Common Implementation Strategy for the Water Framework Directive and the Floods Directive

Working Group on Floods

Pluvial flooding workshop report

Brussels, 18 and 19 May 2022

European Commission, DG ENV

Part A: background on pluvial flooding

1. Introduction to pluvial flooding

1.1 Objectives of this background

The objectives of this background paper on pluvial flooding are to:

- Provide an overview of the existing methods for modelling and mapping for pluvial flood in urban and rural areas in the context of the European Union's (EU) Floods Directive;
- Give a brief summary of the methods used by EU Member States to model and map pluvial floods, together with the challenges that this has presented based on a questionnaire and workshop held in Brussels in May 2022;
- Provide brief details the current state of the art regarding modelling and mapping pluvial floods within the context of meeting the requirements of the Floods Directive;
- Describe the challenges and potential solutions to close the knowledge and implementation gaps with respect to pluvial flood modelling and mapping.

This background paper builds on the following EC Working Group (WG) F on floods thematic workshops:

- WG F thematic workshop on flash floods and pluvial flooding held in Cagliari, Italy in May 2010;
- WG F thematic workshop on pluvial floods held in Berlin, Germany in October 2016.

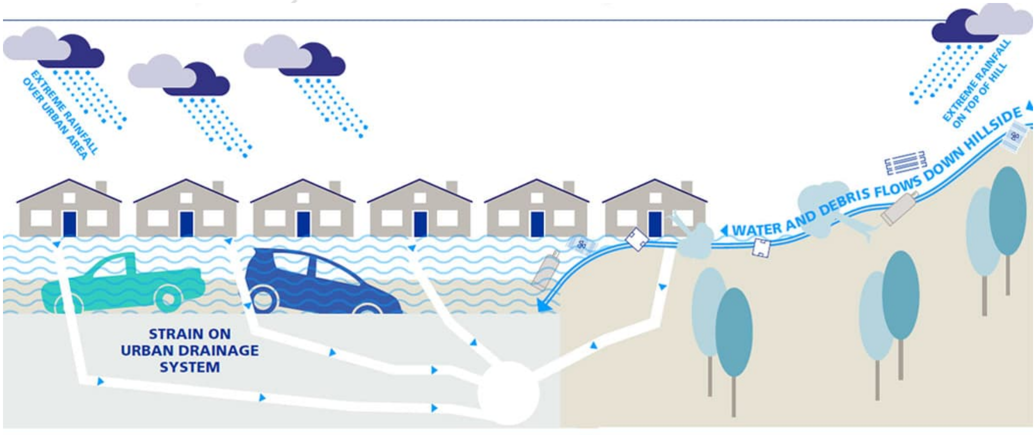
1.2 What is pluvial flooding?

In the Floods Directive pluvial floods are characterised as the flooding of land directly from rainfall water falling on, or flowing over, the land. This source could include urban storm water, rural overland flow or excess water, or overland floods arising from snowmelt (EC, 2021).

At the WG F workshop held in 2010 the following definitions for flash and pluvial floods were proposed:

- **Flash flood:** A flood that rises and falls quite rapidly with little or no advance warning, usually the result of intense rainfall over a relatively small area. A key aspect of the definition is the time scale; i.e. a sudden hydrological response to the causative event (EC, 2011);
- **Pluvial flood:** Direct runoff over land causing local flooding in areas not previously associated with natural or manmade watercourses. A key aspect of the definition is the lack of a proper drainage network in the area impacted by the flood (EC, 2011).

An example of these two types of floods is shown in Figure 1.1.



(Source: Zurich, 2020)

Figure 1.1: Schematic diagram of the mechanisms which cause pluvial and flash floods

Traditionally in the simple design of urban drainage systems there is an assumption that there is an agreement between the annual exceedance probability (AEP) of the rainfall and its flood AEP (Tuyls et al., 2018). This is also often the case when developing pluvial flood maps i.e. the AEPs of the pluvial flood extents are equivalent to the rainfall AEP. However, this assumption often does not apply (Tuyls, et al., 2018). Research in Denmark has shown that there is often an ambiguous relationship between the rainfall AEP and the urban pluvial flood AEP, indicating that a direct relation between the two AEPs cannot always be made (Tuyls, et al., 2018).

2. Overview of modelling and mapping pluvial floods in urban areas

2.1 Summary of the approaches taken by Member States to pluvial flooding in the first cycle of the Floods Directive

In October 2016, a workshop was held in Berlin on pluvial floods which was attended by Member States. A questionnaire was sent to Member States on pluvial floods. The information from this workshop has been used to summarise Member States' approaches to pluvial flooding in the first cycle of the Floods Directive.

For the first cycle Preliminary Flood Risk Assessment (PFRA) most Member States used expert judgement to identify the Areas of Potential Significant Flood Risk (APSFRs) affected by pluvial flooding. Six Member States had used modelling to define APSFRs affected by pluvial floods. Where pluvial APSFRs had been determined by modelling at the PFRA stage, this was generally done based on evaluating areas where pluvial floods were most likely (e.g. based on rainfall data and topographic analyses) in combination with GIS analysis of the vulnerability of land use.

One of the challenges faced by Member States in the first cycle was that pluvial floods can happen anywhere and hence areas at risk from pluvial floods are not as easy as easy to identify as fluvial flooding. There were also challenges in setting significance criteria for pluvial floods in the first cycle of the Floods Directive.

Thirteen out of the 22 Member States who responded to this questionnaire had not developed any Flood Hazard and Risk Maps (FHRMs) for pluvial floods for the first cycle of the Floods Directive. In Member States where separate pluvial FHRMs had been produced a variety of methods had been used ranging from the use of indices based on historical events or vulnerability indices to hydraulic models.

Figure 2.1 shows a summary of the approaches taken by Member States undertaken to pluvial floods in the first cycle of the Floods Directive based on the questionnaire answers provided for the 2016 workshop.

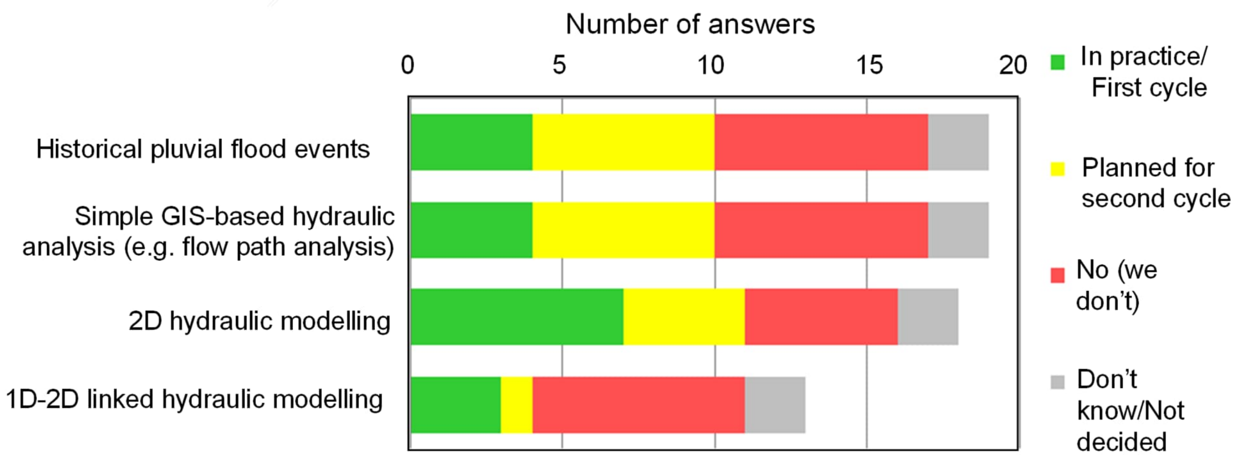


Figure 2.1: Approaches applied by Member States for pluvial floods in the first cycle of the Floods Directive together with their plans for the second cycle

2.2 Hydraulic modelling approaches to urban pluvial floods

There are a number of hydraulic modelling approaches that can be used to represent urban pluvial floods. These models can be categorised as follows:

- **Rapid flood spreading models** are simplified hydraulic models that spread the flood volume over the floodplain accounting for its topography. They do not solve the St Venant equation and the results are not as accurate as fully two dimensional (2D) hydraulic models but they produce results very rapidly;
- **One dimensional (1D) piped drainage models** solve the St Venant equations to represent the piped sewer system. The surface water flood extent is an approximation based on virtual storage;
- **Simplified 2D full shallow water equation models** are computationally more efficient than fully 2D shallow water equations but are less accurate;
- **Fully 2D shallow water equation models** are more accurate than simplified simplified 2D fully shallow water equation models but are computationally more expensive than simplified 2D models;
- **Coupled 1D piped drainage and 2D overland flow models** represent both the piped sewer network and the overland flow. They have the potential to represent pluvial urban flood extents the most accurately.

Table 2.1 provides a summary of the outputs, data requirements, as well as the relative strengths and limitations of the above hydraulic modelling approaches to pluvial urban floods.

2.3 Overview of the state of the art approach to modelling and mapping pluvial floods in urban areas

2.3.1. Introduction

The state of the art methods for pluvial flood hazard modelling and mapping are based on rainfall being applied directly to a two dimensional (2D) hydraulic model, which will dynamically model overland flow paths and surface ponding. Most 2D hydraulic models solve either the full shallow water equations or the diffusion wave equations. A hydraulic model which solves the full shallow water equations will provide more accurate results than one using the diffusion wave equations; however, such models will take longer to run (i.e. be computationally less efficient). The steps in the state of the art approach producing pluvial FHRMs are as follows:

1. Define the extent of the urban hydraulic model.
2. Identify and define the boundary conditions.
3. Collate and pre-process the relevant data.
4. Schematise the urban pluvial hydraulic model.
6. Calibrate and verify the urban pluvial hydraulic model.
7. Run the urban pluvial model for the high, medium and low Annual Exceedance Probabilities (AEP), floods and climate change scenarios.
8. Undertake an uncertainty analysis.
9. Produce urban pluvial flood hazard maps.

These steps are briefly summarised below.

Table 2.1 Summary of the outputs, data requirements and relative strengths and limitations of hydraulic modelling approaches to pluvial urban floods

Modelling approach	Characteristics of the model outputs			Main spatial data requirements	Strengths	Limitations
	Flood extent	Flood depth	Flow velocity			
Rapid flood spreading model	Yes	Yes	No	Digital Terrain Model (DTM)	Computationally efficient e.g. run times of models are often just a few minutes	Does not solve the shallow water equations providing less accurate answers than 2D hydraulic models; Flow velocity is not calculated
1D piped drainage model	Yes but approximated using virtual storage	Yes	No	DTM, details of the piped drainage system	Computationally efficient, Accurate representation of the piped network; Surface water flood extent is only represented approximately via the use of virtual storage	Does not provide an accurate estimate of the flood extent and depth
Simplified 2D full shallow water equation models	Yes	Yes	Yes	DTM; details of: buildings, roads, other structures	Dynamic simulation of urban pluvial flooding with a relatively low computational cost leading to fast simulations; Suitable for urban pluvial flood mapping where a detailed representation of flow dynamics is not required	Piped drainage system is not represented; Cannot capture shock flood wave; Less numerically accurate than fully 2D shallow water equation models
Full 2D full shallow water equation models	Yes	Yes	Yes	DTM, details of buildings, roads, other structures	Full dynamic surface flow simulation including the capturing of the flood shock wave; Able to simulate detailed flow paths e.g. where buildings constrain the flow paths	Piped drainage system is not represented; Computationally expensive; Require a high resolution DTM
Coupled 1D piped drainage and 2D overland flow models	Yes	Yes	Yes	DTM, details of: buildings, roads, piped drainage system, other structures	Full dynamic surface flow simulation including the capturing of the flood shock wave and the piped drainage system; Have the potential to simulate urban pluvial flooding more accurately than other models	Computationally expensive; Require a high resolution DTM; Require details of the piped drainage system

2.3.2. Define the extent of the urban pluvial hydraulic model

The spatial extent covered by the urban pluvial hydraulic model needs to be defined. The 2D hydraulic model domain needs to cover the whole of the urban APSFR for which flood depths and extents are required.

2.3.3. Collate and pre-process relevant data

The following data are required to carry out urban pluvial modelling and mapping:

- **A Digital Terrain Model (DTM)** with a minimum of a 5 m horizontal grid with a suitable vertical accuracy is required covering the whole of the urban area to be modelled. High-resolution topographic data are needed to represent small urban features. However, it should be noted that decreasing the size of hydraulic grid cells increases the density of the model's mesh, and requires more run-time;
- **Rainfall intensity – duration – frequency (IDF) curves** for a range of Annual Exceedance Probabilities (AEPs) are required for each of the APSFRs where urban pluvial flood maps are to be produced;
- **Georeferenced building footprints** providing the area covered by each building in the urban area;
- **Road network**. Geo-referenced details of the road network would be required in order to model these flow paths;
- **Land use information** is required in order to define surface roughness coefficients for the hydraulic model and possibly infiltration rates;
- **Capacity of the stormwater drainage network** is sometimes required. This is can be in terms of the level of service defined by the AEP of the flood which it can convey or the rainfall intensity in mm/hour.

The sections below provide further details of the importance and the representation of these key data sets.

Importance of the DTM

Topographic data plays an important role in determining the accuracy of urban pluvial flood inundation areas. Ideally DTM with a maximum of grid 2 x 2 m (i.e. cell area of 4 m^2) should be used for urban pluvial modelling. Urban pluvial flooding may be greatly over- or underestimated if poor quality elevation data is used. Any feature which influences overland flow paths, flood depths or surface water ponding should be reviewed and where necessary incorporated in the revised DTM. The ways in which the DTM should be edited to incorporated buildings, watercourses and hydraulic structures are outlined below.

Figure 2.2 shows how the difference in resolution of the DTM and different grid sizes used in the hydraulic model of an urban area can affect the results of the pluvial flooding. In Figure 2.2 the top left view has a model with a triangular irregular mesh with a maximum triangle area pf 5 m^2; however, the average mesh size is considerably less than this. This represents the potential flow paths in urban areas better than the regular 2 x 2 m grid show in the top right Figure 2.2. Figure 2.2 also shows that a 20 m x 20 m grid is too coarse to accurately represent the flow paths between buildings in an urban area.

Representation of buildings

Pluvial flooding, especially in urban areas is influenced by features of the urban landscape, particularly buildings and roads. In many urban areas buildings play an important part in determining pathways for pluvial flood water. Not including buildings in a hydraulic model can contribute to inaccuracy in the modelled urban surface water flood depths and extents. The value of modelling buildings has to be balanced against the considerable data processing overheads (for inputs and outputs) and potential implications for model stability.

