Plantche in Soumagne
- Zone 07 - Fond des Gottes in Soumagne
- Zone 08 - Rue Bay Bonnet in Trooz
- Zone 09 - Rue Fonds de Forêt in Trooz
- Zone 10 - Rue Fonds de Forêt, Rue Noirivaux, rue sur les Biez in Trooz

The hydraulic diagnosis revealed that certain structures located in sensitive areas are limiting and cause overflows that affect neighbouring homes, particularly in rue d'Elvaux in Herve, the centre of Soumagne, Fond des Gottes and rue Noirivaux in Trooz. The frequency of these overflows depends on the structural configuration of the structure (dimensions in relation to the size of the watercourse) and upstream inflows. In addition, the diagnosis has made it possible to identify relevant solutions for these sensitive areas, such as the introduction of TIZs and the restoration of certain limiting structures.

Following this detailed diagnosis, several scenarios were analysed to assess the relevance of the proposed solutions. Five main scenarios have been presented in this report, including:

- Scenario 1 : two TIZs in a row near the Herve wastewater treatment plant
- Scenario 2: modification of the opening in rue d'Elvaux and opening of a section of the watercourse in Herve
- Scenario 3: raising the weir of the Soumagne storm water basin
- Scenario 4: modification of the existing opening on the Gottes stream inSoumagne
- Scenario 5: TIZ at the level of rue Noirivaux in Trooz

The analysis of scenario 1 revealed that setting up two TIZs near the Herve wastewater treatment plant has no effect on overflows from Rue d'Elvaux, which is the most sensitive area requiring protection. This is mainly due to the fact that the two TIZs only control 40% of the upstream catchment areas, leaving the rest of the inflow to flow directly towards Rue d'Elvaux.

Scenario 2 revealed that re-routing the pipe in Rue d'Elvaux with greater hydraulic capacity (calculated on the basis of the upstream flow per return period), combined with opening up the watercourse up to its downstream confluence with the Manaihan stream, would improve the situation in this sensitive area up to a return period of 25 years.

Scenario 3 highlights the effects of future works planned at the Soumagne storm water basin in terms of additional storage and flood reduction in the centre of Soumagne. The results showed that the impact of raising the weir is relatively limited and does not result in a sufficient change in the flood hydrograph before and after modification.

Scenario 4 showed that redesigning the two 1000 mm diameter pipes would improve flood management for extreme return periods (between 50 and 100 years). However, some houses would be affected by flooding for a return period of 200 years. In addition, the analysis showed that the installation of a single rectangular pipe with a large hydraulic capacity (calculated in function of the upstream flow per return period) provides a better improvement in the situation, without any homes being affected for all return periods (up to 200 years). These results therefore suggest testing the total or partial opening of the watercourse in order to assess its hydraulic and ecological impact in this sensitive area.

Scenario 5 showed that the creation of a TIZ at the level of rue Noirivaux has no significant impact on flooding in this sensitive area for major return periods, from 25 years upwards. This limitation is mainly due to the relatively limited storage capacity of the TIZ compared with the large inflows upstream of the basin.

It is important to note that most of the proposed solutions will reduce the risk of flooding, but they will not be able to prevent the river from overflowing during major events such as that of July 2021.

Additional scenarios of interest have been mentioned and could be the subject of further analysis in a later phase.

Finally, it should also be emphasised that the measures outlined above are only part of the solution for the river Magne catchment. It is just as crucial to make local residents aware of the issues surrounding the risk of flooding and to promote good practice.

8 Appendices

8.1 Topographic survey work sheets

The structure data sheets and the zoom on the Fond des Gottes pipes are grouped together and listed in the "Structure data sheets + Zoom" file appended to this report.

8.2 Flood photos and videos

A collection of photos and videos of flooding events in July 2021 and June 2018 is available in the "Flood photos and videos" folder appended to this report.

8.3 Rural sub-basin parameters

Table 8-1: CN and time of concentration values for each sub-basin

ID sub-basin	CN	Average TC (min)	ID sub-basin	CN	Average TC (min)
SB1	75.8	45.7	**SB44**	75.9	87.3
SB2	64.7	24.4	**SB45**	66.0	21.3
SB3	66.3	34.1	**SB46**	72.2	7.5
SB4	73.6	35.1	**SB47**	67.0	50.0
SB5	75.0	54.8	**SB48**	70.5	43.2
SB6	75.6	148.0	**SB49**	65.1	20.4
SB7	66.1	33.3	**SB50**	73.2	82.8
SB8	68.7	61.4	**SB51**	69.9	31.3
SB9	69.6	43.6	**SB52**	66.7	32.3
SB10	73.7	64.6	**SB53**	59.7	78.6
SB11	71.0	19.4	**SB54**	69.1	33.0
SB12	71.5	31.6	**SB55**	65.5	37.2
SB13	67.2	17.9	**SB56**	73.8	7.5
SB14	61.6	19.5	**SB57**	79.9	4.8
SB15	67.0	24.7	**SB58**	75.7	2.6
SB16	71.8	20.4	**SB59**	85.4	2.3
SB17	76.6	34.1	**SB60**	82.8	1.3
SB18	71.2	22.4	**SB61**	81.0	1.4
SB19	71.3	27.0	**SB62**	80.3	6.3
SB20	79.0	39.8	**SB63**	81.9	4.5
SB21	75.8	59.6	**SB64**	81.2	4.7
SB22	69.1	29.2	**SB65**	81.2	7.9
SB23	68.4	41.1	**SB66**	80.0	2.9
SB24	66.2	12.4	**SB67**	68.5	8.2
SB25	82.3	14.2	**SB68**	71.2	7.9
SB26	68.0	20.8	**SB69**	68.5	7.2
SB27	73.5	73.0	**SB70**	79.7	3.5
SB28	74.3	94.9	**SB71**	80.1	5.5
SB29	65.0	12.5	**SB72**	95.8	7.5
SB30	65.1	7.6	**SB73**	69.7	5.5
SB31	73.7	43.8	**SB74**	72.3	4.3
SB32	68.8	46.4	**SB75**	43.3	6.4
SB33	71.6	37.1	**SB76**	78.4	1.3
SB34	70.1	46.6	**SB77**	69.4	5.5
SB35	72.3	73.1	**SB78**	71.9	2.5
SB36	74.2	7.0	**SB79**	59.4	1.6
SB37	68.9	22.2	**SB80**	77.7	1.0
SB38	74.5	14.6	**SB81**	81.0	4.4
SB39	80.3	26.8	**SB82**	96.3	6.1
SB40	71.3	63.9	**SB83**	87.8	9.9
SB41	75.3	57.7	**SB84**	75.0	14.8
SB42	71.7	32.9	**SB85**	74.1	5.2
SB43	78.1	9.6	**SB86**	82.4	10.6

