

DELIVERABLE 4.5 – URBAN RUNOFF WATER QUALITY MANAGEMENT PLANS (URUQ-MAP) FOR EACH CASE STUDY

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I. FOREWORD AND OVERVIEW OF THE URBAN RUNOFF WATER QUALITY MANAGEMENT PLAN

I.1 FOREWORD

The current deliverable is associated with the tasks 4.4.1 – Development of the **Urban RU**noff water **Quality MA**nagement **Plan (URUQ-MAP)** - and 4.4.2 - Planning /implementation of the stakeholder panel in case studies. As described in Annex I, Part A of the Grant Agreement of StopUP, one of the objectives of work package 4 is that the URUQ-MAP serves as a proof of concept that may be - based on StopUP results - applicable at city scale. The expected medium to long-term impact is to assist municipalities in their road toward clean environment and zero pollution. Such a plan is especially relevant in the context of the proposal for the revision of the European Wastewater Treatment Directive (Proposal for a Revised Urban Wastewater Treatment Directive - European Commission, 2022). The revised directives have been adopted in 2024 with last modification in the end of 2024 (Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 Concerning Urban Wastewater Treatment (Recast) (Text with EEA Relevance), 2024). They acknowledge that the quality of urban runoff is a concern and as specified in Annex V, integrated urban wastewater management plans, explicitly mentioning runoff are to be established, and that measures have to be taken to reduce pollution from urban runoff. It should be further acknowledged that the new directives aim for an alignment of strategies with respect to the Green Deal (reaching climate neutrality) and the Zero pollution ambition. This alignment further pushed the municipalities and utilities to work in an interdisciplinary context.

The goal of the deliverable is to present the URUQ-MAP as a framework and provide knowledge based on the experience from each of the StopUP case studies to help cities applying it. Therefore, it aims at revising the framework presented in the interim deliverable 4.2, it provides knowledge in the shape of a FAQ (Frequently Asked Questions), based on experience, workshops and interview with the StopUP partners. The structure of the deliverable is as follows; Section 2 – “Steps and structure of the Urban Runoff Water Quality Management Plan” presents the URUQ-MAP itself, updated from the version described in deliverable 4.2. After that, Section 3 – “FAQ – Frequently Asked Questions, How to apply the URUQ-MAP” presents frequently asked questions and their answers. The goal of that section is to, based on the experience of the StopUP partners, as well as other stakeholder involved, provide experience of how to apply the URUQ-MAP in practice. Experience from the case studies applying the URUQ-MAP is directly integrated to the FAQ, further information can be found in the respective deliverable related to each case study. Moreover, the experience from StopUP’s partner also concern the design of monitoring campaigns, the decision support system (DSS) as well as the interception tool (for modelling Green Infrastructure) from the portfolio of tools in WP4 which also contributed to shipping the current deliverable. In appendices, each case study teams are presenting their application of the URUQ-MAP, stepwise and adapted to the context of their case study. It demonstrates how the framework can be implemented. Since the framework is supposed to fit on city scale, not all steps are relevant to each case study.

Since the goal of the current deliverable is to provide an applicable framework, the assumptions, and methods as well as the thinking process are described as well. This way, it is ensured that the document is complete for practical application. Several figures and boxes summarize the key aspects to ensure readability.

The current deliverable is a final deliverable, based on the work realized in StopUP. It is meant to be insightful and helpful for municipalities to apply the revised European Wastewater Treatment

directives. We acknowledge that more investigation will be needed to help utilities as the situation evolves. In particular, we recommend the reader to refer to other case of risk management framework for a more complete overview.

I.2 MAIN HYPOTHESES AND CONTEXT

The URUQ-MAP is a risk management framework for diffuse pollution in urban runoff which can be applied to any urban area. The main hypotheses used for the development of the URUQ-MAP are based on the approaches for risk management laid out in *ISO 31000:2018, Risk Management – Guidelines* (2018) adapting them for the specificity of pollution in runoff and in an urban context (see also Appendix A). The main arguments are that the risk of pollution is dynamic, hard to quantify and uncertain. Both viewpoints are explained in the following.

I.2.1 RISK OF POLLUTION IS DYNAMIC

In an urban environment, land use can be considered as changing rather quickly compared to the inertia of institutions or the time needed to collect extensive datasets. As highlighted by Müller et al. (2020), water quality datasets are prone to obsolescence. For instance, data collected from an industrial area, which was later reconverted to housing, may no longer be relevant. Internal and external changes to the system affect pollutant risks in terms of event likelihood and consequence. Factors related to change, non-exhaustively (see Bunke & Moritz, 2018), are: i) change in infrastructure, ii) pollutant of emerging concern, iii) change in anthropogenic activities, iv) climate change.

The system of infrastructure used to manage stormwater is changing to adapt to changes in land use, deterioration of the system itself, climate change, and to change of stormwater management paradigm (e.g., from combined sewers to separate ones and decentralized solutions). As a result, the pollution pathways from source to outlet are dynamic.

Additionally, new pollutants are emerging as a result of human activity, and maybe more importantly pollutants become classified as pollutants of emerging concern. This means that there may be pollutants that are very much a source of pollution in the urban environment and simply not monitored (Dulio et al., 2018). The result is that some pollutants might need to be managed with only very limited information about their sources and pathways.