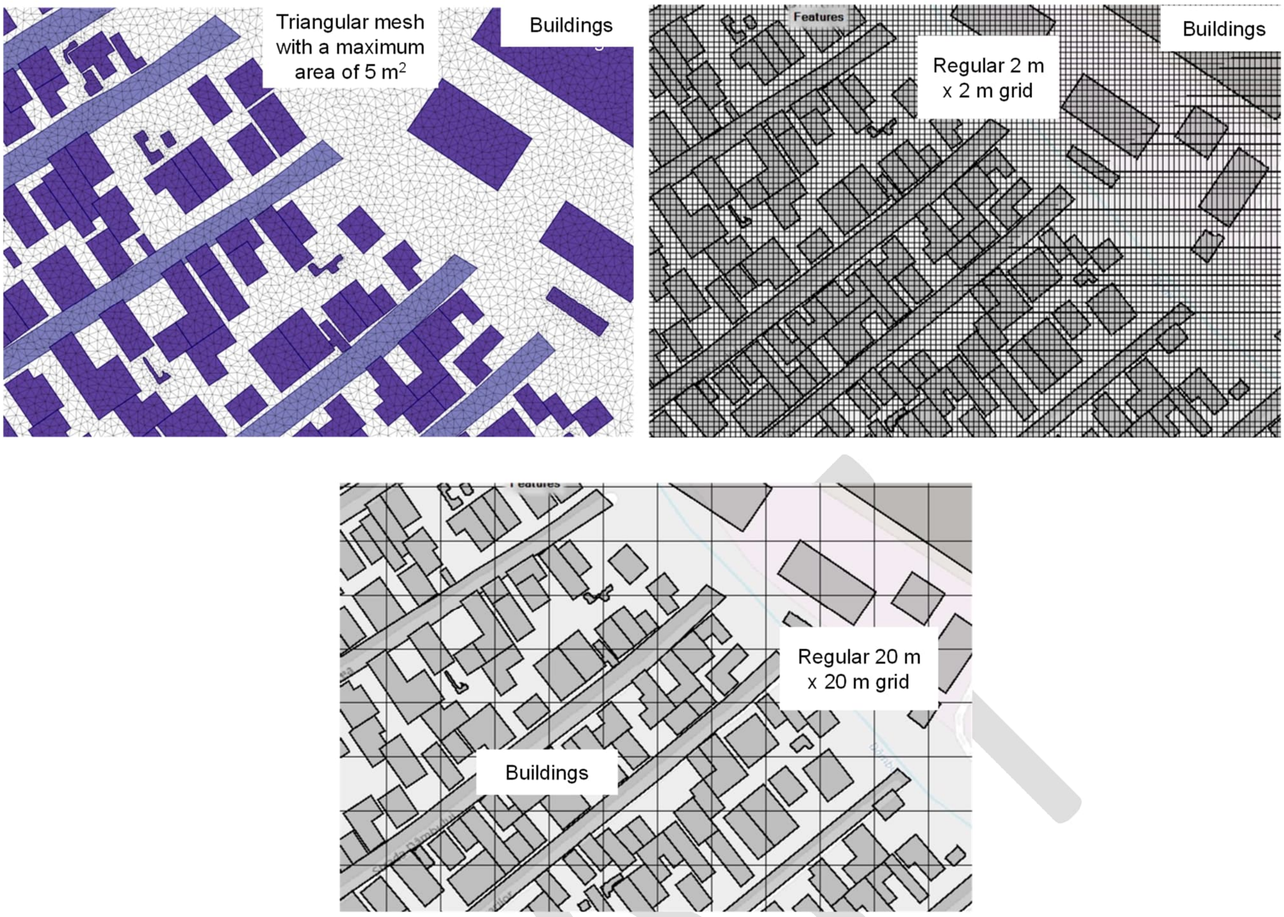


Figure 2.2: Impacts of the resolution of the DTM and the hydraulic model grid size on the potential representation of urban pluvial flow paths

Building can be represented in a variety of ways in the DTM as follows:

- **Buildings are removed from the DTM and left as voids** - In this method buildings are left as voids (i.e. empty spaces); however, in this approach the flood storage within the buildings is not accounted for and the obstruction to the flow caused by a building may be overstated;
- **Buildings are represented as blocks using their actual height** - This method has similar limitations to leaving voids in the DTM;
- **Buildings represented by high surface roughness** - This allows buildings to store water and provides floodwater depths within buildings;
- **Buildings raised to their threshold level (i.e. finished floor level)** - In this method the buildings are represented in the DTM by raising the buildings' footprints to their threshold level. The threshold level is the finished floor level, which is often equivalent to the level of the entrance to the building. Typically thresholds levels for buildings are between 150 mm to 300 mm above the level of the DTM.

The best way to represent buildings is raise their footprints to their finished floor level (i.e. threshold level). An alternative approach is increase the surface roughness of buildings but this should only be used when there is insufficient geo-referenced data on buildings available.

Figure 2.3 provides a good example of the importance of accurately including buildings when undertaking urban pluvial hydraulic modelling. The example is based on urban pluvial modelling carried out for the town of Ploiești in Romania. The view on the left of Figure 2.3 shows the results of hydraulic modelling which indicates that a large shopping centre is likely to be inundated as a result of urban pluvial flooding. However, upon further inspection it was found that the DTM of Ploiești was created whilst the shopping centre was being constructed and hence did not reflect the finished floor of the shopping mall. The DTM was altered to take this into account and the pluvial flood depth map on the right hand view of Figure 2.3 shows that the pluvial flood depths in the shopping mall significantly decreased.

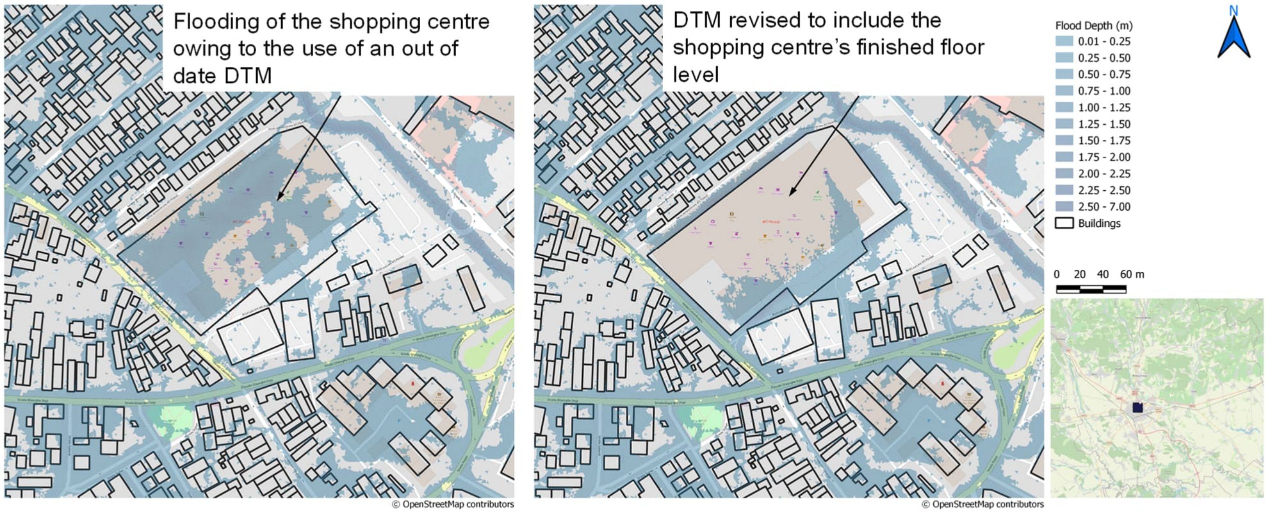


Figure 2.3: Impacts of building floor levels on pluvial urban flood extents and depths for the town of Ploiești in Romania

Representation of the road network

In urban areas roads often act as flow paths during pluvial floods and this needs to be taken into account in any urban pluvial hydraulic modelling which is carried out. For APSFRs where there is a geo-referenced road network it is recommended that the DTM is lower where there are roads in order to represent the flow paths they create. The height of road kerbs in Europe is generally between 100 mm and 300 mm so the amount by which the DTM should be lowered where roads are present is dependent on this.

2.3.4. Identify and define the boundary conditions

An urban pluvial flood models requires two boundary conditions:

1. Design rainfall hyetographs.
2. Downstream water level boundaries along the edge of the 2D hydraulic model grid.

Development of the design rainfall hyetographs

Design rainfall hyetographs are required as an input to the hydraulic model for at least the high, medium and low probability flood scenarios i.e. at least three AEPs. The steps involved in producing the design rainfall hyetographs are as follows:

1. Define the rainfall intensities for the required AEPs for the required storm durations.
2. Estimate the rainfall intensity losses.
3. Develop the design rainfall hyetographs for each AEP and storm duration.

Rainfall intensity data are required in order to develop the design rainfall hyetographs.

Depending on the land use, an infiltration or loss model is required to translate the gross rainfall into the net runoff. Where storm drainage networks are present, an additional loss can be used to represent the contribution of the network to reducing overland runoff. The loss can be based on either a design standard of the drainage network with all rainfall exceeding this being input to the above loss model, or as an estimate of network capacity. Urban drainage systems are generally capable of conveying the flow during frequent rainfall events. The flow is conveyed in pipes or channels and the water either stays below the ground surface or within the drainage channel. Urban drainage systems are usually expected to provide flood protection for rainfall events up to a maximum of a 1 in 30 year return period (3.33% annual exceedance probability) at most, according to the European Standard EN 752 External Drain and Sewer Systems (CEN

1996). The recommended method for the Floods Directive second cycle is to assume no drainage network capacity.

Downstream boundary conditions

The downstream boundary conditions of an urban pluvial model will generally comprise a boundary condition along the edges of the model grids that represents normal depth conditions This is recommended as the default method for producing the downstream boundary. For urban areas where there is a river or coast which could affect peak urban pluvial flood levels the sensitivity of the urban pluvial hazard is these can potentially be investigated.

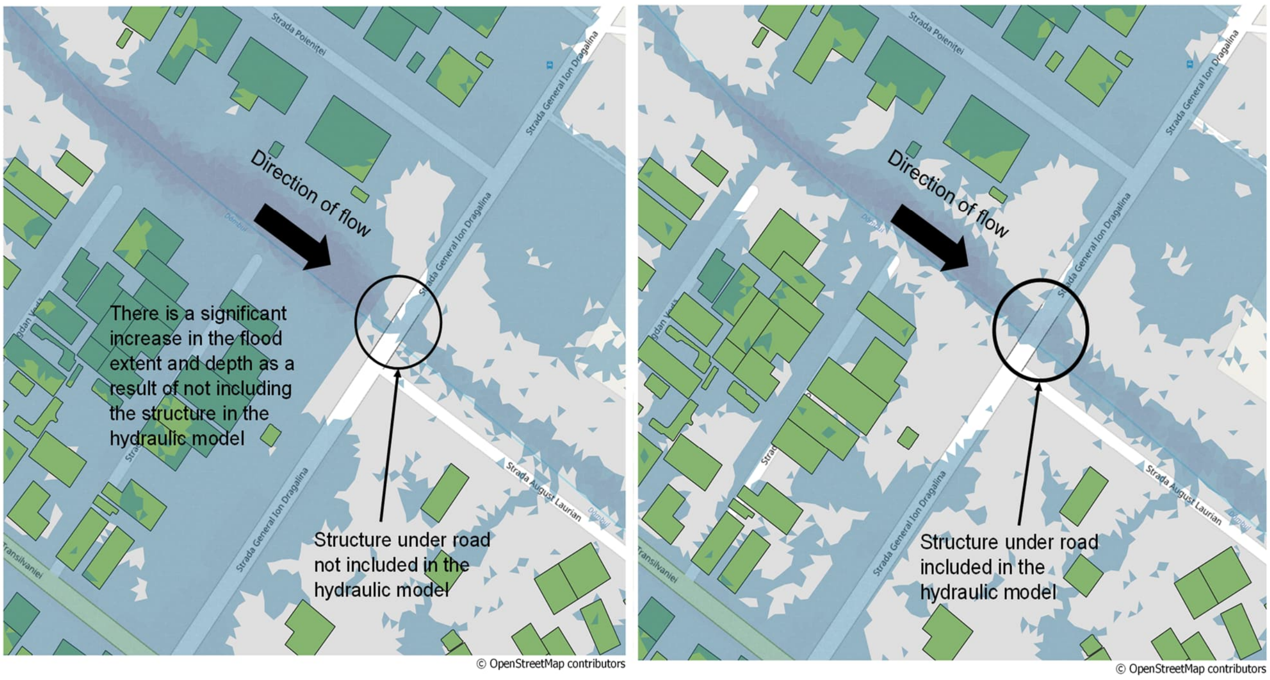
2.3.5. Schematisation of the urban pluvial hydraulic model

In terms of the schematisation of the urban pluvial hydraulic model, in addition to buildings, the following should be considered:

- The representation of hydraulic structures;
- Representation of watercourses;
- Hydraulic roughness coefficients.

Representation of hydraulic structures

It is important critical features such as openings or culverts which are affect urban flow paths flows and flood water depths are included in the hydraulic model. The importance of including hydraulic structures is shown in the Figure 2.4 which shows the effects on the urban pluvial flood extent and depths of not including and including hydraulic structure which carries an urban watercourse under a road in the town of Ploiești in Romania.



View 1: Structure under road not included **View 2: Structure under road included**

Figure 2.4: Impact of including and not including hydraulic structures on urban pluvial flood extents for part of the town of Ploiești in Romania

Representation of watercourses

Watercourses and other surface water features should be included in the model in the 2D domain of the urban pluvial hydraulic model. If a fine resolution DTM is being used (i.e. less than 2 m x 2 m horizontal resolution) then most watercourses which have a significant influence on the surface water flooding will explicitly be represented in the DTM. Where small watercourses, which have a significant influence on surface water flow paths and flood depth, have not been adequately represented in the DTM; then these channels should be “burnt” into the DTM ensure channel gradient is retained.

Representation of hydraulic roughness coefficients

The hydraulic roughness in urban pluvial hydraulic models should be based on a minimum of three land use types: buildings, roads and other areas (e.g. parks, gardens). Land use data such as the CORINE data set could also be used to estimate roughness coefficients.

2.3.6. Calibration and validation of an urban pluvial hydraulic model

Calibration of urban pluvial models is challenging because there are often few if any historical records of urban pluvial water levels together with the corresponding historical rainfall time series. One method of verifying the results of urban pluvial flood models is to compare the flood extents for historical events with aerial photographs or remote sensing data showing flood extents from satellites. For example, in Palermo in Italy pluvial flood models have been verified by means of crowdsourced information and satellite images (Francipane et al., 2021).

2.3.7. Production of pluvial urban flood extents and depths

When carrying out pluvial urban flood modelling, choosing a single representative critical storm duration is challenging. The critical storm duration is also strongly linked to the topography. In low-lying areas, near to rivers, the critical duration is long because surface runoff drains into these areas from larger catchments. On hill slopes the critical duration is generally short because the greatest flood depth arises from high intensity rainfall. Pluvial urban flood models should be carried out for a range of storm durations (e.g. 1, 3 and 6 hours) for each AEP. These are merged into a 'worst case' maximum output for each AEP, to ensure a realistic approximation of critical storm duration is represented in all locations and that the maximum pluvial flood extent and depth is mapped.

2.3.7. Uncertainty analysis

Pluvial flooding in urban areas is particularly uncertain compared to other sources of flooding (Takara, 2014). Urban pluvial floods often occur rapidly as the result of rare, highly localised, intense rainfall events. Assessing the annual exceedance probability of pluvial urban flood events is challenging because:

- Pluvial urban flood events are often rare and few have been experienced at one location in the past (Fontanazza et al, 2011). Rainfall events which produce urban pluvial floods are often highly localised in both space and time (Houston et al., 2011);
- The performance of urban drainage systems is unpredictable because they are often old and subject to blockages which has an impact on their performance (Djordjević et al., 2014)
- Relatively small features in the urban landscape such as the height of road kerbs, can affect flow paths in urban areas.

Ideally an uncertainty analysis should be carried out for pluvial floods taking into account: changes in the rainfall intensity; hydraulic roughness coefficients; building threshold levels; and the assumptions regarding net rainfall.