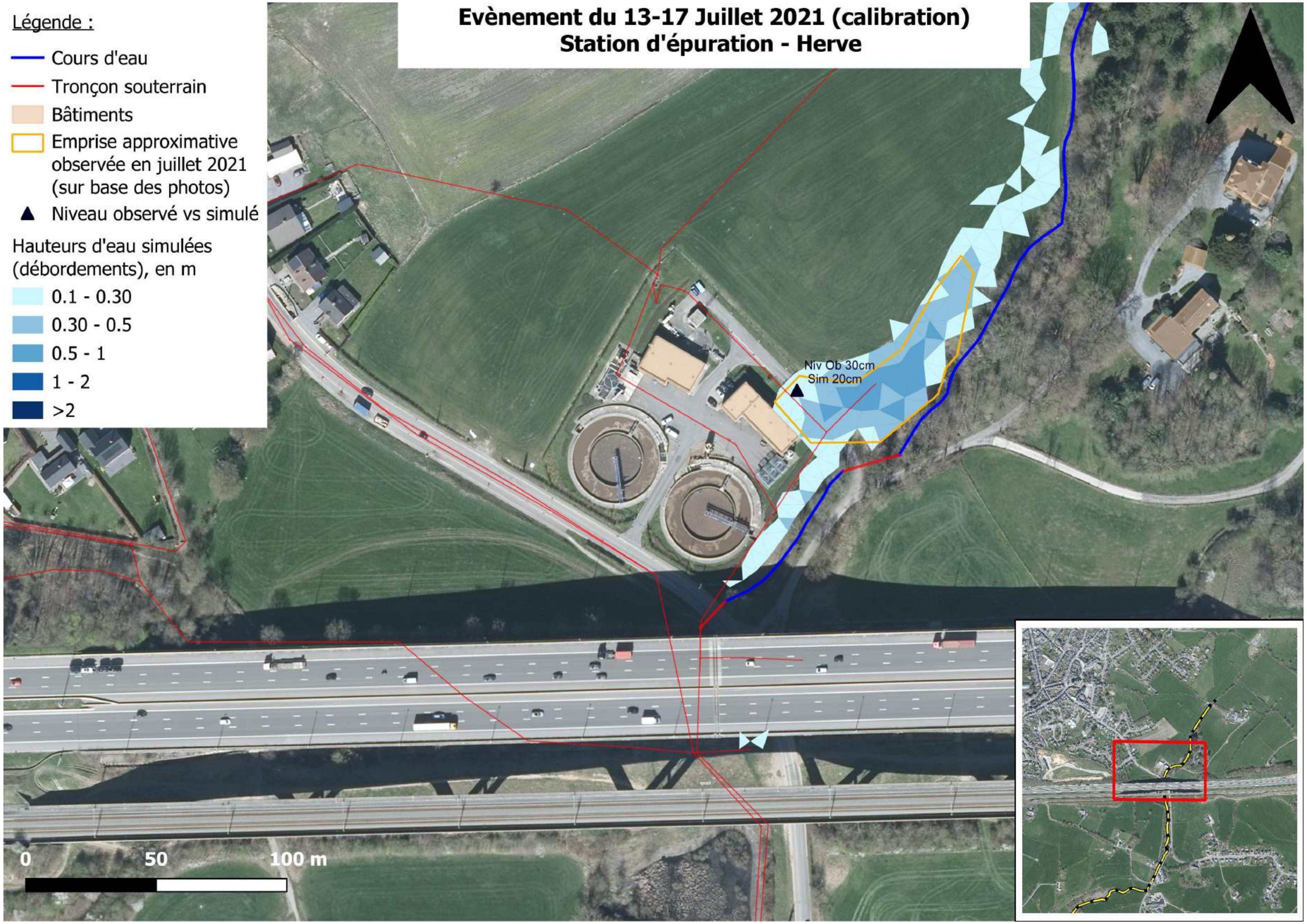
8.4 List of the most critical works

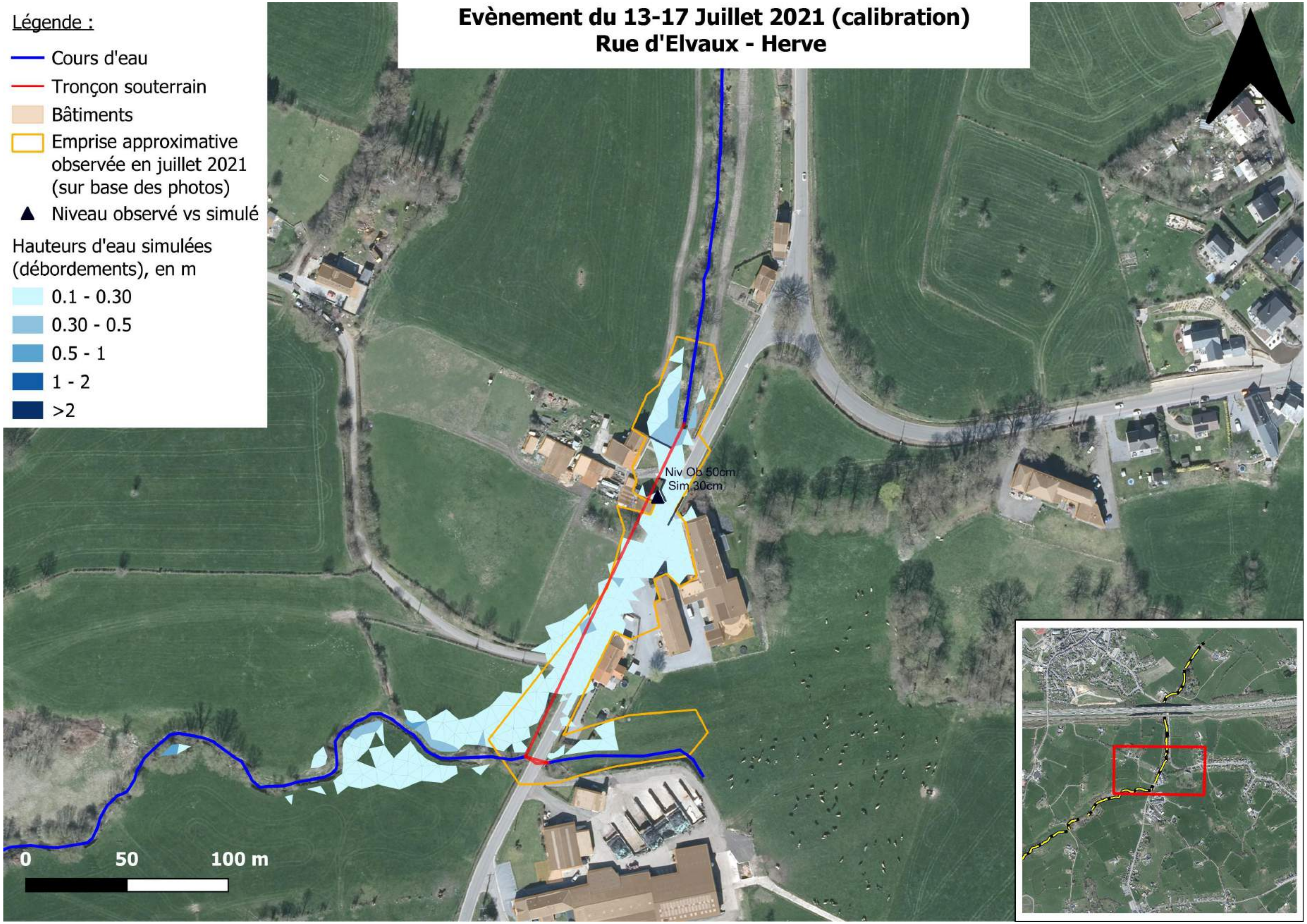
Table 8-2: List of the most critical works