One of the main characteristics of the urban environment is the human activity. Those activities and habits change with the emergence of new behaviour, which can affect pollution. For instance, during the lockdown due to COVID-19, some of the pollutant concentrations have been affected in wastewater (M.-N. Pons et al., 2020). Another example of concern could be linked to the use of shared electric scooters that end up thrown in rivers. Trapp et al. (2022) found however that most of the heavy metal contained in the batteries did not leak in the water. This shows the importance of being vigilant and monitoring the effect of change in human behaviour.

Finally, climate change may affect the pollution level in case of change in weather patterns, by increasing bacterial proliferation with temperature increase or by affecting the maintenance of risk reduction measures such as bioretention cells.

The result of all these factors is that both the pathways and the sources of pollutants may change. This can lead to changes in the level of pollution or the frequency of pollutant release, which is a change in pollution risk. The term risk event is used in this document as the combination of the

likelihood (or probability or frequency) of occurrence and the consequence of that adverse event. A risk event is also characterized by its source. The concept of failure is also important, as a risk event is a negative event that can be understood as a failure of the system of interest. In the context of the URUQ-MAP, a risk event may be a CSO triggered by a day-to-day rainfall event, in which case the likelihood or frequency is high, and the consequences of that single event might be low. However, it should be recognized that the repeated occurrence of a probable and minor risk event may have major consequences. It is therefore important to consider these aspects when defining risk events.

I.2.2 RISK OF POLLUTION IS HARD TO QUANTIFY AND UNCERTAIN

Pollution datasets are prone to obsolescence due to changes (Müller et al., 2020), and are difficult to collect in comparison with, for instance, precipitation or discharge time-series since most of the pollutants cannot be measured continuously, as discussed more in detail in D4.1.

Another challenge for risk quantification is the difficulties inherent to modelling activities. Indeed, diffuse pollution is influenced by several, in themselves uncertain, input variables or information. For instance, precipitation measurements or models have their own levels of uncertainty and are then inputs to the hydrological models. The hydrologic and hydraulic systems also propagate some uncertainty in the flows due for instance to parameters estimation, subcatchment representation, or errors in pipe network documentation. It directly affects the quantification of pollutants. The result of those causal relationships is that large sources of uncertainty are cascading to diffuse pollution processes, which make pollution levels challenging to quantify. Challenges in quantification as well as a high level of uncertainty may make the use of qualitative risk analysis necessary.

I.2.3 TREATING RISK OF POLLUTION REQUIRE COORDINATION AND COOPERATION

Managing the quality of urban runoff, and consequently possible overflow in a receiving water body, requires coordination and cooperation. Indeed, the pollution entering the combined sewers can have various sources, it can come from the materials we use to design our cities, from car traffic, from pharmaceuticals we consume, and more generally from anthropogenic activities and atmospheric deposition. The consequence is that pollution sources may originate under several services in the municipalities before being conveyed in the water. Managing the quality of urban runoff requires the cooperation from stakeholders from those different services. Similarly, treating pollution risk must be done in alignment with the strategies of the municipality, which means in concert with other departments of the municipality. It should also be noted that the impact in the receiving water body may cross the boundaries of the municipality and inherit both from past water conditions and from upstream contributions. For managing urban runoff quality, several governance level and administrative division may be involved, such as the municipality, the region, the utility natural catchment attached to a river system, etc.

I.3 FUNDAMENTAL PROPERTIES OF THE URUQ-MAP

The consequence of those main aspects linked to both diffuse pollution in urban runoff and risk management is that the URUQ-MAP should emphasize, perhaps more than other frameworks, of four principles of the *ISO 31000:2018, Risk Management – Guidelines – Section 4: Principles* (2018), namely i) **Dynamic** (risks can emerge and context change), ii) **Best available information** (information may be qualitative with high uncertainty), iii) **Continual improvement** (the framework should be improved through testing and iterations), and iv)

perhaps the most important **integrated** (the framework should be coordinated and integrated across all involved institutions).

It means that new knowledge, changes in the system, or emerging concern about a pollutant should be accounted for. The consequence for the management plan is the need for an adaptive plan. The framework should be designed for enabling the continuous integration of emerging knowledge as it may affect decisions. It means that it should include some regular revisions of the plan to ensure that new knowledge and changes in the system are integrated. It means, for instance, that the adaptability is an important criterion in the decision processes (e.g., when choosing the most adequate risk reduction measures among a set of alternatives) since it helps with the integration of new knowledge and uncertainties. Since the framework is meant to be applied in an integrated way, adaptability may also help with aligning the decisions across the municipalities' goals in order to avoid missed opportunities.

The second fundamental principle that the URUQ-MAP should follow, is accounting for uncertainties (corresponding to the umbrella of *Best available information* in the ISO 31000:2018). Three consequences of the emphasis on this principle on the decision process can be highlighted:

- i. Under deep uncertainty for long-term management, the decision, and alternatives selected should be adaptable, which means easy to modify if required because of new knowledge,
- ii. Under a large range of variability, the decisions, and alternatives selected should be robust (a solution meeting the target while explicitly accounting for the different uncertainties).
- iii. Risk reduction measures aim at either reducing the likelihood or the consequence of a failure event. If the uncertainty level is considered too high for taking decision, then the best decision could be collecting new knowledge. It aims at reducing the uncertainty on the risk events' likelihood and consequences of occurrence, which mitigate the risk of wasting resources on a potentially poorly known pollution risk (likelihood and consequence).