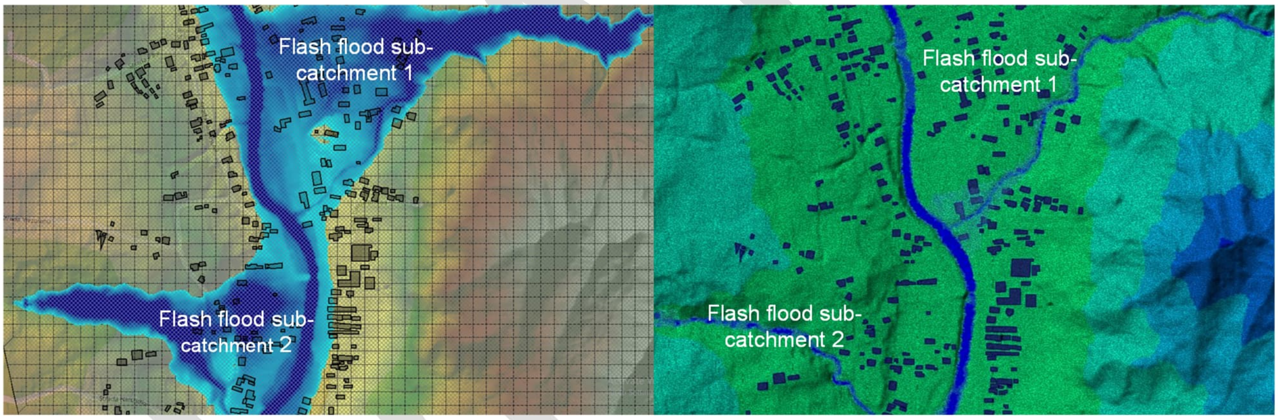
3. Overview of modelling and mapping pluvial floods in rural areas

Pluvial floods in rural areas are often called flash floods. However, flash flooding in many Member States can be from pluvial sources, fluvial sources or a combination of both of these. The Floods Directive classifies pluvial and fluvial flooding as different sources of flooding and flash flooding as a characteristic of flooding. Many flash flooding events can include both pluvial flooding before runoff enters a watercourse, and fluvial for when the capacity of a watercourse is exceeded.

In the context of the Floods Directive a flash flood is defined as a flood which rises and falls quite rapidly with little or no advance warning, usually the result of intense rainfall over a relatively small area. Most of the pluvial flash flood areas in Members States are generally small (e.g. less than 10 km^2), steep ungauged catchments draining the sides of valleys

The steps involved in the state of the art approach to modelling and mapping pluvial (or flash) floods in rural areas are similar to those for urban pluvial floods. Figure 3.1 shows the results of a modelling exercise undertaken for two flash flood catchments in the vicinity of the town of Olănești in Romania.

Figure 3.1 shows the difference in the pluvial flash flood depths and extents for two sub-catchments in the Olănești APSFR in Romania. View 1 shows the results of using a 2D diffuse wave model with a 5 m grid and View 2 the results of using a more accurate 2D hydraulic model which solves the full shallow water equations. The difference between the two flood maps is significance and shows that using a simple hydraulic model with a relatively coarse spatial resolution can in some cases lead to the flood hazard and risk being overstated.



View 1: Maximum flood extent and depths 2D diffuse wave model with a 5 m grid (i.e. area of 25 m^2)

View 2: Maximum flood extent and depths for a 2D hydraulic model solving the full shallow water equation with a triangular mesh with a maximum area of 4 m^2

Figure 3.1: Difference in flood flood extents and depths between using a 2D hydraulic model with a 5 m grid and a 2D hydraulic model solving the full shallow water equations with a triangular mesh with a maximum area of 4 m^2 for two flash flood catchments in the Olănești APSFR in Romania

Part B: workshop on pluvial flooding

4. Workshop and questionnaire on pluvial flooding

4.1 Introduction

This section describes the outcomes of a European Commission (EC) Working Group F (WG F) workshop on pluvial floods held on 18 and 19 May 2022 in Brussels, Belgium. The workshop took the form of a hybrid meeting, with some participants taking part in person and some online via Zoom. This section also provides the results and conclusions from an accompanying questionnaire which was sent to Members States in April 2022 in advance of the workshop.

4.2 Summary of the questionnaire on pluvial flooding

4.2.1. Introduction

A questionnaire on pluvial flooding was sent to Member States in advance of a workshop on pluvial flooding held in Brussels in May 2022. A copy of the questionnaire is included in Appendix A of this report. Twenty-two responses were received, this included two responses from Belgium (one for Wallonia (BE-WL) and one for Flanders (BE-FL)). A summary of the results of the responses are given in the follow sections.

4.2.2. Definition of pluvial flooding

Each Member State was asked how pluvial flooding is defined in their country. There were 22 responses to this question. Definitions included:

- "*Stormwater or meltwater accumulated on the land surface or other similar surfaces in densely built-up areas*" (FI).
- "*Flooding caused by intense rainfall such as cloudburst, typically in summer, were the capacity of the drainage system (both rural and urban) is exceeded*" (BE-FL).
- "*Pluvial floods are defined as surface flow directly induced by rainfall or snowmelt with no connection to a creek, torrent or river*" (AT).
- "*A flood that results from short-term rainfall intensity of typically > 40 mm, usually convective, and that exceeds the runoff capacity in urban areas or the infiltration capacity in rural areas and can therefore inundate land and property far from rivers and small streams*" (LU).
- "*Flooding due to direct runoff over land caused by rainfall, before reaching rivers or drainage system*" (NL).

Six of the definitions (AT, EL, IE, NL, PL, SE) mentioned the fact that pluvial flooding was caused by rainfall falling "*directly*" on to surfaces and not as the result of "*overflow*" from stream or river channels. Two definitions (LU, SE) specifically mentioned rainfall intensities in millimetres that are considered to be "*high*" or "*extreme*" above which pluvial flooding is likely to occur. There was a common theme in the definitions of pluvial flooding of some respondents (BE-FL, FR, HU, LU, LV, MT, PT) relating to the fact that pluvial floods in urban areas generally happen rapidly (i.e. in less than two hours).

Table 4.1 summarises the characteristics used by Member States in their definitions of pluvial floods. The two most frequently mentioned characteristics of in the definitions of pluvial floods were were that they are caused by intense rainfall falling and that the flooding is not related to the overflow from a watercourse. These two characteristics were mentioned in seven of the definitions. The second most frequently mentioned characteristics were that pluvial floods happen rapidly and that they are caused by rainfall falling directly on to a surface. These two characteristics were mentioned by six Members States.

4.2.3. Mapping of pluvial flooding in the first cycle of the Floods Directive

Figure 4.1 shows the responses to whether pluvial floods were modelled and mapped as part of the first cycle of the Floods Directive's implementation. Of the respondents who answered yes, two of the responses were qualified. SE stated that pluvial floods had been modelled for some Areas of Potential Significant Flood Risk (APSFRs) but not for the whole country and EL stated that pluvial floods had been modelled and mapped based on the "*hydromorphological characteristics of the watersheds in Greece*".

Table 4.1: Characteristics mentioned by Member States in their definitions of pluvial floods

Member state	Characteristics mentioned in Member States' definitions						
	Rain falling directly on a surface or direct runoff	Not related to the overflow of a stream or river	Capacity of drainage system exceeded	Intense rainfall	Concentrated runoff	Rapid response	Occur in urban or built up areas
AT	✓	✓					
BE-FL			✓	✓		✓	
BE-WL					✓		
CY		✓	✓				
CZ		✓					
DE		✓		✓			
DK				✓			
EL	✓						✓
ES		✓		✓			
FI							✓
FR					✓	✓	
HR							
HU						✓	
IE	✓	✓					✓
LU			✓	✓		✓	
LV	None of these characteristics were mentioned						
MT						✓	
NL	✓	✓					
PL	✓						✓
PT				✓		✓	
SE	✓			✓			
SK	None of these characteristics were mentioned						

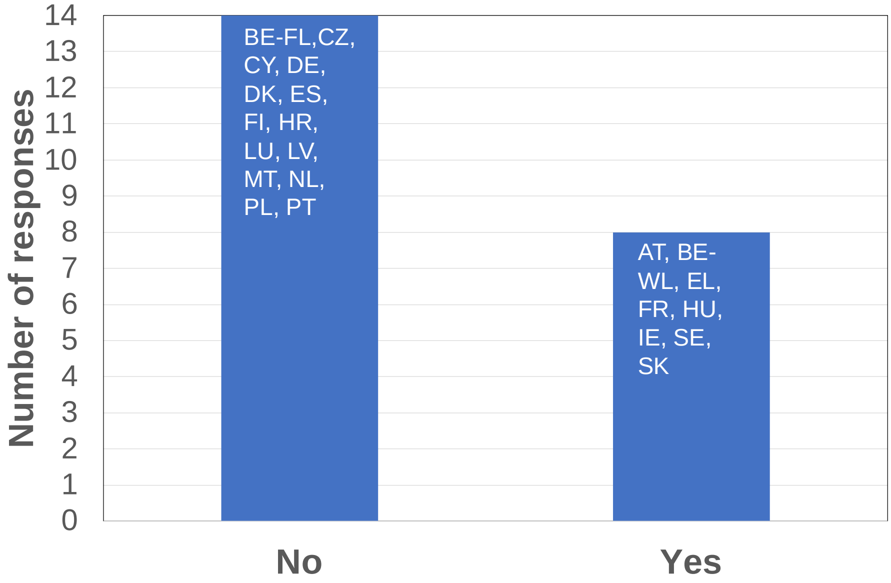


Figure 4.1: Number of respondents who stated whether they had modelled and mapped pluvial floods in the first cycle of the Floods Directive

The eight respondents who had modelled and mapped pluvial floods in the first cycle of the Floods Directive were asked if the way in which this was undertaken in the second cycle of the Floods Directive had changed since the first cycle. Apart from IE and SK, all the respondents stated that the methods that been employed to model and map pluvial floods had changed since the first cycle.

In IE, in the first cycle of the Floods Directive, pluvial flood mapping was undertaken at a national level as part of the Preliminary Flood Risk Assessment (PFRA) using a rapid flood spreading model. Detailed urban storm water (i.e. pluvial) flooding was then mapped for Dublin City and the town of Raphoe, where pluvial flooding had been found to be a potentially significant risk. In IE no further modelling or mapping of pluvial floods was undertaken during the second cycle because all the areas where the pluvial flood risk was significant had already been mapped in the first cycle.

In AT, the first cycle pluvial maps were produced based on historical data. For the second cycle of the Floods Directive, the "*rolling ball method*" was used to map pluvial floods in AT. The rolling ball method uses GIS tools to analyse ground elevation models to identify natural flow pathways and depressions. It can be undertaken at low-cost, is quick to apply and can clearly define depressions and flow pathways. In AT it allowed nationally consistent pluvial flood maps to be produced for the whole country. For the third cycle of the Floods Directive AT intends to produce pluvial flood hazard and risk maps based on hydraulic modelling.

Six (BE-FL, CY, ES, FI, LU, MT) out of the 14 respondents who did not model pluvial floods in the first cycle of the Floods Directive modelled and mapped them in the second cycle.

4.2.4. Dealing with pluvial flooding within the context of the Floods Directive

The respondents were asked how pluvial flooding was dealt with within the context of the Floods Directive and whether there were other tools and regulatory processes which were applied. There were nine responses to this question. These are summarised below.

In DE, the management of pluvial flood risks was identified as a key issue for both the federal government and the federal states, in particular with climate change and the related increase in intense rainfall events,. To meet the future challenges, the DE Working Group on Water Issues of the Federal States and the Federal Government (LAWA) has developed a strategy for effective management of the risks posed by intense rainfall. The strategy addresses the improvement of pluvial forecasting and early warning systems, risk assessment and risk communication to stakeholders, as well as aspects related to urban/spatial planning and land use. In DE, the LAWA is currently working on evaluating and updating the strategy. The LAWA decided that flood risk caused by "*heavy rainfall*" is to be classified as a "*general risk*", but not as a "*significant risk*", in the flood risk assessment. This was justified primarily by the fact that, in contrast to fluvial floods, occurrence probabilities for surface runoff from intense rainfall events cannot be determined with sufficient statistical accuracy. Convective precipitation events can occur at any location and cannot be adequately predicted. DE indicated that, "*The available data on past events is also too unsystematic or the time series too short*". To date in DE, the management of the risks posed by "*heavy rainfall*" has concentrated on the local/regional scale in terms of hazard and risk analysis, as well as measure planning and implementation such as the production of "*heavy rainfall hazard maps*". However, following the summer floods in 2021 in DE, the LAWA is going to re-examine, as a matter of priority, whether elements of risk management for intense rainfall events should or can be taken into account in the flood risk assessment according to the Floods Directive.

In DK pluvial flooding is not dealt with within the context of the Floods Directive. The incorporation of the Floods Directive in legislation in DK only included coastal and fluvial flooding. However, municipalities in DK have developed climate adaptation plans and pluvial flooding is a primary focus for many municipalities.

In HR pluvial flooding was considered in the second PFRA as a significant issue, especially in larger cities with large impermeable areas. However, pluvial flooding was not taken into consideration in the Flood Risk Management Plan (FRMP) for technical reasons, these were not further elaborated on in HR's response. HR was a partner in the Interreg RAINMAN project[1] which developed various tools for modelling, mapping and communicating pluvial flood risk. HR intends to model pluvial floods in the next cycle of the Floods Directive.

In LU, pluvial flooding only emerged to be a significant source of flooding following flood events of 2016 and 2018. In LU a decision was made to include a strategy for the management of pluvial floods as an annex to the FRMP. LU published national pluvial flood hazard and risk maps for a design rainfall event with a duration of 60 minutes with an Annual Exceedance Probability (AEP) of 1% (i.e. a return period of 1 in 100 years). The main goal of this exercise was to raise public awareness of pluvial risk in LU.

In LV rainfall is not on the list of the main flood risk sources. However, in LV's second cycle FRMP pluvial flooding has been mentioned as a potential risk for the whole of the country owing to climate change. As a result, measures for mitigating pluvial flooding such as the improvement of drainage systems were included in the second cycle Programme of Measures (PoM). LV intends to carry out pluvial flood modelling and mapping for the third cycle of the Floods Directive.

NL stated that, "*In the first and second cycles* [of the Floods Directive], *the risks of pluvial flooding were considered much less significant than that of fluvial and coastal flooding*". In the third cycle of the Flood Directive NL intends to evaluate pluvial flooding in the PFRA.

In PL pluvial floods were considered in the PFRA. Historical pluvial floods events were identified but not classified as "*significant floods*". PL stated that "*The analyses of spatial and temporal distribution of pluvial flooding in PL showed that it is not possible to aggregate data in larger areas and to determine the APSFRs*".

PT stated that it had developed a model for fluvial floods which included the characteristics of the drainage systems in the urban areas. PT has carried out modelling in one pilot APFSR site, located in an urban area, where a combination of flood sources (i.e. pluvial and fluvial) were considered. PT is currently working with some municipalities to characterising and collect data on pluvial floods (e.g. historical floods, drainage system characteristics) for use in the third cycle of the Floods Directive.