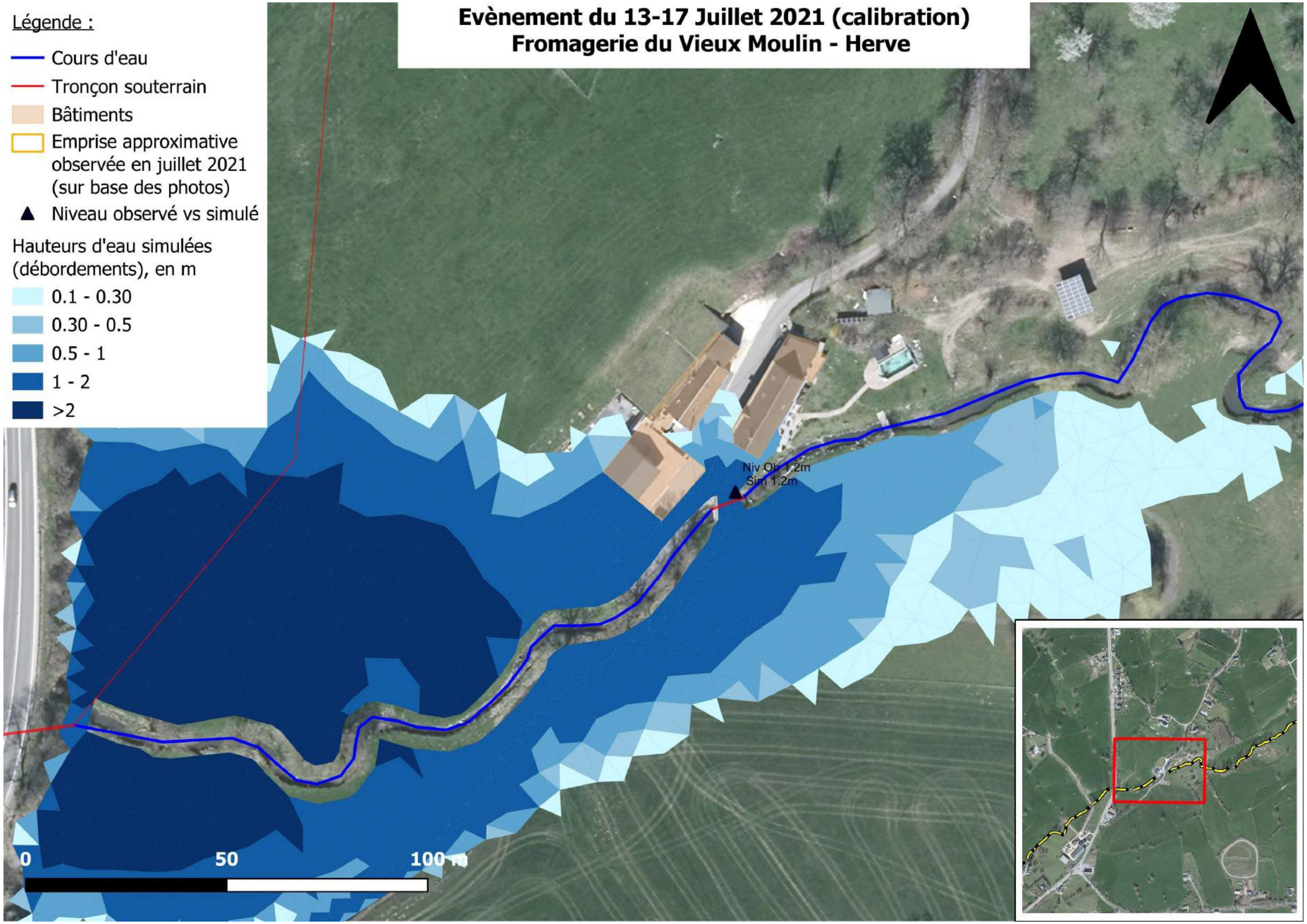
Work	Permissible flow rate (m^3/s)	Critical return period
OA01_H	0.7	5 years
OA02_H	2.4	5 years
OA03_H	1.9	5 years
OA04_H	1.8	5 years
OA05_S	5.8	10 years
OA07a_FG	1.1	50 years
OA07b_FG	1.1	50 years
OA09_T	3.7	10 years
OA13_T	10.5	10 years
OA14_T	6	5 years