This last consequence (iii.) leads to the third key principle, continual improvement. The framework is a cycle, and collecting new knowledge during an iteration may be beneficial in the long term in the next iterations. This is in particular highlighted in *ISO 31000:2018, Risk Management – Guidelines – Section 5: Framework* (2018) and more specifically: subsection 5.6 Evaluations which requires to periodically measure the risk management framework against its purpose as well as its suitability to achieve objectives, subsection 5.7 Improvement requires to continuously monitor, improve and adapt the risk management framework.

The application of the URUQ-MAP can only be successful if its application is coordinated and properly managed within and across institutions. The tools and the steps presented in the current deliverable hold to that necessity: putting in common information for identifying risks or using models for comparing alternative risk reduction measures can lead to a successful management of urban runoff quality risk if cooperation and, for instance, data flows across utilities is ensured.

Box 1: Key message – Main hypothesis and context.



MAIN HYPOTHESIS AND CONTEXT



Revision of the European Wastewater Treatment Directive

- Wastewater management plan to be developed (including runoff pollution),
- Measures to be taken to limit urban runoff pollution.

ISO 31000:2018 – Risk management – Guidelines:

- The URUQ-MAP is aligned with the ISO and emphasis on the principles of *Dynamic*, *Best available information*, and *Continual improvement*,
- Not all the aspects of the ISO are discussed in the current deliverable. The ISO remains a reference for the reader,
- Following the principle of continual improvement of the ISO, the URUQ-MAP is to be updated based on feedback from application in the different case studies,
- Coordination between stakeholder and across institutions is essential for a successful and integrated approach.

Pollution and risk:

- Pollution risk is dynamic,
- Likelihood and consequence of pollution risk events are hard to quantify and subject to large uncertainties,
- The URUQ-MAP should be adaptable and explicitly account for uncertainties.

1.4 OVERVIEW OF THE URBAN RUNOFF WATER QUALITY MANAGEMENT PLAN

The URUQ-MAP, as a risk management plan, is built heavily on the principles of the *ISO 31000:2018, Risk Management – Guidelines* (2018) to improve its potential for applicability and rigor in its structure. This section describes succinctly the different steps of the plan as well as their link to the *ISO 31000:2018, Risk Management – Guidelines – Section 6: Process* (2018) is divided into several sections: 6.3 Scope context and criteria, 6.4 Risk assessment which includes risk identification, risk analysis and risk evaluation., 6.5 risk treatment, and 6.6 Monitoring and review. The sections 6.2 Communication and consultation and 6.7 Recording and reporting of the *ISO 31000:2018* are discussed further in Section 1.5 Stakeholder panels.

The URUQ-MAP itself consists of **4 iterative steps** (Figure 1) that follows the content of *ISO 31000:2018*, but that may differ in terms of structure due to the specificities of pollution risk in water quality, as explained and detailed hereafter. The different steps are all interrelated and must be iteratively updated with new information.

1.4.1 STEP 0 AND STEP 1: CONTEXT, OBJECTIVES AND RISK IDENTIFICATION

Step 0 of the URUQ-MAP consists in defining the system of interest and the water quality objectives of the plan. The definition of the objective must be done in accordance with the definition of the

system, which is more detailed in Step 1. It is also the step where the different stakeholders and utilities involved must be identified.

Once objectives have been defined, the different inputs that are necessary for the Urban Runoff Water Management Plan need to be gathered and evaluated (Step 1). This step aims at estimating i) the level of detail (e.g., in time and space), ii) the level of reliability (uncertainty level) and iii) the likelihood of change (e.g., when and where the system will be modified gives information about when the URUQ-MAP should be revised) of the available information.

Step 0, together with step 1, corresponds to 6.3 Scope context and criteria, and 6.4.2 Risk identification of the *ISO 31000:2018, Risk Management – Guidelines* (2018). Step 0 and 1 of the URUQ-MAP are realized in parallel and constant communication between the stakeholders involved. Due to the large range of information required for the URUQ-MAP, the risk identification section of the ISO 31000:2018 is already included at the step 0 of the URUQ-MAP. It is necessary to align the early identification of the risks, the definition of the system, and the collection of available information. The risks events are to be identified and updated continuously during the application of the URUQ-MAP.

1.4.2 STEP 2 AND STEP 3: RISK EVALUATION

Based on Step 1, it should be evaluated if the available information is sufficient with respect to the objectives. It may be concluded that the level of information is not sufficient to carry out a risk analysis. In that case, it is necessary to plan new measurement campaigns, or to adjust the objectives (Step 2). Once the level of information has been considered sufficient to carry out a risk analysis, the risks need to be defined and assessed (Step 3). It should be noted that the level of information available will influence the choice of the risk evaluation method.

Step 2, together with step 3, corresponds to 6.4.3 Risk analysis and 6.4.4 Risk evaluation of the *ISO 31000:2018, Risk Management – Guidelines* (2018). To some extent, the URUQ-MAP diverges here from the ISO 31000:2018 due to the nature of water quality management in urban runoff. Indeed, Step 2 corresponds to a decision node where it is evaluated to which extent risk analysis and risk evaluation can be conducted. Linked to 6.6. Monitoring and review, it also acts as an iteration point where the system is re-evaluated.