4.2.5. Data availability for historical pluvial flood events

Figure 4.2 shows the results to the question focusing on the availability of data from historical flood events. Most respondents had historical rainfall data (both daily and sub-daily available); however, only eight respondents stated that they had historical flood extents data readily available for past pluvial events. In the "*other*" category there were a variety of responses which were provided including:

- Registers of pluvial flood impacts which have been collected by municipalities and local authorities (AT, BE-FL, HU, FR, PT). These are often collected by local municipalities, based on the compensation paid by insurance companies or reports from emergency responders such as the fire brigade.
- Databases of historical flood events (BE-FL, DE, FR, PL),
- Information from emergency responders (FI, HR, PL).
- Documented evidence from news articles and empirical evidence from people living in areas subject to pluvial floods (MT).
- Photos and descriptions from social media (CZ).
- Historical flood marks on buildings affected by flash floods (LU).
- Data related to compensation received by stakeholders affected by pluvial floods (e.g. flood insurance, data held by local municipalities for when certain criteria have been met with respect to pluvial floods).
- Databases of interventions by the fire service in relation to the removal of the effects of intense rainfall.
- Coordinates, time, and other information from flood-related rescue operations.

[1] https://www.interreg-central.eu/Content.Node/RAINMAN.html

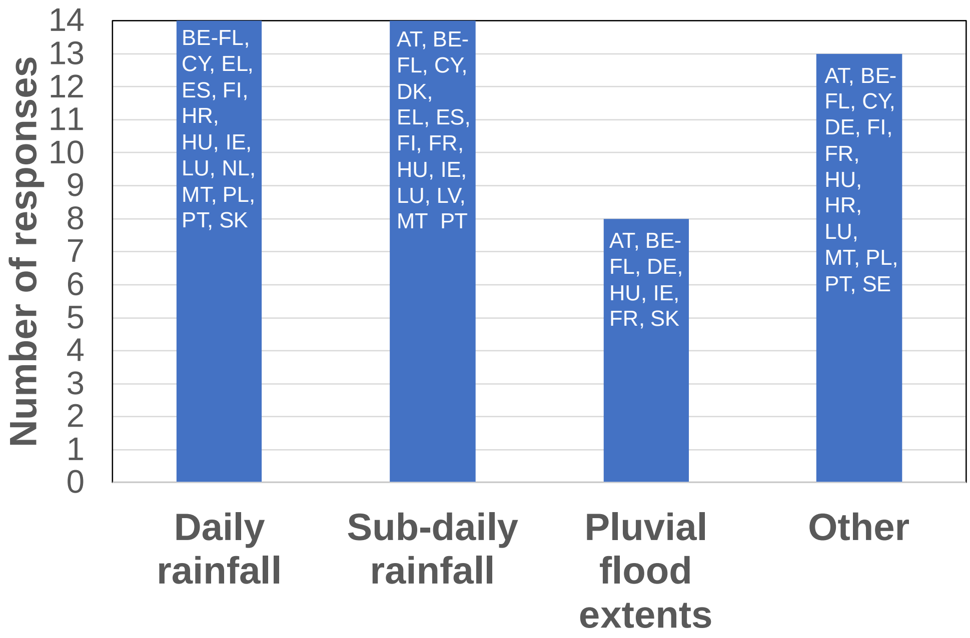


Figure 4.2: **Number of respondents who stated they had readily available data for historical pluvial flood events**

4.2.6 Defining Areas of Potential Significant Flood Risk for pluvial floods

Member States were asked if Areas of Potential Significant flood Risk (APSFR) for pluvial floods had been defined in a different way to other sources of flooding. There were 17 responses provided which are shown in Figure 4.3.

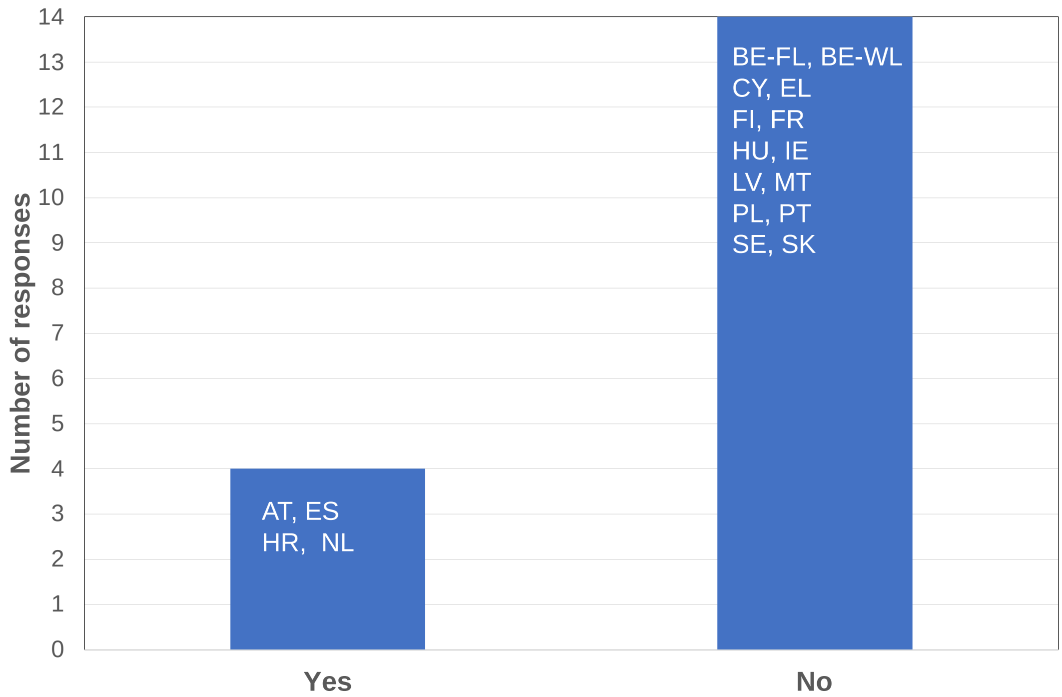


Figure 4.3: **Number of respondents who stated they had defined Areas of Potential Significant Flood Risk differently for pluvial floods compared to other sources of flooding**

If the Member State answered yes they were asked what the difference was in how pluvial flood APSFRs were defined compared to other sources of floods. The answers of the Member States who answered yes to this question are given below:

- AT- "*For pluvial flooding expert judgement based on indication maps and historic data was done. For fluvial floods the significance as a first step was defined for 500 people exposed in the 300-years flood inundation area per municipality. Under consideration of further datasets this preliminary assessment was fine-tuned and APSFRs identified*".
- ES – "*Delimitation of the pluvial APSFR has been based on an exhaustive analysis of: Priority Action Points (PAP) identified by Civil Protection of Catalonia, included in the risk maps of Civil Protection of Catalonia (MRPCC), related to pluvial floods with effects on urban areas, communication routes, and with a rating of "medium" or "high" risk classification; Different studies available where pluvial floods in a certain area were analyzed. In addition, economic costs of damage caused by floods of pluvial origin occurred in the period 2011-2017, collected in the database of the 'Consorcio de Compensación de Seguros' (CCS)*[2]*, were considered, however, this criterion is also used for the pre-selection of fluvial and fluvial-pluvial APSFR. Those areas associated with a problem of a fluvial nature (or in a public channel), as well as those associated with insufficient urban drainage, were ruled out from the pluvial ASPFR selection. In contrast to fluvial and pluvial-fluvial APSFRs, a specific section (line) is not delimited within the pluvial APSFR, instead corresponds to the delimitation of the urban sector to which it is associated (does not respond to hydrographic criteria)*".
- HR – "*Areas of Potential Significant Flood Risk for pluvial floods were not identified. However larger cities with high degree of soil sealing were identified as some kind of APSFR candidates for next planning cycle and priorities for action*".
- NL – "*The first exploratory analysis for the PFRA for pluvial flooding was done through a rainfall-runoff model. Coastal and fluvial flooding are carried out in a more sophisticated way based on flood risk (including both the occurrence of flood levels and the strength of flood protection)*".

4.2.7 Mapping pluvial floods separately to other sources of flooding

The respondents were asked whether pluvial floods had been mapped separately to other sources of flooding in the second cycle of the implementation of the Floods Directive. The results are shown in Figure 4.4. There were some further details provided by Member States. In DE pluvial hazard maps have been produced mainly at a local / regional level. In 2021, the Federal Agency for Cartography and Geodesy (BKG) in DE published an interactive web-based map showing hazard information for intense rainfall for the area of North Rhine-Westphalia. The BKG project will be extended to other federal states in the near future. FR stated that pluvial floods had been mapped separately "*only for some APSFRs*".

[2] The Consorcio de Compensación de Seguros is a government tool used by the Spanish insurance sector. Its function is to reimburse the insurance holder for damage produced by natural phenomena, or because of political or social incidents.

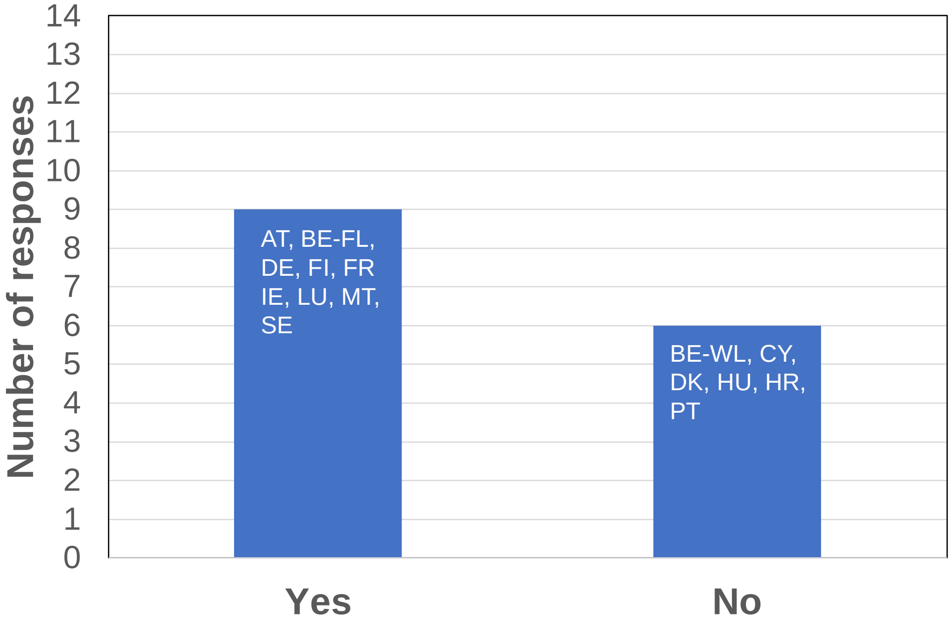


Figure 4.4: Number of respondents who stated they had mapped pluvial floods separately to other sources of flooding

The respondents were asked how Areas of Potential Significant Flood Risk (APSFRs) for pluvial floods were identified and what thresholds were used to define "*significance*" for pluvial floods. Five (BE-FL, EL, FR, IE, PL) of the 17 respondents stated that the method to define APSFRs was the same for all sources of flooding. Two respondents (BE-WL, LU) stated that APSFRs for pluvial floods were not defined because the whole of the country is at risk from this source of flooding.

In CY, historical pluvial flood extents and frequencies together with expert judgement were used. FI produced preliminary pluvial flood hazard maps to help municipalities assess the pluvial flood risks for the second cycle of the Floods Directive. These maps show the potential flood hazard areas caused by intense rainfall for two rain events. The maps were produced for most urban areas using a surface water flow model and a national digital terrain model with a 2 x 2 metre grid. AT produced pluvial hazard "*indication maps*" for the whole country based on the rolling ball method (see section 2.3). These maps showed where there were pluvial flow routes into settlements, the area of the upstream catchment size and the average slope. For recent pluvial flood events in AT, damage data were available. In AT this information, together with expert judgement, was used to define pluvial APSFRs.

In HR, APSFRs for pluvial floods were not identified. However, cities with large impermeable areas were identified as potential candidates to be defined as APSFRs in the third cycle of the Floods Directive. In ES pluvial flooding was considered in the "*fluvial/pluvial*" category of APSFR, except in the case of one APSFR in the Distrito de Cuenca Fluvial de Cataluña River Basin District which was defined as pluvial APSFR. A minimum threshold of €0.1 million of economic damage caused by pluvial floods associated with an event and municipality from the database of the 'Consorcio de Compensación de Seguros' (CCS) was established as a threshold.

4.2.8 Probabilities for which pluvial flood were mapped

The Member States who had mapped pluvial floods were asked which probabilities they had modelled and mapped for the high, medium and low probability scenarios.

The various responses are provided below:

- BE-FL - Return periods of 1 in 10, 1 in 100 and 1 in 1,000 years were mapped similar to fluvial floods.
- BE-WL – The following rainfall return periods were used: 1 in 25 year, 1 in 50 year, 1 in 100 year and 1 in 100 years plus a 30% increase in rainfall.

- CY – For pluvial floods the following return periods were modelled 1 in 20 year (high probability), 1 in 100 year (medium probability) and 1 in 500 year (low probability). The same return periods were modelled for fluvial floods.
- FI – Pluvial flooding was modelled using two different rain events: a four hour event with the probability of 1 in 100 years and a lower probability event observed in the city of Pori in 2007 which had a return period of approximately 1 in 1,000 years.
- HU – The following AEPs were modelled: 1% (low probability), 5% (medium probability) and 10% (high probability).
- IE - 10%, 1% and 0.1% AEPs for one pluvial APSFR (the town of Raphoe) and 10%, 1% and 0.5% AEPs for the other pluvial APSFR (Dublin City). Fluvial and coastal probabilities were mapped for 10%, 1% and 0.1% and 10%, 0.5% and 0.1% AEPs respectively.
- LU - Pluvial floods were modelled for a rainfall with a duration of 60 minutes and a return period of 1 in 100 years (i.e. 1% AEP).
- MT - For pluvial floods the high probability of occurrence was a 1 in 5 year return period (20% AEP), the medium one was a 1 in 50 year return period (2% AEP) and the low probability one was a 1 in 200 year return period (0.5% AEP).
- NL - In the exploratory analysis carried out for the PFRA, rainfalls of 35 mm , 70 mm and 140 mm with a 2 hour duration were used. These correspond to return periods of 1 in 10, 1 in 100 and 1 in 1,000 years respectively.
- SE - The probabilities modelled differed for different regions and the local conditions.

The responses are summarised in Table 4.2.

Table 4.2: High, medium and low probabilities mapped for pluvial floods by Member States

Member State	Annual Exceedance Probability (AEP) in percentage and return period in years								
	20% (1 in 5 years)	10% (1 in 10 years)	5% (1 in 20 years)	4% (1 in 25 years)	2% (1 in 50 years)	1% (1 in 100 years)	0.5% (1 in 200)	0.2% (1 in 500 years)	0.1% (1 in 1,000 years
BE-FL		✓				✓			✓
BE-WL				✓	✓	✓			
CY			✓			✓		✓	
FI						✓			✓*
HU		✓	✓			✓			
IE		✓				✓	✓#		✓#
LU						✓			
MT	✓				✓		✓		
NL		✓				✓			✓

*This probability is based on an historical event which has an AEP of approximately 0.1%
0.1% AEP was modelled only for the town of Raphoe and the 0.5% AEP was modelled only for the city of Dublin

From Table 4.2 it can be seen that the most popular AEP mapped was 1% (i.e. a 1 in 100 year return period) followed by the 0.1% AEP (i.e. 1 in 1,000 years).

4.2.9 Challenges faced in terms of data for the modelling and mapping of pluvial floods

Member States were asked about the biggest challenges they faced in terms of data for the modelling and mapping of pluvial floods. The following options were provided.

- Availability of Digital Terrain Model (DTM).
- Rainfall intensity data to define scenarios.
- Data on land use and soil properties.
- Details of the urban drainage system.
- Details of previous significant pluvial events.

- Other data.