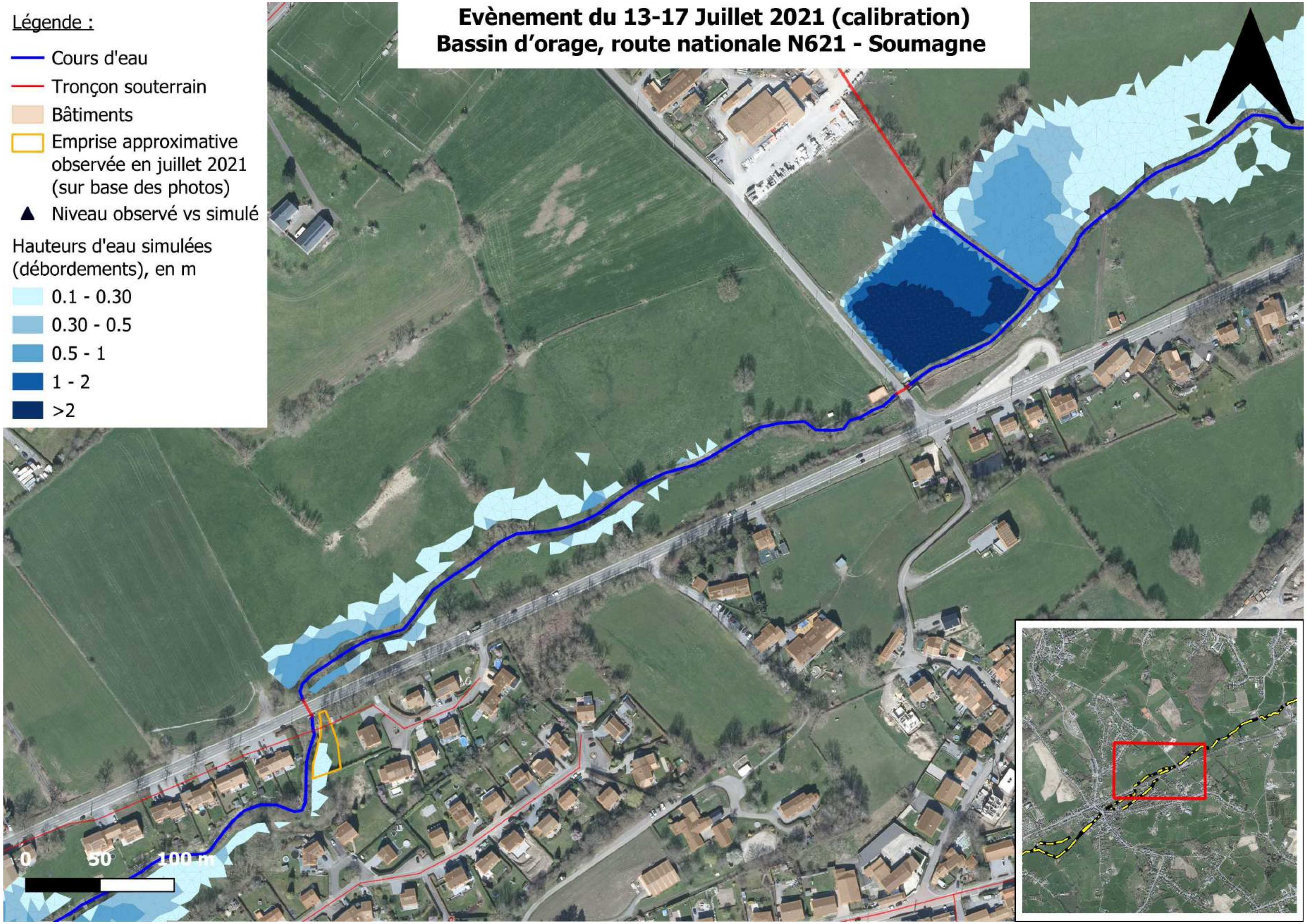
8.5 Flood maps for the existing situation

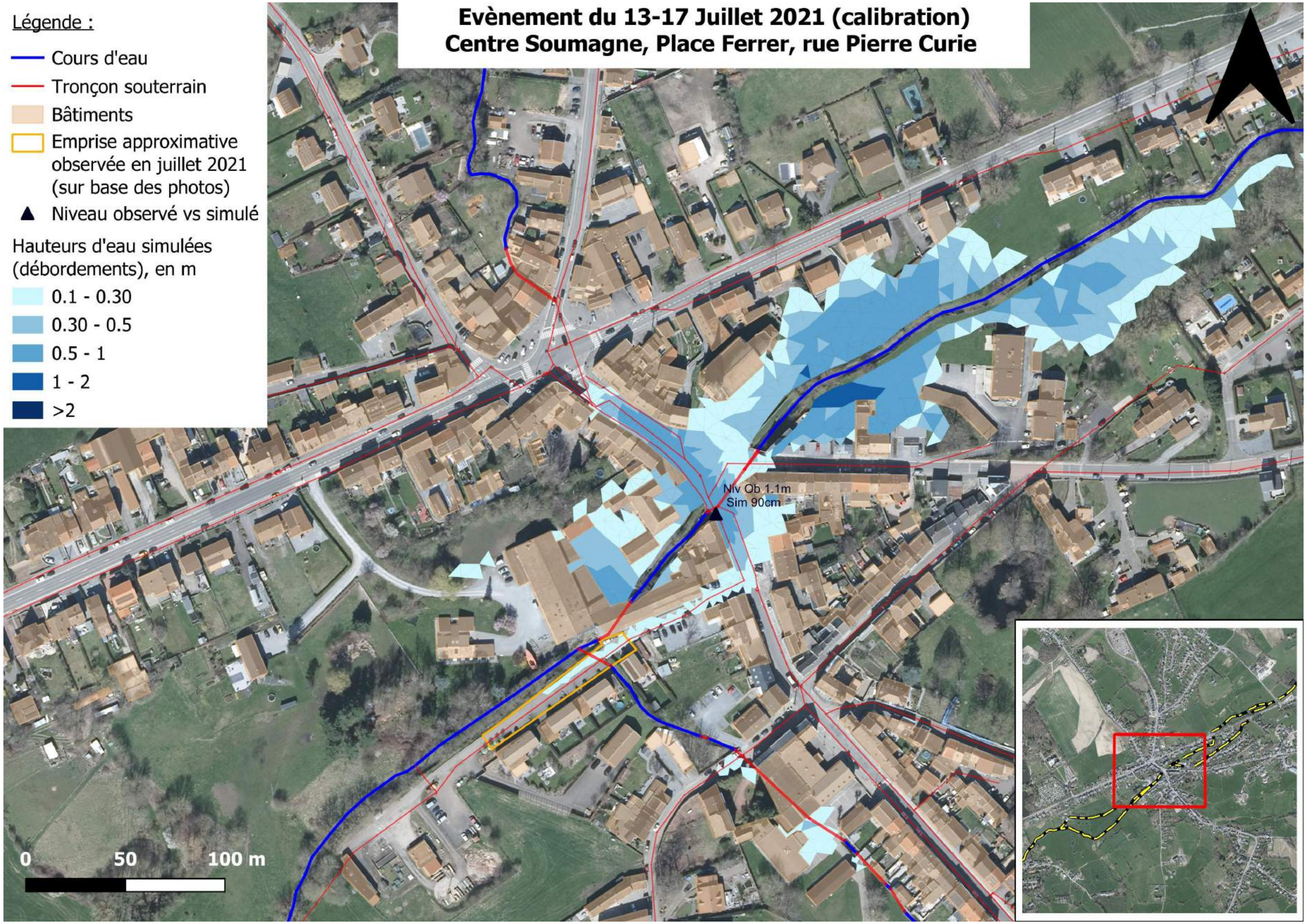
Existing condition flood maps for all sensitive areas are shown below. High resolution versions are provided in the "**Existing Condition Flood Maps**" folder appended to this report.