1.4.3 STEP 4: RISK MITIGATION AND ITERATION

Once the risks have been evaluated, risk reduction measures can be planned (Step 4), which is linked to 6.5 Risk treatment of the *ISO 31000:2018, Risk Management – Guidelines* (2018). It should be highlighted, as mentioned in 6.1 Managing the quality of urban runoff, and consequently possible overflow in a receiving water body, requires coordination and cooperation. Indeed, the pollution entering the combined sewers can have various sources, it can come from the materials we use to design our cities, from car traffic, from pharmaceuticals we consume, and more generally from anthropogenic activities and atmospheric deposition. The consequence is that pollution sources may originate under several services in the municipalities before being conveyed in the water. Managing the quality of urban runoff requires the cooperation from stakeholders from those different services. Similarly, treating pollution risk must be done in alignment with the strategies of the municipality, which means in concert with other departments of the municipality. It should also be noted that the impact in the receiving water body may cross the boundaries of the municipality and inherit both from past water conditions and from upstream contributions. For managing urban runoff quality, several governance level and administrative division may be

involved, such as the municipality, the region, the utility natural catchment attached to a river system, etc.

Fundamental properties of the URUQ-MAP, that if risk treatment consists in evaluating different alternatives to mitigate risks, it does not mean that only decisions linked to risk reduction measures can be taken. It is possible to loop back to step 2 to collect new information, for instance through monitoring, to better characterize risks (which is lowering the uncertainty in both risk event likelihood and consequences). Collecting supplementary information in Step 2 may consist either in aligning the level of information and the objectives, which can consist in lowering uncertainty in risk identification and evaluation.

The URUQ-MAP also includes several feedback loops that are used for iterations and are related to 6.6 Monitoring and review of the *ISO 31000:2018, Risk Management – Guidelines* (2018). Monitoring is explicitly mentioned in step 4. Any risk treatment measure implemented must be monitored. A review of the plan, as well as further iteration, must ensure that the plan remains aligned with possibly evolving objectives. It is also necessary to ensure that stakeholders, remain involved in the long-term, including possible knowledge transfer in case of change in the organisation.

The current deliverable, as detailed above is heavily built on the *ISO 31000:2018, Risk Management – Guidelines* (2018), however not all the details of what is mentioned in the ISO as part of risk management approaches are detailed here. One of the reasons is to keep the report concise, another one is that the framework is expected to be modified for the final deliverable based on the feedback from the different case studies. Concerning the aspects of the ISO that are not discussed exhaustively in this deliverable, the reader is invited to directly refer to the ISO. These aspects are not less important than the ones discussed in this deliverable and should be addressed when implementing the URUQ-MAP. The reader is referred to the appendix for a figure

PROTECTING THE AQUATIC ENVIRONMENT FROM URBAN RUNOFF POLLUTION

summarizing the alignment between the URUQ-MAP and the *ISO 31000:2018, Risk Management – Guidelines* (2018).

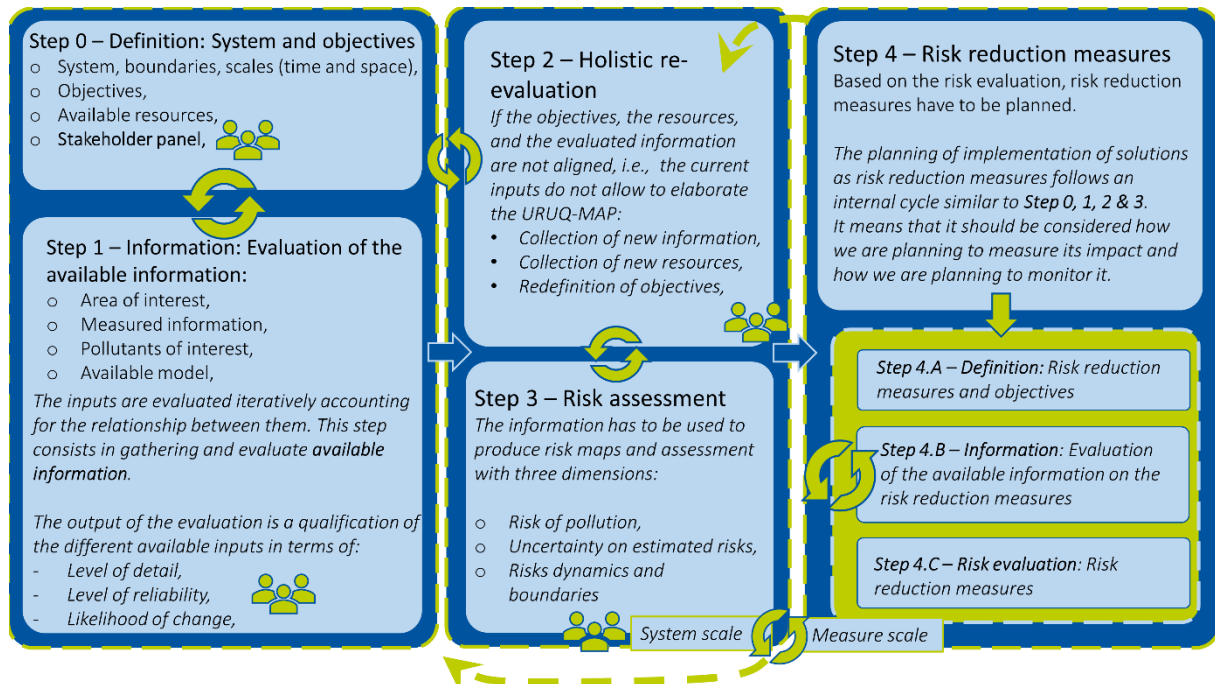


Figure 1: Overview of the Urban Runoff Water Quality Management Plan.