The respondents were asked to rank the options from “1” being the most challenging to “6” being the least challenging. The question received 17 responses (AT, BE-FL, BE-WL, CY, PT, ES, FI, FR, HR, HU, IE, LU, MT, NL, PL, SE, SK) . The average responses are shown in Figure 4.5. This clearly shows that the biggest challenge perceived by Member States is obtaining details of the urban drainage system.

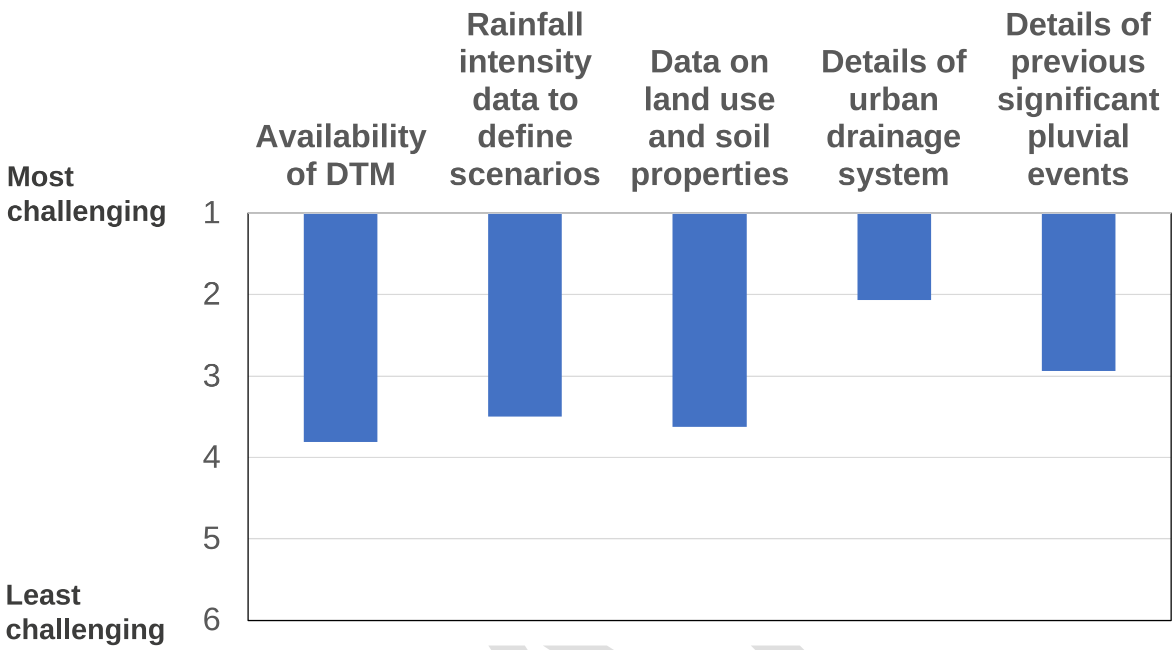


Figure 4.5: Challenges faced in terms of data for the modelling and mapping of pluvial floods

Other challenges related to data mentioned by respondents were:

- No effective monitoring system for the calibration of the pluvial flood models (MT).
- Lack of digitally available data e.g. exact location of gullies and pipes in rural areas, together with blockages (LU).
- Details of rural drainage systems, e.g. the presence of culverts (BE-FL).
- Availability of “breaking edges”, “enclosures” and culverts (AT).

4.2.10 Differences of approaches used for the modelling and mapping of surface runoff in rural areas (i.e. pluvial rural floods) and urban pluvial floods

The Member States were asked if they had used different approaches to the modelling of pluvial flooding in urban and rural areas. The results of the question are shown in Figure 4.6.

Six respondents (AT, BE-FL, IE, FR, MT, NL) stated that different approaches had been used, these are summarised below:

- AT - In the second cycle of the Floods Directive only areas outside settlements were included in the rolling ball method.
- BE-FL - Some extra parameters were included to take into account the urban drainage systems.
- IE - Pluvial rural floods in the town of Raphoe were modelled using a 1D-2D dynamically linked hydraulic model to allow for in-channel flow as well as overland flow, whereas urban rural floods were modelled with a 2D hydraulic model.
- FR – The modelling was adapted depending on the area to be mapped. Different parameters were adopted. e.g. the roughness coefficients used in rural areas and urban areas. Sewage and drainage networks were considered where relevant. The size of the hydraulic model's mesh was varied dependent on the land use.

- MT - Urban pluvial flood model were more refined than pluvial rural floods owing to the exposure of the receptors at risk.

Ten respondents stated that they did not use different approaches for the modelling and mapping of pluvial floods in urban and rural areas. Of these ten respondents, one (CY) stated that "*No APSFRs with rural pluvial floods were identified*" and another (BE-WL) stated that "*No but a mask was applied in heavily urbanised areas where the sewage system influence the results*". It is unclear from BE-WL's response what exactly applying "*a mask*" means in terms of the method used.

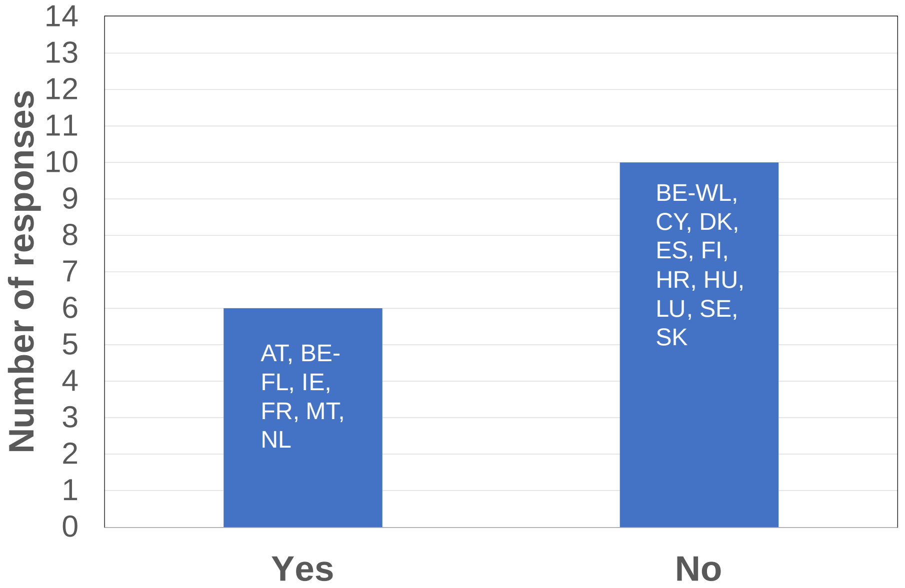


Figure 4.6: Number of respondents who stated they had used different approaches to model pluvial floods in urban and rural areas

4.2.11 Addressing uncertainty in the modelling of pluvial floods

Respondents were asked if uncertainty in the modelling of pluvial floods had been addressed. The results are shown in Figure 4.7.

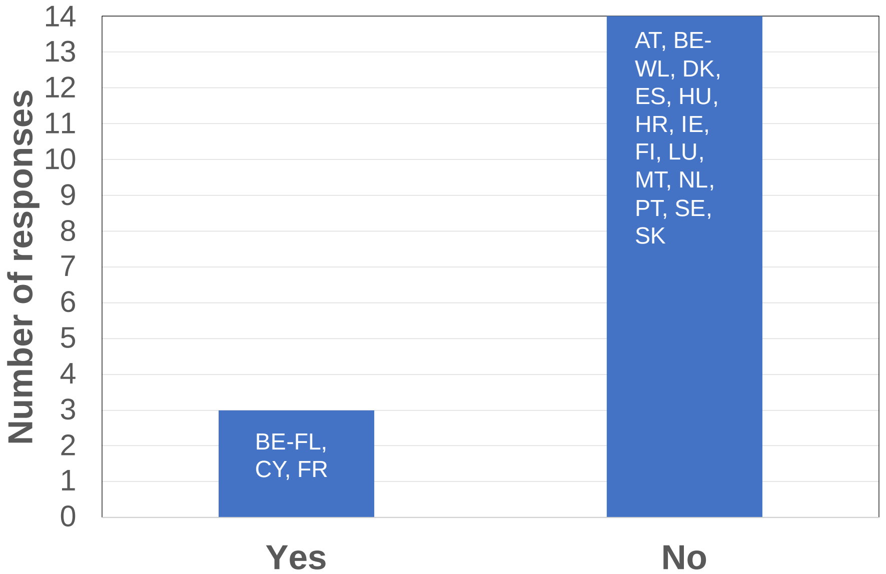


Figure 4.7: Number of respondents who stated they had addressed uncertainty in the modelling of pluvial floods

Only three respondents stated that they had addressed uncertainty in the modelling of pluvial floods and one of these responses (CY) indicated that modelling development was still ongoing with the aim of addressing uncertainty. The two respondents who stated that they had taken uncertainty into account in pluvial modelling stated that sensitivity analysis were conducted in one case (BE-FL) and in another case (FR) that uncertainty and limits were described and presented alongside maps information. From the responses received, it appears that no rigorous uncertainty analysis for pluvial flood modelling has been undertaken by any of the respondents.

4.2.12 Addressing uncertainty in the mapping of pluvial floods

Respondents were asked if uncertainty in the mapping of pluvial floods had been addressed. The results are shown in Figure 4.8.

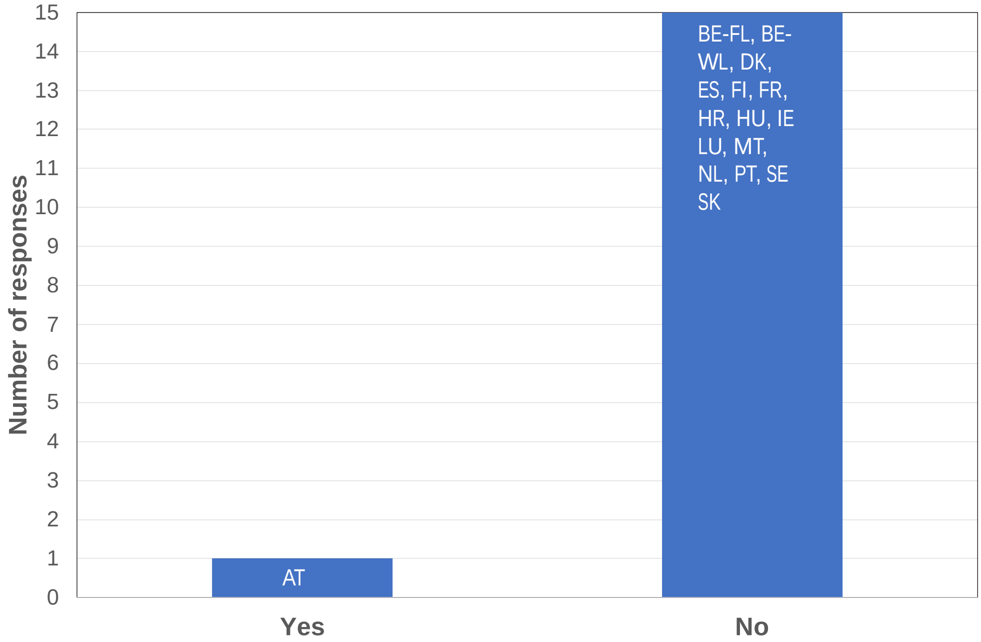


Figure 4.8: Number of respondents who stated they had addressed uncertainty in the mapping of pluvial floods

Only one respondent (AT) stated that uncertainty had been addressed in pluvial flood maps and this had been done by highlighting uncertainties in information published, including in communication with the public.

4.2.13 Taking into account climate change in the modelling and mapping of pluvial floods

Respondents were asked whether they took into account climate change in the modelling and mapping of pluvial floods. The results are shown in Figure 4.9.

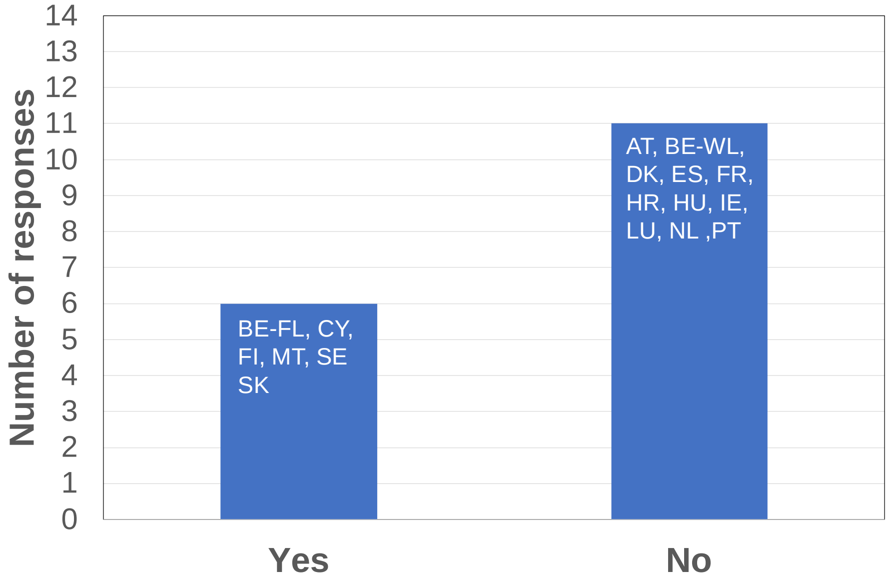


Figure 4.9 Number of respondents who stated they taken into climate change account in the modelling and mapping of pluvial floods

A total of six respondents stated that climate change had been taken into account in the modelling and mapping of pluvial floods and provided further details on how this was undertaken. :

- BE-FL – "*Separate climate change maps were modelled. They make use of adapted rainfall intensity scenarios based on perturbated rainfall time-series*".
- CY – "*A future scenario for the year 2080 taking into account climate change and expected land use change was modelled and mapped for the 1 in 20 year return period. The climate change scenarios used were RCP4.5 and RCP8.5*[3]".
- FI - "*Floods map for the PFRA of future floods were based primarily on a very rare events i.e. flood maps with an annual probability about 1 in 1,000 years. The assessment aims to take into account the different sources of error and uncertainty, such as the impacts of climate change. However, pluvial flood maps taking in to account the change are difficult to produce. Design rainfall information is at this time based on observations and it does not take into account the effect of climate change. For pluvial climate change flood maps increased intensity and amount of rain could be used to produce rough hazard maps, but for future pluvial flood risk maps, uncertainties are too large and the effects of land use change, urbanisation etc. play bigger role*".
- MT - "*In order to take into account, the potential impacts of climate change, the maps in Malta for a specific catchment were produced considering a design low, medium and high probability return period rainfall duration equal to the time of concentration of that catchment multiplied by a factor of 1.5 therefore extending the duration of the rainfall by 50% as a precautionary procedure*".
- SE – "*Unclear how climate change was taken into account and to what extent*".
- SK – "*Precipitation as an input to the models was adjusted by climate change scenarios*".

Of the six respondents, it is noticeable that three highlight the uncertainties related to how they had taken into account climate change in the modelling and mapping of pluvial floods, SE and FI stated that it was not clear how this had been undertaken and to what extent. MT added that only the duration rather than the intensity of the rainfall had been increased to account for climate change.

[3] This is a Representative Concentration Pathway (RCP) which is a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC). RCP4.5 is described by the IPCC as an intermediate scenario. Emissions in RCP4.5 peak around 2040, then decline. In RCP8.5 emissions continue to rise throughout the 21st century.