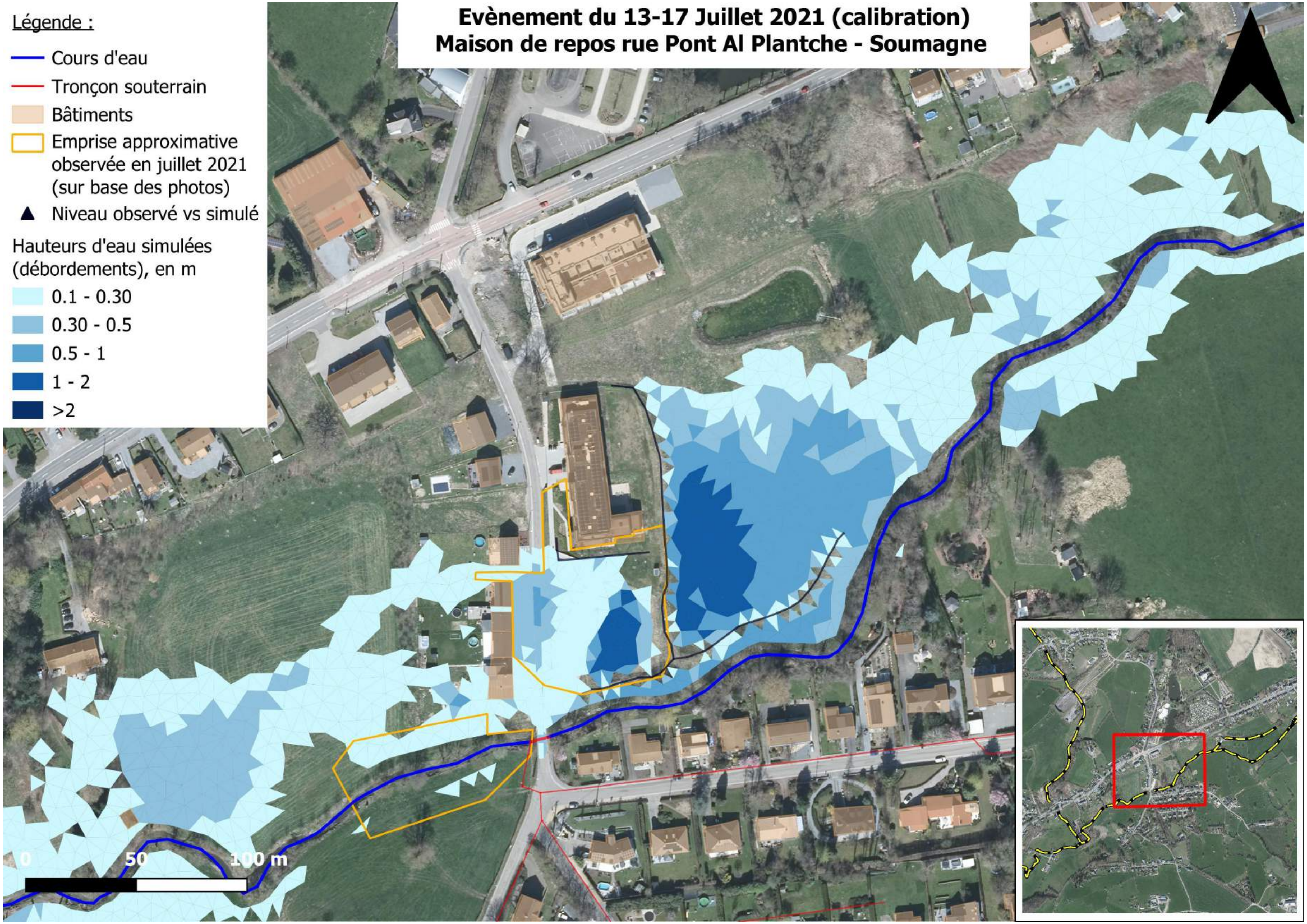

Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
Evènement du 13-17 Juillet 2021 (calibration)
Station d'épuration - Herve
Niv Ob 30cm
Sim 20cm
0
50
100 m