Box 2: Key message – Overview of the URUQ-MAP.



OVERVIEW OF THE URUQ-MAP



Step 0 – Definition: System and objective

The system, the objective of the URUQ-MAP as well as the preliminary risks to treat must be defined. The different actors as well as resources available for the implementation of the plan must be identified.

Step 1 – Information: Evaluation of the available information

The available knowledge and information about the system must be gathered with the goal to evaluate if the state of knowledge complies with the objective of the plan.

Step 2 – Holistic re-assessment

The pieces of information collected at the previous step are holistically assessed in order to decide on what action to take. It is a decision-making step.

Step 3 – Risk evaluation

The current status of pollution risk is evaluated. Once solutions have been evaluated in step 4, updated pollution levels are evaluated through scenarios.

Step 4 – Risk reduction measures

Risk reduction measures are considered and analysed to evaluate their suitability for implementation.

Compliance with the ISO 31000:2018

The URUQ-MAP is designed in compliance with the ISO 31000:2018 and detailed aspects specific to the context of urban runoff water quality. The user is encouraged to use the URUQ MAP as complimentary to the ISO 31000:2018.

1.5 STAKEHOLDER PANELS AND STAKEHOLDER INVOLVEMENT

Similarly to the recommendations in the Section 6.2 Communication and consultation of the *ISO 31000:2018, Risk Management – Guidelines* (2018), the urban runoff water Quality management plan is to be established in collaboration with the stakeholder panel. The stakeholder panel aims at including representatives for pollution emission, pollution impact, as well as pollution management. It is important to involve these three types of stakeholders to better understand where to act on the pollution risk. A reduction of sources of pollution may be more affordable than a treatment. Representative of pollution impact, which can be linked to health impact, or environment impact are crucial stakeholders in order to keep the management plan adaptive. Indeed, some environment protection agencies, or researcher organisation, such as the NORMAN network, may pledge for the monitoring and/or reduction of some substance before their regulation. Knowing ahead of time which substance may harm the local environment and become a future concern is a huge advantage toward pollution management. The stakeholders are included in several steps of the URUQ-MAP.

A distinction is made between the stakeholder panel and the stakeholder involvement. A stakeholder panel, within the frame of the URUQ-MAP, is a body with representatives from each stakeholder types and utilities involved. Such a panel needs to be established to ensure seamless application and coordination of the URUQ-MAP (e.g., ensuring communication and involvement of all parties, ensuring good data flow between utilities).

Stakeholder involvement refers to the processes used to involve stakeholders, which includes the elaboration of a stakeholder panel, the organisation of workshops to collect information and help linking several utilities. Workshops do not necessarily involve the entire stakeholder panel and may be conducted on smaller groups of stakeholders. Several key aspects related to stakeholders should be highlighted:

- There should be a stakeholder panel for URUQ-MAP application. This panel should meet regularly to be a driving force in the coordination and development of the urban runoff water quality management plan. The panel should include representatives from each utility and stakeholder types and should be regularly updated.
- There should be stakeholder involvement for each case study. Different stakeholders from different organisations may have relevant information or knowledge, and they should be involved at several stages of the plan. Stakeholder involvement can occur more regularly than meeting with the stakeholder panel, since fewer stakeholders are usually involved. In this way, it is a way to stay in regular contact with the stakeholders to keep the level of engagement in the project high.
- The composition of the stakeholder panel must be adapted to each of the case and their context. The administrative division differs from a European country to another, which means that the barriers in terms of stakeholder involvement may differ. The composition of the stakeholder panel as well as the action taken for involving stakeholder should reflect those aspects and get anchored in the local context and culture.

Stakeholders should be involved in each of the different steps of the development of the URUQ-MAP as shown in Figure 2. The stakeholder panel should help to coordinate the process, as well as ensuring continuity over the iterations of the risk management plan.

Within the frame of the URUQ-MAP, Step 0 requires the identification of the stakeholder panel. Such a list is dynamic, so it may be modified for each case study between the current status and the one for the final deliverable. However, it is important to acknowledge that all types of stakeholders should be represented, and that long-term follow up of stakeholders as well as punctual interventions are relevant.

During steps 1 and 2, information is gathered and evaluated. This step is key for involving the stakeholders. They might have relevant knowledge that would allow strengthening confidence in some information. It is also a good opportunity to involve them and establish a horizontal discussion and empower them.

Finally, the stakeholder panel should be involved during the process of risk assessment (for instance to discuss risk perception, acceptability of risks, and raise awareness), and in the selection of risk reduction measures and iterations of the plan. One of the specific reasons to involve stakeholders in the implementation of risk reduction measures, is that risk reduction measures

should be monitored. Including the community in implementation may help to detect malfunctions and misuses related to the solution.