4.2.14 Use of the second cycle pluvial flood maps be used to support decisions related to land use and spatial planning

Member States were asked whether they would be using their second cycle pluvial flood maps, if available, to support decisions related to land use and spatial planning. There were 17 responses to this question the results of which are shown in Figure 4.10.

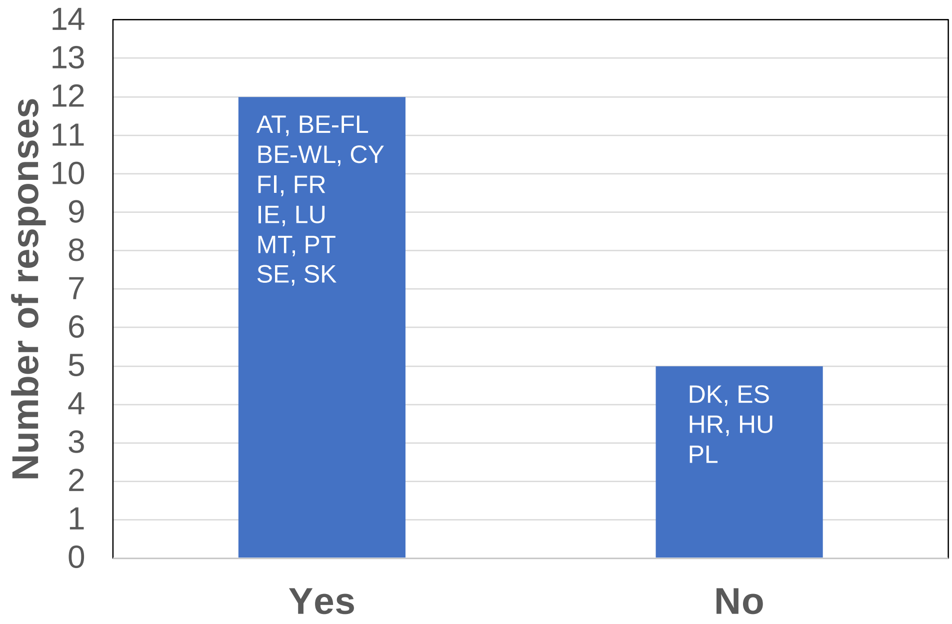


Figure 4.10: Number of respondents who stated their second cycle pluvial flood maps will be used to support decisions related to land use and spatial plannings

All 12 respondents who answered yes to this question, provided further information on how the pluvial flood maps would be used to support decisions related to land use and spatial planning.

- AT – "*As a first indication. It is clearly communicated that due to the inherent uncertainty an expertise is needed when it comes to local decisions in the frame of spatial planning or building regulation. "If an entry point to the settlement is indicated, please consider further steps of local inspection, modelling or expertise'*"".
- BE-FL – "*The data will be incorporated in the water-check when applying for planning permits and in the obligation to inform about flood risks when selling (or renting) a property*".
- BE-WL – "*In the vicinity of these areas, advice is required when applying for planning permission*".
- CY – *"Work is still in progress*".
- FI – "*The indicative pluvial flood maps have been used in some municipalities as assessment tool for general master plan work (stormwater surveys etc.). The maps show areas where surface runoff easily accumulates, and which areas can be recommended to be left unbuilt. Alternatively, nature-based solutions may be done to these areas or their catchment areas*".
- FR – "*In some cases (for instance in the absence of any other document), the medium probability scenario maps can be used in building permit instructions, by application of the R. 111-2 article of the French town planning code*".
- IE - "*Flood maps are used to inform 'Flood Zones' that should then be taken into account in spatial planning in line with national guidelines*".
- LU - "*The surface runoff maps are publicly available (http://g-o.lu/3/8tlp) and are intended to raise awareness of the need for action to strengthen resilience. Within the framework of local, communal heavy rainfall prevention concepts, future development planning is also specifically examined for the risk of heavy rainfall and measures are proposed to prevent it from the outset. Nevertheless, these maps are not regulated by law as the pluvial flood hazard maps are less certain then the fluvial flood hazard maps*

and therefore cannot be given a legal basis. Furthermore, we support the municipalities by and advise them to take the maps into account in their development planning".

- MT – "*The updated maps shall be made available to the relevant government entities responsible for land use and spatial planning, for these to be considered into their existing planning processes*".
- PT – "*All maps will be used to support decisions related to land use and spatial planning*".
- SE – "*According to the Planning and Building Act the flood situation should be taken into account and is therefore often planning measures in the FRMPs*".
- SK – "*The proposed measures to eliminate pluvial floods should be incorporated into the spatial plans of municipalities*".

4.2.15 Use of the second cycle pluvial flood maps be used to support decisions related to emergency planning

The Member States were asked if the findings of the pluvial flood modelling and mapping had been used to help to improve emergency management (e.g. awareness, preparedness, response or recovery) for pluvial flood events. There were 16 responses to this question the results of which are shown in Figure 4.11. CY stated that the pluvial flood maps were "*still in progress*" and were not included in the results.

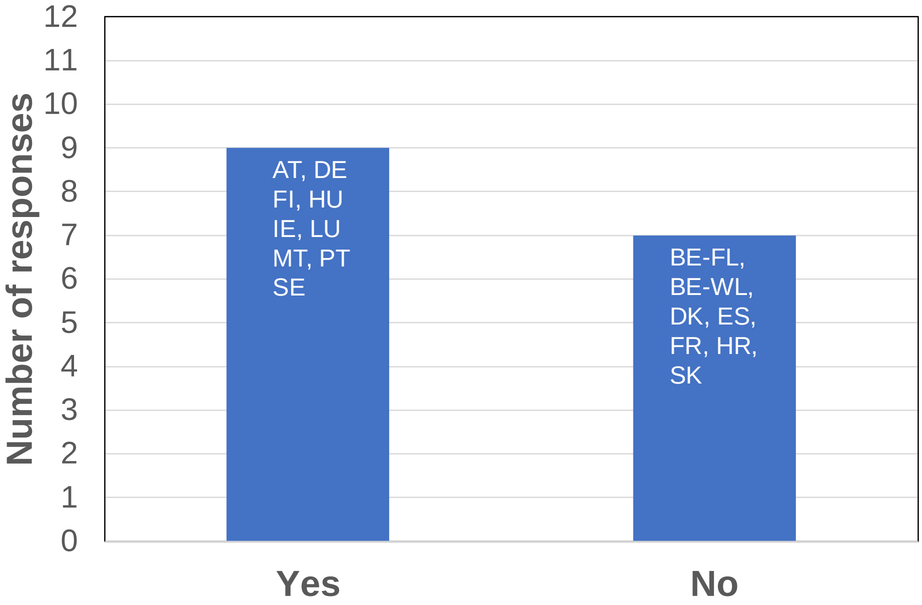


Figure 4.11: Number of respondents who stated the findings of the pluvial flood modelling and mapping had been used to help to improve emergency management (e.g. awareness, preparedness, response or recovery) for pluvial flood events

The respondents who answered yes to this question were asked how the pluvial flood modelling and mapping had been used to help to improve emergency management. The responses to this questions are provided below:

- AT – "*To raise awareness and strengthen individual responsibility a guideline was developed "Precaution for surface flow: A guideline for planning, new construction and adaptation". https://info.bmlrt.gv.at/themen/wasser/schutz-vor-hochwasser/bewusstsein/leitfaden-eigenvorsorge-bei-oberflaechenabfluss.html*"
- DE – "*The municipal heavy rainfall hazard maps are a useful supplement to the FHRM. At the local/regional level, they already provide numerous municipalities with valuable information for citizens, but also for planning offices, administration and disaster control, about the possible risk of flooding from heavy rainfall events for buildings, subways and general as well as critical infrastructure. Furthermore, they provide the basis for the preparation of municipal action concepts to prevent or mitigate damage resulting from heavy rainfall events. Similar to the FRM approach, the measures can be subdivided into different fields such as area and building precautions, natural water retention, technical protection*

facilities, crisis management, disaster control and hazard prevention, self-provision as well as information and risk precautions".

- FI – "*Some rescue services have identified the most critical pluvial flood risk areas, e.g., the roads to be broken, based on the indicative pluvial flood maps. This is useful information in emergency management planning when e.g., planning routes for emergency responders*".
- HU – "*The results of the pluvial floods, and the experience of the past pluvial flood events were used for preparing municipal flood protection plans*".
- LU – "*The maps are available to the public and are discussed as part of local, municipal heavy rainfall prevention concepts and explained at public information events to raise awareness. The population is also directly shown fields of action how to improve their situation. In the context of emergency management, the maps are included in the emergency planning system and in the analysis of the fire brigade's routes*".
- MT – "*EWA is in discussion with the Civil Protection Department (CPD) to develop a collaboration about data sharing between the two entities to further validate the flooding maps that EWA will produce during this cycle and next one which in turn will help CPD in prioritizing intervention at locations posed in danger by an extreme rainfall event within the Maltese River Basin District*".
- PT – "*All maps will be used to support decisions and the models are being included in our awareness system"*.
- SE – "*In general, all lessons learnt form floods and other natural disasters in Sweden are taken into the risk management cycle as knowledge for the fire and rescue services*".

4.2.16 Communication of pluvial flood maps to the public

Member States were asked if pluvial flood maps are communicated to the public. There were 17 responses to this question. The results are shown in Figure 4.12.

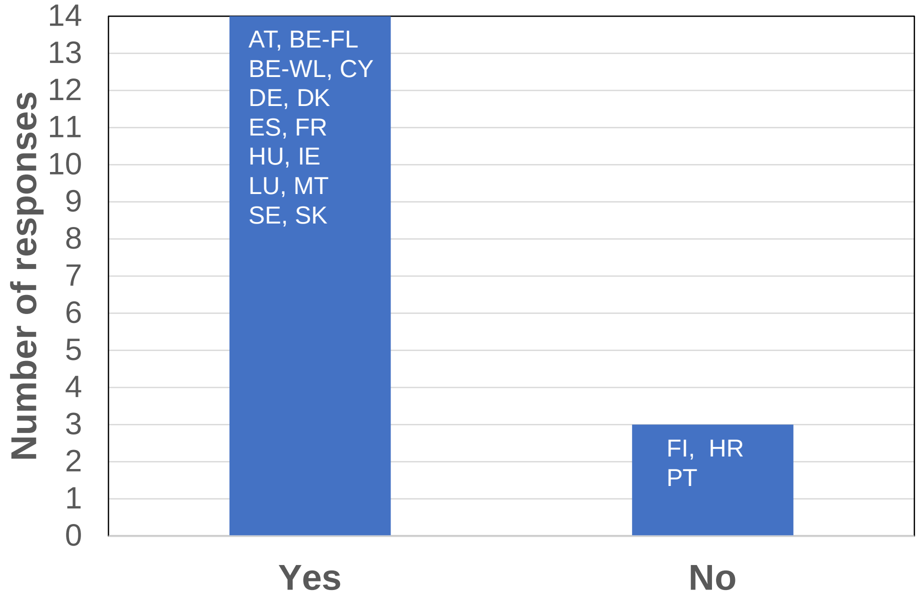


Figure 4.12: Number of respondents who stated second cycle pluvial flood mapping would be communicated to the public

CY stated that although the pluvial flood maps were a work in progress that they would be communicated to the public. The respondents who stated that the pluvial flood maps would be communicated to the public were asked how this would be done. Their responses are provided below.

- AT – "*Via web tools: https://maps.wisa.bmlrt.gv.at/vorlaeufige-risikobewertung-2018; https://hora.gv.at/*".
- BE-FL – "*Together with all the other flood maps they are available on a portal for viewing and via webservices. And as mentioned above they are also communicated as part of the water check and obligation to inform what makes it more widely known*".

- BE-WL – "*Available on a web site : http://geoapps.wallonie.be/Cigale/Public/#CTX=ZI*".
- CY – "*Published on website, WebGIS, Geoportal, disseminated to local authorities, and land use planning agencies, presented in public consultations*.
- DE – "*At the local/regional level, information campaigns on heavy rainfall prevention are carried out from time to time. In addition, the municipal heavy rainfall hazard maps are also published on the websites of the competent municipal authorities so that citizens can inform themselves and, if necessary, take appropriate precautionary measures (here is an example from the city of Bonn: https://www.bonn.de/starkregen). In addition, the German Federal Office for Civil Protection and Disaster Assistance (BBK) has published a handbook on "The underestimated risks of heavy rainfall and flash floods". The handbook is only available in German and can be accessed via the following link: https://www.flussgebiete.nrw.de/system/files/atoms/files/bbk_starkregen.pdf. It is intended to provide an overview of all important issues related to extreme weather events such as heavy rainfall and flash floods. The addressees are the citizens, competent municipalities, authorities and also the disaster relief workers themselves. The aim is to present protection options against such natural hazards for the various addressees in a perspective, citizen-oriented and practical manner. Communication between the experts, the municipalities and the citizens also plays an important role, because due to the need for joint cooperation in the event of a disaster, it makes sense and is also necessary that the different actors not only have knowledge about their own emergency plans, but also know the perspectives of the other side*".
- DK – "*Pluvial flood maps, which are available for the municipalities' preparation of climate adaptation plans, are published on a digital platform (https://kamp.klimatilpasning.dk/). Digital maps and the web-portal are, however, not part of the implementation of the Floods Directive*".
- ES – "*In the same way as the fluvial flood maps, pluvial flood maps are presented by the river basin authorities for public consultation for 3 months, so that people can make contributions and formulate observations and suggestions before their publication. Then, they are published and their information can be consulted in the National Mapping System of Flood Zones in Spain (SNCZI) viewer, and free downloaded in GIS format*".
- FR – "*Data are available on line: https://www.georisques.gouv.fr/donnees/bases-de-donnees/zonages-inondation-rapportage-2020*".
- HU – "*In the second phase, the measures to be taken to manage and reduce the flood risk were consulted by holding online forums together with the Second River Basin Management Plan. The public consultation were held in spring and summer period in 2021. Prior to the forums, we published thematic presentations on this page under the menu item https://vizeink.hu/akk-elso-felulvizsgalata/ to present the results*".
- IE – "*Maps are published via the Office of Public Works flood portal; www.floodinfo.ie. Guidance notes are provided on the preparation and specification of the maps*".
- LU – "*The maps are available to the public (http://g-o.lu/3/8tlp). Within the framework of local, communal flash flood risk prevention concepts, the flooding situation is evaluated locally and measures are identified and prioritized. These are then gradually implemented according to this roadmap. As part of this work, there is also always planned at least one awareness-raising event for the local population. Here, information is provided on the topic, the map, its production, and fields of action are identified for personal precautions*".
- MT – "*The pluvial flood maps have been made publicly available on the website of the Energy and Water Agency and on SIntegram portal, a national spatial data infrastructure to store geo-spatial/GIS technology maps and data for Malta. Furthermore, the results of pluvial flooding modelling have been also presented in inter-ministerial committee meetings on the implementation of the WFD and FD. Moreover, the results have been also communicated to both public and private stakeholders (including environmental NGOs) through the multi-stakeholder Water Table platform which provided an opportunity for these stakeholders to voice their concerns and assist in the future implementation of the following cycles of the Floods Directive*".

- SE – "*Published on the local (municipality) or the regional (county administrative board) websites. Reference: "Extrem nederbörd i Sverige under 1 till 30 dygn, 1900 – 2011, METEOROLOGI Nr 2012-143 SMHI, Lennart Wern*".
- SK – "*The communication of the extent of the pluvial flood hazard and the proposed measures are part of the assessment of the impact of the strategic document on the environment*".

A summary of the results are provided in Table 4.3.