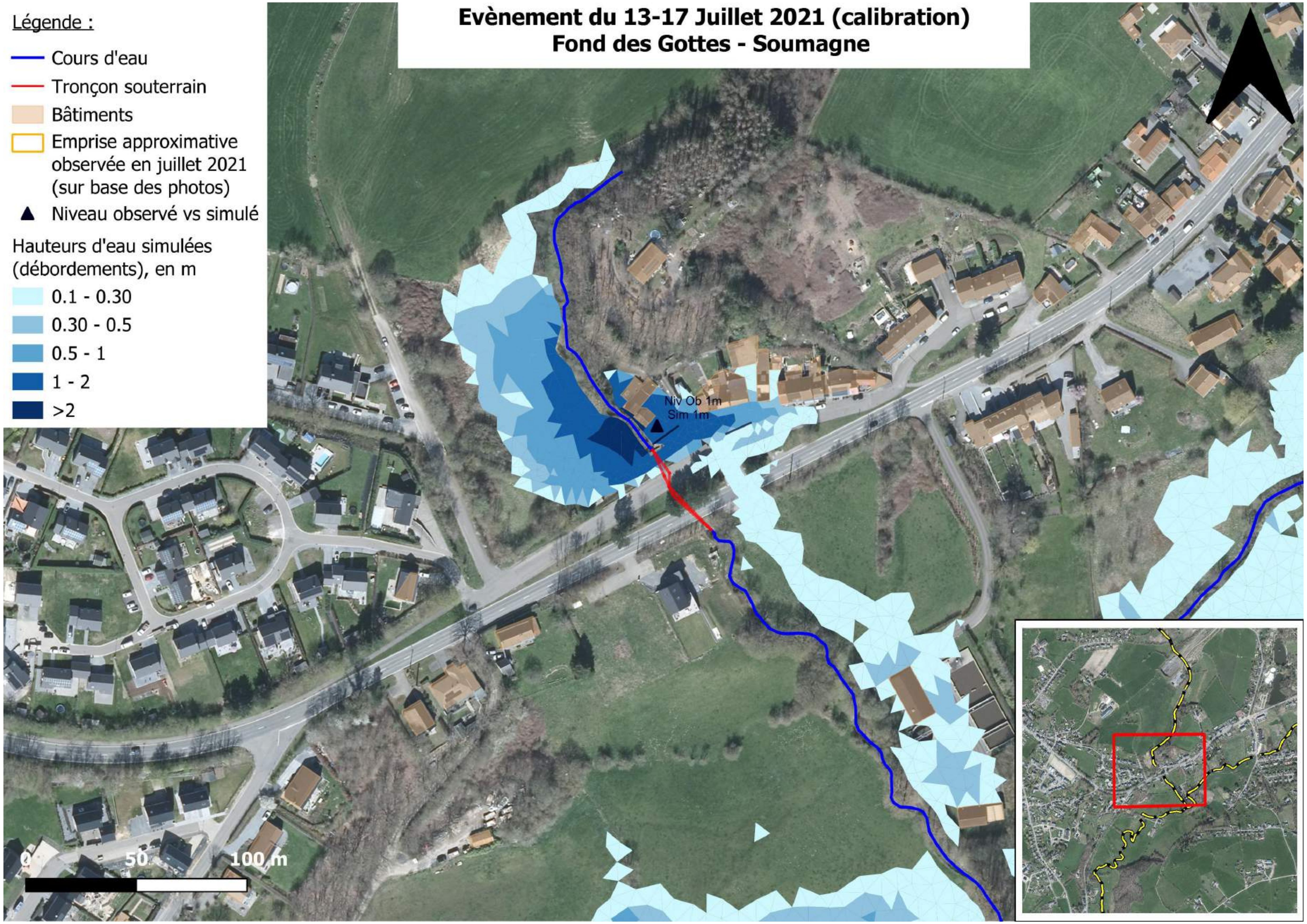

Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
Evènement du 13-17 Juillet 2021 (calibration)
Rue d'Elvaux - Herve
Niv Ob 50cm
Sim 30cm
0
50
100 m

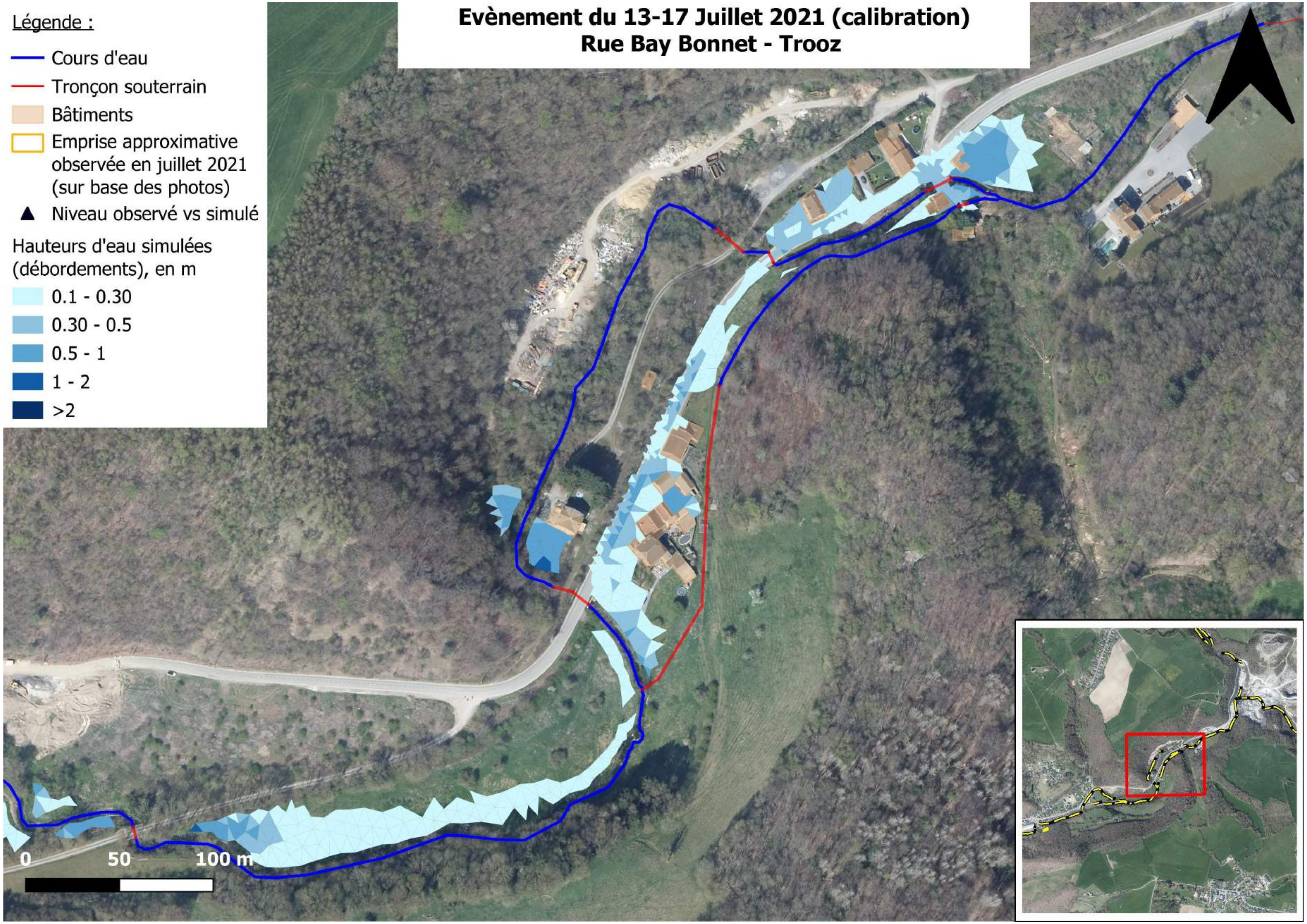

Evènement du 13-17 Juillet 2021 (calibration)
Fromagerie du Vieux Moulin - Herve
Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
Niv Ob 1.2m
Sim 1.2m
0
50
100 m


Evènement du 13-17 Juillet 2021 (calibration)
Bassin d'orage, route nationale N621 - Soumagne
Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
0
50
100 m