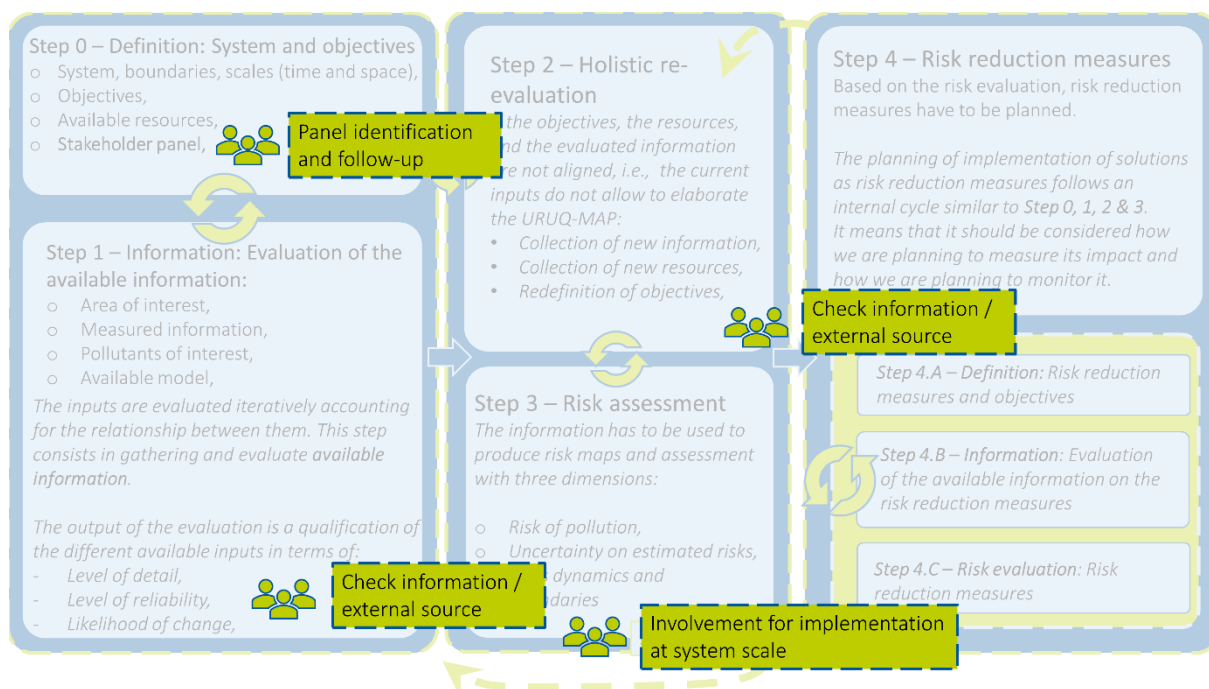


Figure 2: Stakeholder panel involvement within the URUQ-MAP.

2. STEPS AND STRUCTURE OF THE URBAN RUNOFF WATER QUALITY MANAGEMENT PLAN

2.1 STEP 0 – DEFINITION: SYSTEM AND OBJECTIVES

This step (see summary in Box 3 at the end of this section) reflects key aspects of risk management corresponding to section 6.3 Scope, context and criteria of the *ISO 31000:2018, Risk Management – Guidelines* (2018). Not all aspects of section 6.3 Scope, context, and criteria are discussed here, only specificities for urban runoff quality. The reader is referred to the *ISO 31000:2018* for further details. Both the risk events and tools for risk assessment are preliminarily identified in this step as well. Those risk events and tools for evaluation are developed iteratively in order to remain aligned to the context and level of information (in step 1, 2, 3 and 4).

2.1.1 DEFINING OBJECTIVES, RISKS, AND INDICATORS

When it comes to what the URUQ-MAP is aiming to achieve, there is a need to identify the key objectives, as well as to define the indicators representing the likelihood and consequences of the risk events. In the StopUP grant agreement, Key Performance Indicator 1 is defined as 50% overall pollutant reduction facilitated by better methods to develop urban runoff water quality management plans. It is a project Key Performance Indicator that may or not coincide with the context of any individual URUQ-MAP. This indicator must be reconsidered and reformulated for each case study. Specifically, some pollutants in some case studies may necessitate lower or higher reduction. The objectives must be adapted to the context of the case study and translated into performance indicators.

The identification of risk criteria is done in concert with the information collection in Step 1. It means that risk events are continuously updated when new information allows characterizing a risk. They must be discussed with stakeholders to identify which dimensions are relevant in terms of risk management for the URUQ-MAP. The risk characterization is linked to the first Work Package of StopUP “Pollution risk characterization”, and more specifically in the context of the case studies to Deliverable 1.1 “Pollution and pollution induced risk profiling of urban catchments in Case Studies – interim evaluation” where information about potential risk sources in the different case studies are compiled.

In order to mitigate risks, we refer here to risk indicators, especially for the case of quantitative analysis, an indicator of likelihood and/or consequences of a risk event based on observed and/or modelled data. As specified earlier, such indicators must include the notion of uncertainty in their formulation.

2.1.2 DEFINING THE SPATIAL AND TEMPORAL SCALE

The temporal scale of the URUQ-MAP may be aligned with the 7-year plans of the European Water Framework Directives, or with the plans of some local authorities, but it must be acknowledged that the pollutants dynamics should be considered for re-evaluations and iteration processes (see Section 0).

The spatial scale may also be influenced by local governance, but the flow and pollutant pathways should be considered. The relevant scale for managing urban runoff water quality might not equal the preferred one in terms of administrative division. In that sense, the definition of the spatial area of the project, together with its boundaries, is crucial. It is also important to account for the receiving water bodies and their sensitivity. Conversely, the scale of the receiving water body must be considered. The water in a receiving water body close to the system may be affected by water quality discharged from the system, while the overall water body may not be significantly affected.