Table 4.3: Summary of the communication of pluvial floods to the public

Member State	Pluvial flood maps communicated to the public	Available on the internet	Web link
AT	Yes	Yes	https://maps.wisa.bmlrt.gv.at/vorlaeufige-risikobewertung-2018 https://hora.gv.at/
BE-FL	Yes	Yes	-
BE-WL	Yes	Yes	
CY	Yes	Yes	http://geoapps.wallonie.be/Cigale/Public/#CTX=ZI
DE	Yes	Yes	Various municipality web sites
DK	Yes	Yes	https://kamp.klimatilpasning.dk/).
ES	Yes	Yes	-
FI	No	-	-
FR	Yes	Yes	https://www.georisques.gouv.fr/donnees/bases-de-donnees/zonages-inondation-rapportage-2020"
HR	No	-	-
HU	Yes	Unclear if the maps are published on the internet	-
IE	Yes	Yes	www.floodinfo.ie
LU	Yes	Yes	http://g-o.lu/3/8tlp
MT	Yes	Yes	-
PT	No	-	-
SE	Yes	Yes	Local and regional municipality web sites
SK	Yes	Unclear if the maps are published on the internet	-

4.3 Summary of the workshop on pluvial flooding

4.3.1 Introduction

On 18 and 19 May 2022 a hybrid workshop on pluvial flooding was held in Brussels which was attended by around 30 participants in person and 30 online. The objective of workshop was to assess where Members States were with regards to assessing pluvial floods at the end of the second cycle of the Floods Directive and also to look to the future with regard to mapping pluvial flood hazard and risk in the third cycle of the Floods Directive.

As part of the workshop a number of breakout groups were held addressing key issues as follows:

- How to define significance for pluvial floods to identify APSFRs.
- How to define scenarios for pluvial flood maps.
- Managing pluvial flooding at national or regional levels and whether this is relevant to a local scale.
- Planning for the third cycle Preliminary Flood Risk Assessment (PFRA) with respect to pluvial flooding.
- Production of separate pluvial flood hazard and risk maps in the third cycle in Member States which have not already produced them.

- Production of separate flood hazard and risk maps in the third cycle in Member States which have already produced them.

The outcome of these discussions is provided below.

4.3.2 How to define significance for pluvial floods to identify APSFRs

In AT for fluvial floods, if 500 people are within an inundated area with a 1 in 300 year return period this was classed as significant. AT said that for pluvial flooding this calculation was challenging because of a lack of information, so AT had relied on historical data. RO said that it had used only historical information with certain thresholds. RO had also used reports of pluvial flood impacts such as media reports. It was suggested that a simplified pluvial model for the whole country like that used in LU could be useful to define significant pluvial floods. This could be a useful first step because although these maps would show indicative areas they may still be of help.

SE said that the challenge with pluvial flooding is that there have been no areas assigned to pluvial flooding in SE as being significant. In a large , sparsely populated like SE it makes it challenging to carry out national pluvial flood modelling. SE raised the question of what is significance? SE said that pluvial floods can happen everywhere. LU modelled the whole country and it helped to raise the awareness of pluvial flooding and also LU did not have to set significance criteria.

In AT a 1 x 1 m DTM was used together with a 2D hydrodynamic model covering 86,000 km^2 (i.e. the whole of AT). AT said that it was convinced that the rainfall is accurate but there should be awareness that there are differences between different areas. AT said that it had developed soil maps and that it will take a pragmatic approach to the soil moisture. AT said that it currently has six pilot areas models developed using the FLO2D software.

It was stated that the sources of information to define significance are important Significant pluvial events can be based on observations but also expert knowledge of the municipalities who have qualitative knowledge of impacts of pluvial floods. In MT a matrix with receptor, exposure and vulnerability was used to define the significance.

4.3.3 How to define scenarios for pluvial flood maps

LU published 1 in 100 year return period (i.e. 1% AEP) pluvial flood maps but also looked at two other scenarios. LU said that only the 1 in 100 year maps had been published because it was similar to a well know historical flash flood. DE said that it did not consider heavy rainfall as a significant risk, but as a general risk because heavy rainfall can occur anywhere. DE said that local authorities can produce pluvial flood maps if they want. DE said that national standard for these is being developed. HU said that it uses historical data. NL said that it had far less information for pluvial floods than fluvial or coastal ones. NL said that all local authorities are now responsible for analysing the effects of pluvial floods.

CZ said that the significance of pluvial flooding was considered to be low based on historical data. CZ had identified critical points based on a simple GIS analysis i.e. by defining potential pluvial flow paths and where they intersected critical points such as settlements. CZ said that pluvial flood maps were an obligatory input for urban planning.

ES said that it was not clear who has to produce pluvial flood maps. In ES there are five pilots being undertaken in five cities. ES said that fluvial floods are worse in terms of risk, than pluvial floods in ES. LV said that they had not carried out pluvial flood mapping, but there is an indication that pluvial floods are of national significance in urban areas.

It was stated that scenarios based on the probabilities of rainfall could be used. In urban areas the link between the probability of the flood and rainfall is closer than in rural areas because the antecedent moisture conditions do not play such a big part.

4.3.4 Managing pluvial flooding at national or regional levels and whether this is relevant to a local scale

Pluvial flood processes are affected by local phenomena. There was a discussion related to modelling pluvial flood at a national and/or regional level and whether this was useful for the local scale.

LU said that it carried out as a first step pluvial flood modelling at the national level to get feedback from the local stakeholders so that they could come up with local solutions. In LU national pluvial flood maps are used as a screening tool or a guide. RO said that if a national DTM with a 5 x 5 m resolution grid were available, a national indicative pluvial flood map could be produced for the whole country. RO produced a climate change scenario for the 1 in 100 year return period (1% AEP) based on adjusting the rainfall intensity based on study carried out by the meteorological institute. Municipalities in SE counties have produced pluvial flood maps using different methods. SE said that there is national guidance for pluvial mapping.

It was stated that communication is key to get information from the local to the national level. It was also noted that significant pluvial events which have result in significant damage can act as a catalysts to help Member States.

4.3.5 Planning for the third cycle Preliminary Flood Risk Assessment (PFRA) with respect to pluvial flooding

There was a discussion relating to what Member States are planning for the third cycle of the Floods Directive Preliminary Flood Risk Assessment (PFRA) with respect to pluvial flooding, e.g. with regards to defining pluvial APSFRs. LU has pluvial flood risk maps for the whole country but it will not be reported as a map it will be reported as a measure. There is an indicative map showing where the pluvial hazard is high in LU. In the next cycle LU will consider how to define significance with respect to pluvial flooding.

RO has preselected areas that have been affected in the past by pluvial floods. These are primarily urban areas with more than 3,000 inhabitants. RO accepts the idea that the pluvial flood mapping will be part of third cycle. Stakeholder participation is a challenge because municipalities need to put measures in their plans. RO intends to extend the pluvial analysis. RO needs to extend its DTM and have more information on the stormwater drainage system. AT said that in the first cycle pluvial flooding was based on historical events, in the second cycle AT used "*a rolling ball method*" (see Section 2.3), in the third cycle AT will use a rapid flood mapping model.

NL said that for the past 10 centuries it has concentrated on fluvial and coastal sources of flooding. In the second cycle of the Floods Directive simple modelling was carried out for pluvial floods. In the past few years local authorities have had to carry out "stress tests" for intense rainfall, because pluvial flooding is happening more frequently. In NL all local authorities are doing stress tests for pluvial flooding independently (i.e. this means the results will not necessarily be consistent). Pluvial measures will be related to spatial planning adaptation. In the third cycle, of the Floods Directive NL will look at pluvial flooding as a result of the July 2021 floods. The stress test is mentioned in the PFRA and will be developed in the third cycle.

IE said that it had assessed pluvial risk in the first cycle of the Floods Directive. IE said that their PFRA was based on flood maps and historical data. Pluvial floods are not a significant risk apart from in Dublin City. In Dublin more detailed pluvial flood mapping has been done. There is a second location in IE, a small town in Donegal called Raphoe, where pluvial flooding is an issue and detailed studies have been taken, and measures are underway. In the third cycle of the Floods Directive IE does not anticipate more local pluvial mapping. IE said that one thing that is being looked at is the impact of climate change. IE said that the conclusion is that downscaling Global Climate Models (GCMs) to daily or sub-daily rainfall is "*stretching the results too far*" and not appropriate. IE said that it had decided to look from the bottom up with respect to climate change. IE said the reason that for most places in IE pluvial flooding is not considered significant. This is based on the amount of damage and the number of people at risk. IE said that pluvial flooding is not a significant risk and that their Office of Public Works works closely with local authorities to produce surface water management plans and the implementation of nature based solutions.

EL said that pluvial flooding is mostly a secondary problem and it is hard to distinguish it from fluvial floods. EL said that rainfall is considered to be a secondary source of flooding. RO said that in some some mountain areas it is hard to separate flash and pluvial floods.

LV said that it had not carried out pluvial flood modelling. LV said that first it would carry out a risk assessment to see what data there are and they will try to incorporate information on climate change because all climate change scenarios for LV show an increase in intense rainfall.

SE has not decided that pluvial is significant yet and is investigating this. SE is awaiting a report relating to a city that was flooded which will be available June 2022. Guidance on investigating pluvial floods in terms of the economic damage caused by pluvial floods have been produced. Pluvial maps which have been produced by local authorities will be looked at to see if these can inform the third cycle PFRA.

4.3.6 Production of separate pluvial flood hazard and risk maps in the third cycle in Member States which have not already produced them

There was a discussion about whether separate pluvial flood Flood Hazard and Risk Maps (FHRMs) will be produced in the third cycle for members states who have not done this already and how will this would be done. The World Bank said that for planning the Programme of Measures ideally a coupled 2D-1D hydraulic model (i.e. with the piped drainage system modelled in 1D and the surface water flow in 2D) is needed to define the measures accurately. LU agreed that at this is the case at a local level necessary, but not at a national level.

ES said that the return period rainfall storm that of drainage system in ES can carry is between 1 in 10 years (10% AEP) to 1 in 25 years (4% AEP). ES said that many regions in southern Europe have torrential rainfall events and have ephemeral watercourse systems. ES said that it is important to include the drainage capacity of surface water systems in models. In ES more than 50% of the towns and 70% big towns and cities have developed drainage master plans in the past few years and it is important to take these into account. ES said that stormwater is the responsibility of the municipality but sometimes it is not easy to distinguish between flash and pluvial floods.

The European Investment Bank (EIB) said that utilities and/or municipalities are responsible for stormwater systems and that there is an institutional challenge because fluvial flood protection is the responsibility of river basin authorities, and stormwater and pluvial floods are generally the responsibility of municipalities. The EIB stated that the costs of improving drainage systems are high. In LU it was stated that there is a water fund which can be used by municipality.

CZ said that they do not consider pluvial flooding to be significant but at a central level they support pluvial modelling and include sewer models in their studies. MT said that it was trying to think “out of the box” and instead of upgrading infrastructure trying to implement natural flood management solutions e.g. if the sewer system takes the 1 in 10 year return period (10% AEP) rainfall then other other measures could be taken to reduce flows into the sewers.

DK does have national pluvial maps and there are tools that can be used to look at the measures and the municipalities can look at this. High groundwater levels affect the rivers. DK said that in the winter there are storm surges and if this happens at the same time as pluvial flooding this can increase flooding.

4.3.7 Production of separate flood hazard and risk maps in the third cycle in Member States which have already produced them

AT had produced a pluvial flood map based on the “*rolling ball method*” showing what flow is likely to come into the urban area and the steepness and what is likely to happen. For the third cycle of the Floods Directive AT is in the process of producing maps based on 2D hydraulic models. ES said that it was not simple to put together combined pluvial and fluvial maps. ES is trying to simplify the online maps.

The EIB said that there are two types of investment projects:

1. Increase stormwater capacity which is engineering driven.
2. The more holistic approach which focuses on more nature based solutions.

In FI there are indicative flood maps for the PFRA but currently the methodology is being updated because not all the information is available from the municipalities. In FI the municipalities are responsible for flood risk. It does not seem to be an efficient approach to be take. FI is still deciding what needs to be done. LU said that it thought pluvial flooding was just a local issue before July 2021, when there was a heavy rainfall events.

SE said that it is important for the public to distinguish between different sources of flooding because they have different times to prepare. In AT the government is funding schemes to reduce runoff.

For the next cycle FI is planning to improve guidance and report templates for municipalities to assess pluvial flood risk and possibly start implementing the Floods Directive process of Flood Hazard and Risk Maps and FRMPs, improve the national indicative pluvial flood hazard map, (used in the second cycle) and investigate the possibility of adding information on pluvial floods to the national flood information system. In FI the indicative pluvial flood maps are not available as open data, owing to the high degree of uncertainty in the modelling. There is a free licence that the users of the data must agree to, which describe the limitations and uncertainties of the pluvial flood modelling and mapping results. This ensures that municipalities can get information of potential pluvial flood risk areas, but if development is considered there, they would initiate further and more accurate studies of pluvial flood risk.

5. Challenges of pluvial flood modelling

5.1 Introduction

This chapter outlines some of the challenges that Member States face in relation to pluvial flood hazard and risk mapping, as well as the development of measures. Pluvial floods can happen anywhere and hence areas at risk from pluvial floods are not as easy to identify as fluvial flooding. Pluvial flooding is a local phenomenon and there is a need for different approaches at different scales. For example at the PFRA stage it may be appropriate to use a rapid flood spreading model with a relatively coarse grid (e.g. 20 x 20 m) over large areas to ascertain which APSFRs are affected by pluvial floods.

The Annual Exceedance Probabilities (AEPs) of urban pluvial flood events are not necessarily equivalent to the AEPs of the rainfall events that cause them. For example, the hydraulic infrastructure found in urban drainage systems can increase the system heterogeneity and affect its response to extreme rainfall events (Tuyls, et al., 2018).

The availability of data for mapping is still an issue for some Member States. For example, high resolution DTMs and the locations and areas occupied building may not be available for urban areas. In addition, there is often a paucity of historical information on pluvial floods, especially in urban areas, with which to calibrate and verify models. For example, for urban pluvial floods there is often no accurately documented evidence of the flood extents for historical events. In addition, the flows generated by pluvial floods in urban areas, unlike fluvial floods, are generally not gauged. Flash floods often occur on small ungauged catchments for which measured flood flow data are also often unavailable.

To accurately model pluvial floods in urban areas, and to a lesser degree rural areas, a 2D hydraulic model which solves the full shallow wave equations should be employed. However, this can be time consuming to set up and computationally costly.

The responsibilities for pluvial flood risk are often split between local and municipality levels. This means that the budgets and capacity for assessing pluvial floods often vary across Member States. There is also an issue as to how to communicate pluvial flood risk. Some Member States have developed separate pluvial flood maps and some have integrated the pluvial flood maps with fluvial ones.

The key challenges related to pluvial flood modelling are briefly detailed below together with potential solutions.

5.2 Determining the annual exceedance probability of pluvial flood maps

The Annual Exceedance Probabilities (AEPs) of pluvial flood events are not necessarily equivalent to the AEPs of the rainfall events that cause them. For example, the hydraulic infrastructure found in urban drainage systems can increase the system heterogeneity and affect its response to extreme rainfall events (Tuyls, et al., 2018). It is thus challenging to ascribe an AEP to an urban pluvial map based on the AEP of the rainfall. In urban areas, because there is a higher percentage of impermeable area, and the antecedent moisture conditions are less in important than in rural areas, there is a higher chance that AEP of the rainfall will be similar to the AEP of the mapped pluvial flooding.