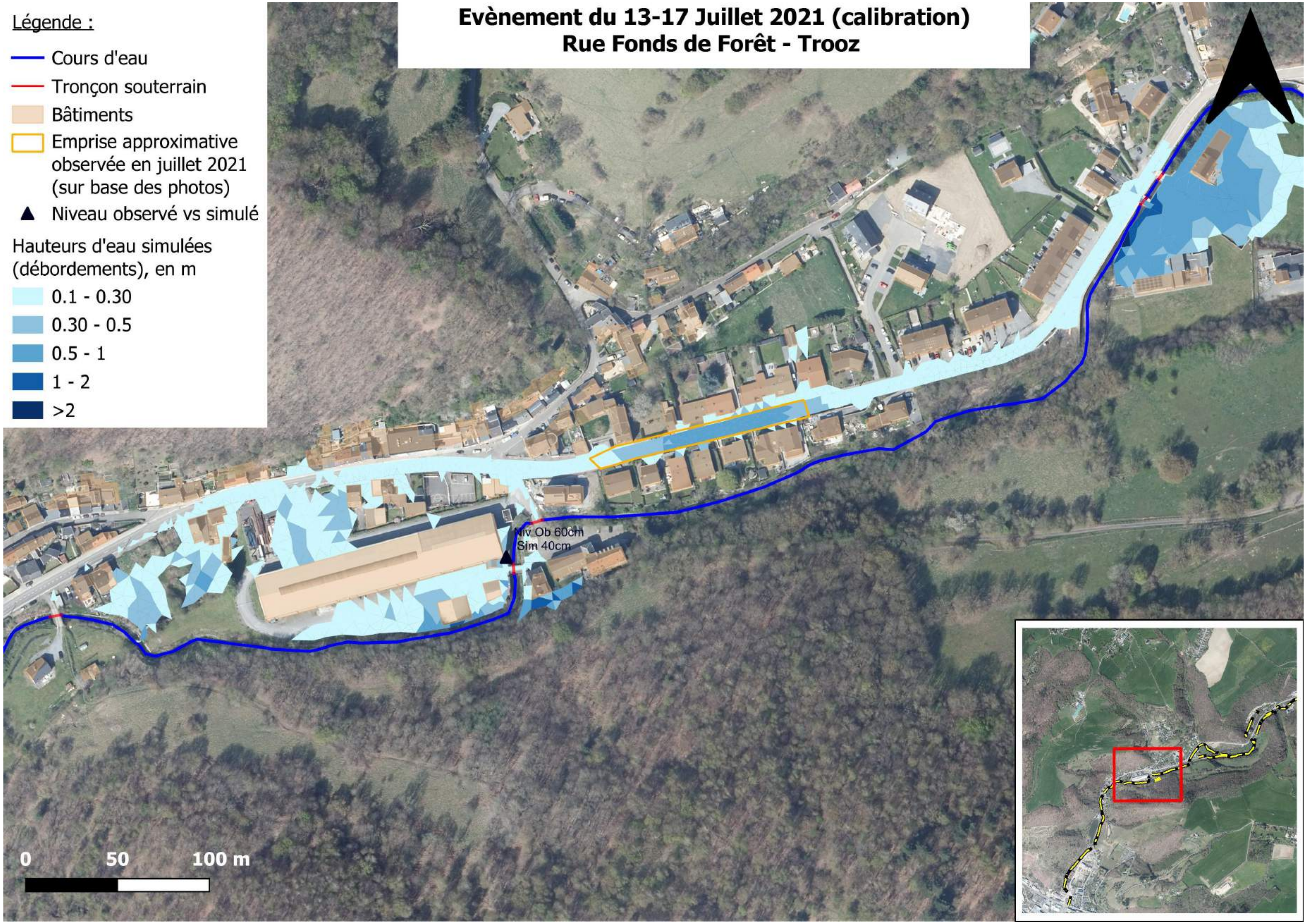

Evènement du 13-17 Juillet 2021 (calibration)
Centre Soumagne, Place Ferrer, rue Pierre Curie
Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
Niv Ob 1.1m
Sim 90cm
0
50
100 m