The resolutions, spatial and temporal (for modelling, monitoring, sampling, or evaluating risks), must be defined based on the processes involved and in accordance with risk indicators. They should be updated with available information. Deliverable 4.1 of the StopUP project discusses the temporal resolution to be considered in terms of water quality monitoring.

2.1.3 DEFINING THE AVAILABLE RESOURCES

Conducting a risk management plan, in the context of runoff water quality, requires different types of resources which should be carefully considered for a successful plan. Resources include data, human and financial resources, time, qualified personnel, and monitoring equipment. Those resources are particularly important because monitoring water quality is very time, labour, and cost expensive. Another aspect that should be considered is the skill availability. The application of the URUQ-MAP requires the development of scenarios of risk mitigation measures and for the consideration of the dynamic and uncertain nature of risks. It means that personnel with the necessary skills should be identified, and the relevant methods should be studied. This also include the availability of personnel for coordinating the implementation of the plan, and to ensure good communication and involvement between stakeholders.

The available resources also include the awareness of the innovation landscape, both in terms of runoff quality management and monitoring. Indeed, the field of monitoring water quality is a rapidly evolving field, coming with complex challenges. One could argue that the Proposal for a

Revised Urban Wastewater Treatment Directive (European Commission, 2022) may increase the speed of development of the field with the requirement of European cities to monitor water quality. Consequently, the awareness of the different monitoring solution as well as feedback on their potential implementation are important to take the right decision. The reader is referred to the StopUP Deliverable 4.1 for a broader overview. For instance, solutions such as automatic sampler triggered through online measurement (see StopUP task 1.3) may be a solution toward more efficient sampling. The service delivered through the deployment of IoT (Internet of Things) sensors, which is data collection and automatic data processing, can be considered as a way to reduce the workload associated with data collection and validation. Similarly, low-cost sensors, despite their possible high maintenance needs, may be considered as a viable option due to their low cost (Zhu et al., 2023). The knowledge of the innovation is therefore a resource required for a successful application of the URUQ-MAP.

Managing stormwater quality is, by definition, resource intensive. It comes for several reasons:

- Monitoring water quality, in the urban drainage system, and in the receiving water body is highly resource intensive compared to monitoring only water quantity (see the StopUP deliverable 4.1).
- It is a multidisciplinary problem. As it has been highlighted in Section 1.5 Stakeholder panels and stakeholder involvement, pollution is emitted and transported in the urban environment before being released in the environment. It has then an impact on the environment at both short and long-term. The emission of pollution in the urban environment poses a challenge because it can be linked to drivers that are external to water management, such as car traffic. Car traffic, in the city, may be monitored by a relevant authority, that may differ from the water authority. The URUQ-MAP is an integrated plan that requires the involvement of multiple utilities.
- It has multidisciplinary solutions. For instance, green infrastructures are envisioned as possible solution for stormwater management and are inherently multifunctional (e.g., water management, aesthetic, recreational, biodiversity, etc.). It makes the evaluation of the cost of implementation, maintenance and monitoring more complex as the municipalities' services may not be adapted to such infrastructures (Cossais et al., 2017). It is therefore important to question how the relevant authorities will monitor and maintain solutions, and if there is a need to adapt the organisational structure of those authorities.

Moreover, it is important to understand the URUQ-MAP as a cyclic, interconnected framework; for instance: the decision taken in step 4 – Risk reduction measure, may result in a modification of the resource needed. It is therefore necessary to re-evaluate the resources available as well as the needs. Designing a monitoring campaign of urban runoff quality, as well as the resources needed to do so, is also a complex task. The reader is referred to the deliverable D 4.1 for further insights on the topic.

2.1.4 DEFINING THE SYSTEM'S BOUNDARIES

Tightly linked to 2.1.2 Defining the spatial and temporal scale, the definition of the system's boundaries, in time and space, must be emphasized. Once the system (e.g., urban catchment), and temporal and spatial scales have been defined, one must ensure that the specificities of boundaries of the system (included in the suprasystem, e.g., the entire city) are not ignored in the study. Indeed,

the application of the URUQ-MAP involves several physical processes and areas that may not be entirely compatible (e.g., hydrological catchment may not overlap with biodiversity pathways). Moreover, the chosen risk mitigation measures may involve other management plans, such as plans associated with biodiversity. It must be accounted for since biodiversity conservation and restoration involve the development of corridors to increase the connectivity of areas at a scale that might largely exceed the one of the URUQ-MAP. In the meantime, cutting of subcatchment and subparts of the area must be done with respect to hydrology and network's hydraulics. It should be reminded that modification in the system may lead to the definition of new boundaries.

Box 3: Key message – System and Objectives.



SYSTEM AND OBJECTIVES: an iterative cross-scale process

Link to the ISO 31000:2018 – 6.3 Scope, context, and criteria



Spatial and temporal scales and boundaries:

- Need for cross-scale, cross-disciplinary, and cross-institution assessment,
- Attention paid to the receiving water body and natural processes involved,
- Need for update with new information.

Available resources should be listed (Skills, awareness of the innovation landscape, available methodology, time, money, data, monitoring equipment, computational power, etc.).

Identification of key stakeholders from the relevant utilities to ensure good communication and facilitate information collection.

Risk event indicators and objective:

- Iterations with Step 1,
- Discussion with stakeholders.