For pluvial flooding, each part of the catchment will have a different “critical storm duration”. The critical storm duration is the duration of a specific design rainfall event (e.g. 5%, 1%, 0.1% AEP) which creates the largest flood extent. One reason that the AEP of the flood maps is not necessarily the same as the rainfall AEP is choosing a single representative critical storm duration is challenging because any pluvial APSFR will include a number of sub-catchments of different sizes, shapes and steepness.

Short duration storms (e.g. ~1 hour) generally better represent the type of event that leads to surface water flooding; however, there is evidence that in flatter areas longer duration storms may be critical.

The critical storm duration is also strongly linked to the topography. In low-lying areas, near to rivers, the critical duration can be long because surface runoff drains into these areas from larger catchments. On hill slopes the critical duration is generally short because the greatest flood depth arises from high intensity rainfall.

One potential solution to this is model a range of storm durations (e.g. 1, 3 and 6 hours) for each rainfall AEP. These can then be merged into a “worst case” maximum pluvial flood extent and depth for each AEP, to ensure that a realistic critical storm duration is represented in all locations. This is also more likely to produce urban pluvial flood extent and depth maps where the AEP of the maps equates to the rainfall AEP.

5.3 Identifying APSFRs where pluvial flooding is significant

One key challenge identified by Members States was defining significance for pluvial floods so that APSFRs affected by pluvial floods can be identified. One potential solution to this is to carry out a high level screening exercise of the potential for pluvial flooding. This can be used to provide sufficient information to enable a preliminary assessment of the level of pluvial flood hazard to be made over a wide area (e.g. at a national or regional scale). This can then be used to inform the Preliminary Flood Risk Assessment (PFRA), identification of pluvial APSFRs and the development of a resource efficient strategy for subsequent modelling and mapping of pluvial floods using more detailed techniques.

A preliminary assessment of pluvial flooding could be carried out a national pluvial or regional scale using a rapid flood spreading model, which would be used to map and identify pluvial flood hazard “hotspots”. This could be used with information on receptors (e.g. people, buildings, businesses) to provide a preliminary estimate of where the pluvial flood risk is highest. This method requires a national or regional scale DTM to be available, although for this type of exercise a DTM with a 10 x 10 m resolution (or even coarser) could suffice. A level of significance could then be adopted, for example, in terms of the number of people at risk from or the economic damage caused by pluvial floods. The spatial extents above these thresholds could then be used to identify pluvial APSFRs where more detailed and accurate pluvial modelling and mapping would be carried out as part of the Flood Hazard and Risk Mapping and FRMP.

5.4 Addressing climate change

The latest Intergovernmental Panel on Climate Change (IPCC)[4] reports have stated that in the future rainfall intensity is expected to increase. The impact of climate change on design rainfall intensities needs to be taken into account to assess the effects on future pluvial flood hazard and risk. To incorporate climate change in pluvial flood hazard and risk maps information on how sub-daily extreme rainfall will change under different emissions scenarios are required. One solution is to use the IPCC's Representative Concentration Pathways for different emissions scenarios and uplift each rainfall intensity for each AEP by an appropriate amount to provide a representation of future rainfall intensities under different greenhouse gas emissions scenarios.

5.5 Accurate estimates of design rainfalls for high, medium and low Annual Exceedance Probabilities (AEPs)

Having accurate estimates of high intensity, short duration rainfall for high, medium and low AEPs with high spatial and temporal resolution is often challenging. Pluvial flooding is often caused by small-scale thunderstorm (~10 km), whose magnitude and distribution are difficult to monitor. One potential solution to improve the accuracy of short duration, high intensity rainfall is to use radar network rainfall data, where available, for urban areas. This radar-based rainfall can be merged with data from rainfall gauges to improve its accuracy and the extrapolated using statistically techniques to produce design rainfalls for a range of AEPs.

5.6 Verification of pluvial flood models and maps

Records of urban pluvial and flash flood in rural areas can enable better calibration and verification of pluvial flood models and the resulting maps. Complete records of historical urban pluvial and rural flash floods are seldom available, in particular surface water flow data. One solution is to set up a systematic and standardised documentation for pluvial and flash flood events. This can be used to document the lo cation of pluvial flood events, flood depths and the damage that has been caused. These data can then be used to help validate pluvial flood hazard and risk mapping. It some cases it may be possible to use satellite based information of recorded historical pluvial flood extents in urban areas to assist with the verification of pluvial modelling.

5.7 Accurate Digital Terrain Model (DTM)

DTMs with a suitable level of accuracy and spatial resolution to carry out urban pluvial flood modelling and mapping are often not available for urban areas. One solution is to invest in high resolution and accurate LIDAR topographic survey which can be used not just for flood risk management but other purposes (e.g. urban planning).

5.8 Database of building footprints

The way in which buildings are represented in pluvial urban hydraulic models can significantly affect flood flow paths and the resulting urban pluvial flood depths and extents. It is thus important that buildings are accurately represented within any urban pluvial hydraulic modelling. To represent buildings requires a georeferenced database of buildings' footprints. The solution is to develop a georeferenced database of buildings together with their floor area. There are machine learning techniques which can be used to automatically produce building footprints from remote sensing data and aerial orthophotos.

[4] https://www.ipcc.ch/reports/

5.9 Accurate, yet computationally efficient hydraulic models for pluvial floods

The flow paths of flood water in urban areas are highly complex, small features such as road kerb heights can affect flooding. In addition there are often complex interactions between the surface and sewerage systems. 1D sewer and/or stormwater drainage models coupled to 2D hydraulic models are time consuming to set up and require accurate information on the sewerage system which is often not available. The use of purely 1D hydraulic models is not accurate enough to define flood alleviation measures. The use of 2D hydraulic models can provide an estimate of the urban flood extents and depths taking into account the amount of rainfall "absorbed" by the urban drainage system.

There are numerous modelling methods that can be used to map and assess pluvial flood risk. To model urban pluvial flooding in the most accurate manner a coupled 1D model of the piped drainage network coupled to a 2D which solves the full shallow water equations should be used, or a full 2D full shallow water equation. In some Member States there are challenges related to the availability of DTMs which have a suitable level of accuracy and resolution, sub-daily rainfall and geo-referenced building data sets. Table 5.1 provides an overview of the relative accuracy, run-time requirements and suitable spatial extents for different pluvial flood modelling approaches which can be used to meet the requirements of the Floods Directive.

Table 5.1: Relative accuracy, run-time requirements and suitable spatial extents for different pluvial flood modelling approaches

Model type	Accuracy for assessing flood hazard and risk	Run time	Suitable spatial extents
Rapid flood spreading model	Low	A few minutes	Macro (e.g. national scale)
1D piped drainage model			
Simplified 2D full shallow water equation models			
Full 2D full shallow water equation models			
Coupled 1D piped drainage and 2D full shallow water equation models	High	Many hours dependent on the size of the model	Micro (e.g. city or town scale)

(Source: Adapted from Bulti and Abeba, 2020)

5.10 Assessment of the joint probability for pluvial flooding occurring at the same time as other sources of flooding

Many urban areas experience both fluvial and pluvial floods, as well as in some cases coastal floods. In the first and second cycle of the Flood Directive fluvial or pluvial flood hazard were generally analysed separately. Where there is a surface water drainage system discharging to the coast and there is the potential for tide locking caused by high tidal water or where fluvial water levels are high and surface water sewers cannot discharge into rivers there may be a need to take into account joint probability. One way that this could be undertaken is by assuming independence of the two flood types (e.g. pluvial and fluvial floods) and taking the seasonality and probability of coincidence into account. All the combinations of pluvial and fluvial hazards would be modelled and probabilistic flood hazard maps showing the maximum inundation depths for a selected set of probabilities of occurrence could be produced.

5.11 Uncertainty analysis for pluvial flooding

Pluvial flooding in urban areas is particularly uncertain compared to other sources of flooding (Takara, 2014). Urban pluvial floods often occur rapidly as the result of rare, highly localised, intense rainfall events. Assessing the annual exceedance probability of pluvial urban flood events is challenging because:

- Pluvial urban flood events are often rare and few have been experienced at one location in the past (Fontanazza et al, 2011). Rainfall events which produce urban pluvial floods are often highly localised in both space and time (Houston et al., 2011).
- The performance of urban drainage systems is unpredictable because they are often old and subject to blockages which has an impact on their performance (Djordjević et al., 2014).
- Relatively small features in the urban landscape such as the height of road kerbs, can affect flow paths in urban areas.

Ideally an uncertainty analysis should be carried out for pluvial floods taking into account: changes in the rainfall intensity; hydraulic roughness coefficients; building threshold levels; and the assumptions regarding net rainfall.

5.12 Increasing the awareness of the risks of pluvial flooding

Some stakeholders have a low awareness of the risks posed by pluvial floods. This can be a result of a lack of coordination between flood authorities (e.g. local municipalities often deal with urban pluvial floods and river basin authorities with flash floods in rural areas). This can lead to apathy and a low awareness of urban pluvial and flash floods by stakeholders. One solution is to have clear definitions of the roles of flood authorities and to raise awareness of the issues related to urban pluvial and flash floods.

6. Areas of future work for pluvial flood modelling and mapping

Areas which potentially require future work to improve pluvial flood hazard and risk maps produced in the third cycle of the Floods Directive include:

- Development of national and regional scale pluvial flood models to identify APSFRs where pluvial floods are significant.
- Refining estimates of sub-daily duration rainfall at a suitable spatial resolution for use in pluvial flood models.
- Developing climate change scenarios for sub-daily rainfall so that climate change can be taken into account in pluvial FHRMs.
- Improving understanding of spatial and temporal variation in rainfall within extreme events.
- Producing geo-referenced databases of building footprints together with their finished floor level.
- Improving the resolution of DTMs for urban areas to allow accurate 2D hydraulic models to be used.
- Using satellite based information on historical pluvial flood extents in urban areas to assist with the verification of pluvial modelling in urban areas.
- Taking into account joint probability, for example, where there is a surface water drainage system discharging to the coast and there is the potential for tide locking caused by high tidal water or where fluvial water levels are high and surface water sewers cannot discharge into rivers.
- Producing geo-referenced databases of building footprints together with their finished floor level.
- Improving the resolution of DTMs for urban areas to allow accurate 2D hydraulic models to be used.
- Using satellite based information on historical pluvial flood extents in urban areas to assist with the calibration and verification of pluvial modelling in urban areas.

- Increasing the awareness of the risks of pluvial flooding of key stakeholders.

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Appendix A – Pluvial flooding questionnaire

Survey to support the CIS WGF workshop "Pluvial Flooding"

Dear WGF member, this is an initiative in line with the WGF's work programme for the period 2022-24[5]. By replying to this survey you will support the discussions during the "Pluvial flooding" workshop (to be held 18-19 May in Brussels) and more generally the coordination and information exchange between Member States, the Commission and other stakeholders (including other CIS Working Groups) on themes relevant to the implementation of the Floods Directive. The ultimate objective is to enhance flood risk management in the EU.

The deadline for completing the survey is **3 May 2022**. By completing and returning the survey within the deadline you will help us processing the results in a timely manner so as to present them during the workshop.

Please send your reply to the contact indicated at the end of the survey.

Survey questions

0. I belong to the following organization

1. How is pluvial flooding defined in your country?

2. Were pluvial floods modelled and mapped as part of the first cycle of the Floods Directive?

☐ YES

☐ NO

2.1. If YES,

Has the way in which pluvial floods are modelled and mapped changed since the first cycle of the Floods Directive?

☐ YES

☐ NO

2.1.1 If YES,

☐ Hazard indication maps are provided based on simplified models on national level

☐ Detailed hazard maps, based on hydrodynamic models, are provided for the local level (pilot sites, areas of special interest, etc.)

☐ Both

2.1.1.1 If YES,

Please briefly elaborate what revisions and improvements were made in the modelling and mapping of pluvial floods compared to the first cycle of the Floods Directive (e.g. in terms of data availability, type of model used, model resolution, scenarios, uncertainty, rural/urban distinction)

2.1.1.2 If NO,

Did you model and map pluvial floods in the second cycle?

☐ YES

☐ NO

2.1.1.3 If NO,

[5] https://circabc.europa.eu/ui/group/9ab5926d-bed4-4322-9aa7-9964bbe8312d/library/36bd43c0-07dc-4e74-803c-57a3f306cb4a/details

How is pluvial flooding dealt with in the context of the Floods Directive? More generally, are other tools, regulations or processes applied? Or, are perhaps pluvial floods not a significant issue in your country?

3. What data do you have readily available for historical pluvial flood events?

☐ Daily rainfall data

☐ Sub-daily rainfall data

☐ Pluvial flood extents

☐ Other information

4. How were Areas of Potential Significant Flood Risk for pluvial floods identified? What thresholds did you define for significance?

5. Were Areas of Potential Significant flood Risk (APSFR) for pluvial floods defined in a different way to other sources of flooding?

☐ YES

☐ NO

5.1. If YES,

Please state what the difference was in how pluvial flood APSFRs were defined compared to other sources of floods

6. If pluvial floods were modelled what high, medium and low probability scenarios were considered? (Please state these as a percentage (%) Annual Exceedance Probability or a return period in years. Please indicate if these scenarios are in line with the scenarios for e.g. fluvial or coastal flooding.)

7. Were pluvial floods mapped separately to other sources of flooding?

☐ YES

☐ NO

8. What were the biggest challenges that were faced in terms of data for the modelling and mapping of pluvial floods? (Please rank the answers below from 1 to 6 with 1 = the biggest challenge and 6 = the smallest challenge)

Ranking	**Replies**
	Availability of a digital terrain model (DTM) with a suitable spatial resolution and accuracy
	Rainfall intensity data to define scenarios
	Data on land use, soil properties
	Details of urban drainage systems
	Details of previous significant pluvial flood events
	Other (please state)

9. Were different approaches used for the modelling and mapping of surface runoff in rural areas (i.e. pluvial rural floods) and urban pluvial floods?

☐ YES

☐ NO

9.1 If YES,

Please briefly elaborate on the approaches and considerations

10. Have you addressed uncertainty in the modelling of pluvial floods? (For example, by estimating a confidence interval for the modelled results)

☐ YES

☐ NO

10.1 If YES,

How has the uncertainty in the modelling process been taken account of?

11. Have you addressed uncertainty in the mapping of pluvial floods? (For example, by adding a line on a pluvial flood map to show a limit of uncertainty)

☐ YES

☐ NO

11.1 If YES,

How has uncertainty taken into account in the pluvial flood maps:

12. Was climate change taken into account in the modelling and mapping of pluvial floods?

☐ YES

☐ NO

12.1 If YES,

Please briefly describe how climate change was taken into account in pluvial flood modelling and mapping and what climate change scenarios were used:

13. Will the second cycle pluvial flood maps (if available) be used to support decisions related to land use and spatial planning?

☐ YES

☐ NO

13.1 If YES,

Please provide brief details of how this is done:

14. Have the findings of pluvial flood modelling and mapping been used to help to improve emergency management (e.g. awareness, preparedness, response or recovery) for pluvial flood events?

☐ YES

☐ NO

14.1 If YES,

Please provide details:

15. Are pluvial flood maps (if available) communicated to the public?

☐ YES

☐ NO

15.1 If YES

Please provide brief details of how pluvial flood maps are communicated to the public:

THANK YOU FOR RELYING TO THIS SURVEY!

Please send your reply to Eliska.NOHYNKOVA@ec.europa.eu
(cc Ioannis.KAVVADAS@ec.europa.eu)
by **3 May 2022**