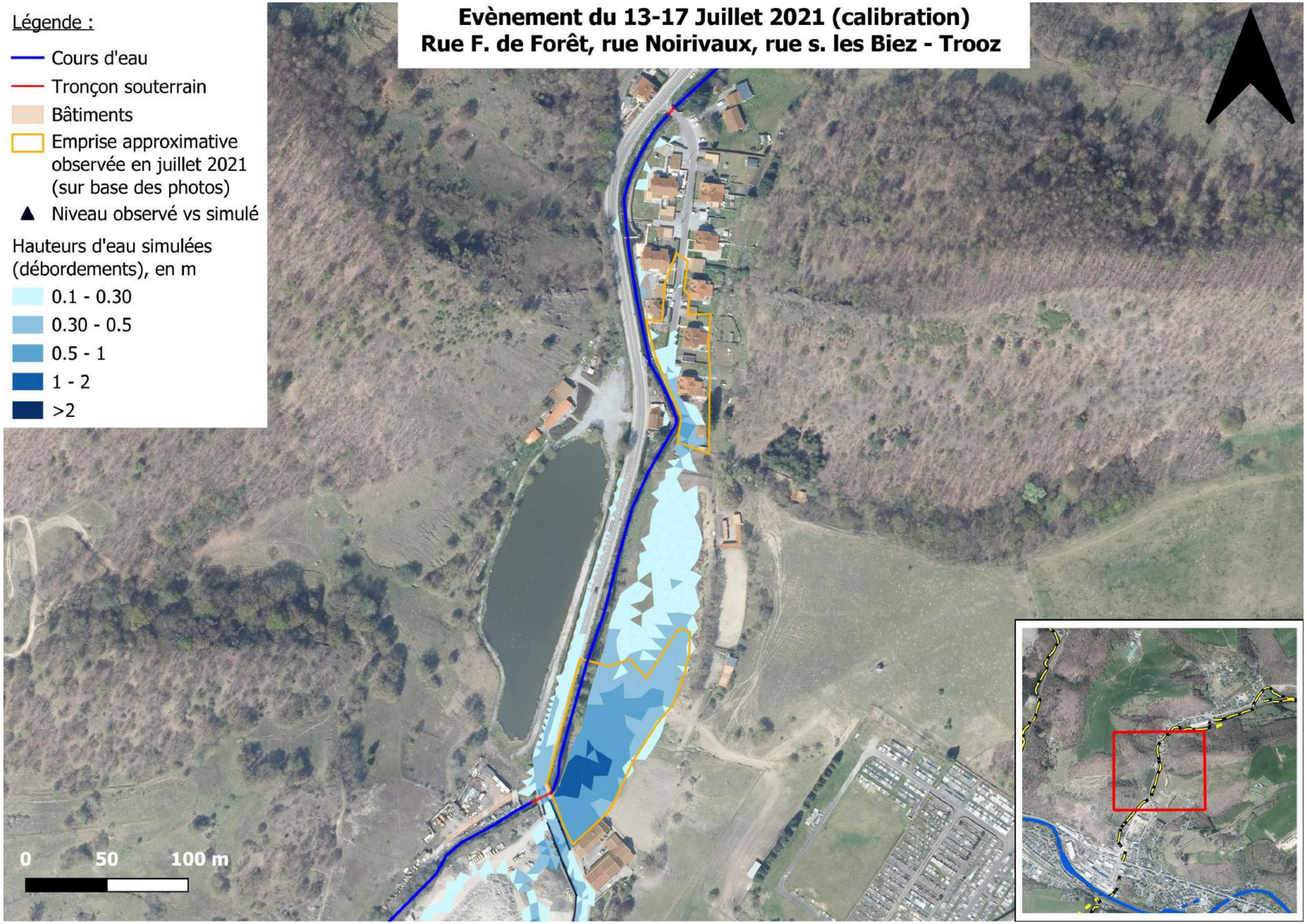

Evènement du 13-17 Juillet 2021 (calibration)
Maison de repos rue Pont Al Plantche - Soumagne
Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
0
50
100 m

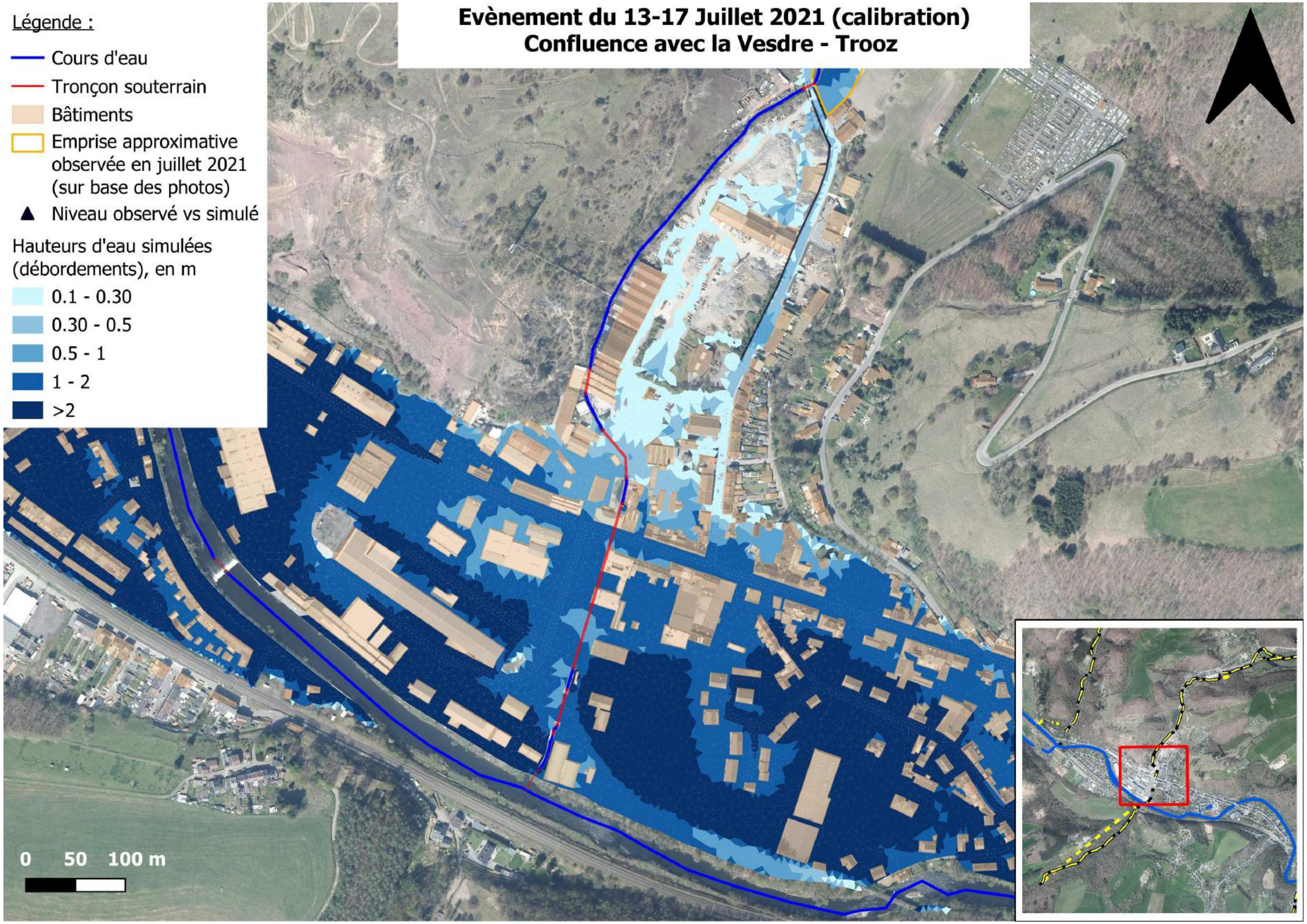

Evènement du 13-17 Juillet 2021 (calibration)
Fond des Gottes - Soumagne
Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
Niv Ob 1m
Sim 1m
0
50
100 m


Evènement du 13-17 Juillet 2021 (calibration)
Rue Bay Bonnet - Trooz
Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
0
50
100 m

Evènement du 13-17 Juillet 2021 (calibration)
Rue Fonds de Forêt - Trooz




Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
Evènement du 13-17 Juillet 2021 (calibration)
Rue F. de Forêt, rue Noirivaux, rue s. les Biez - Trooz
0
50
100 m


Evènement du 13-17 Juillet 2021 (calibration)
Confluence avec la Vesdre - Trooz
Légende :
Cours d'eau
Tronçon souterrain
Bâtiments
Emprise approximative observée en juillet 2021 (sur base des photos)
Niveau observé vs simulé
Hauteurs d'eau simulées (débordements), en m
0.1 - 0.30
0.30 - 0.5
0.5 - 1
1 - 2
>2
0 50 100 m