2.2 STEP 1 – INFORMATION: EVALUATION OF THE AVAILABLE INFORMATION

The goal of this step is to evaluate the inputs for the urban runoff water quality management plan in amount and quality information. More specifically, this consists in evaluating the level of detail available, the level of reliability and the likelihood of change. Those attributes must be evaluated qualitatively for each information to be related to the needs formulated in the Step 0.

The level of detail is directly related to the scale of the system in time and space and the formulated objectives. For instance, if an objective is to reduce the number of hours of overflow per year and measured information is available at minute resolution, then the level of detail is high in comparison to the objective of the management plan.

The level of reliability is an important factor explicitly mentioned in the *ISO 31000:2018, Risk Management – Guidelines* (2018). Indeed, it is crucial to know how reliable a source of information is in order to make a decision based on it. A strategy on uncertainty management has

to be applied accordingly. For instance, with the previously mentioned objective of reducing hours of overflow, using a hydro-dynamic model is relevant to test the impact of potential risk reduction measures. If during the calibration and testing of the model it is found to underestimate annual hours of overflow significantly, it is important to diagnose to which extent and if it is possible to use an uncertainty mitigation strategy to better estimate the reliability of the estimates.

The likelihood of change, similarly to the two previous attributes, is one of the key aspects of *ISO 31000:2018, Risk Management – Guidelines (2018)*. In terms of risk identification, the change in the external and internal context must be evaluated because risks are dynamic. In particular, in the context of pollutant management, the human factor is a driver that changes the systems. It directly affects the climate, the urban morphologies, the sewer networks, and the pollutant sources, which therefore is likely to modify pollutant levels and pathways. For instance, if a model is developed using data corresponding to a given year, but the network has evolved in years prior and posterior to development, this must be accounted for in the modelling tasks since it will affect the reliability of results and will need as a mitigation strategy to update the models regularly.

The different categories of inputs are:

- The area of interest
- The measured information
- The pollutants of interest
- The available models

It should be noted that the evaluation of the different inputs requires putting in common inputs of different nature. For instance, the knowledge of the area can be useful to evaluate the likelihood of a change in pollutants of interest. Moreover, in Step 1, the alignment between each individual source of information and the objective is evaluated. But step 2 requires a holistic assessment of the level of information and the objectives of the management plan. Indeed, some individual medium level of reliability might cumulate to a point where it is necessary to take actions.

2.2.1 AREA OF INTEREST

To manage urban runoff water quality, it is necessary to first evaluate the state of knowledge in the area of interest and the likelihood and level of change. It is also important to have reliable information if it becomes necessary to develop a model. Key aspects of investigation related to the area of interest are listed in Box 4 at the end of this section.

(1) HOW AND WHERE TO GET INFORMATION?

The information about the area of interest is directly related to the stakeholders involved. A large part of the relevant information and knowledge is held by them, which is why it is crucial to involve them.

The primary source of information is often the municipality. It might be possible to access urbanization plans, network maps, and get expert knowledge during field visits and discussions with field operators. It is important to not only get a dataset but also discuss the data collection,

update, and monitor in order to evaluate the reliability of the information. The discussion with stakeholders may also lead to other sources of information initially not considered.

The archives may be considered as a secondary source of information. Indeed, it may give hints of when a system has been changed, what material buildings could be made of, etc.

The tertiary source of information is the community. The information may come from citizens, news, etc. This type of information may not be quantitative but rather qualitative. It may inform of flooding points, for instance in the catchment. It can be considered as a way to identify flaws in information collection approaches and needs for further information. It may also be useful to further involve the community in the projects (Quick & Bryson, 2022).

(2) IS THE CATCHMENT KNOWN WELL ENOUGH? IS IT LIKELY TO CHANGE?

The land-use, soil composition, and buildings' history are important components of the system. They are necessary to understand the catchment's hydrology and pollutant diffusion. Several types of information sources are complementary to establish an overview of the knowledge about the catchment:

- **Information from official sources:** Is it possible to access the municipality's urbanization plan? Accessing to the maps of current land use and areas planned to be modified in future years can provide information of both the current state of the catchment and the likelihood that the catchment evolves. Official sources also account for the type of soils in the catchment and the geology. It may also provide information about the catchment hydrology. In some cities, some rivers or streams have been buried.
- **Information from historical sources:** Historical sources are important to account for the evolution of the catchment but may also reveal some particularities of the catchment. For instance, the area may have been flooded in the past, or there may have been a landslide which informs about the catchment's particular geology and hydrology. Archives may also reveal previous land-use, allowing to identify potential past pollutants or sites non-suitable for infiltration. Archives may also be useful to analyse past time-series. Indeed, when using data to model the catchment, it is necessary to know if monitored flow in a past period can correspond or not to the current system. The evolution of the catchment may inform on the likelihood of change of the land-use.
- **Information from field sources:** The apparent accuracy of the available information does not prevent from visiting on-site. The maps provided by the municipality may not be up to date. Soil maps do not ensure accurate information about hydraulic conductivity. It may be necessary to go on-site and perform conductivity tests in parks. In particular, the soil in a park may be very dense if many people gather there. This may impact the hydrology of the catchment. Visiting the site during rain events may also inform on the water flows.

(3) IS THE URBAN DRAINAGE SYSTEM IN GOOD CONDITION AND IS IT LIKELY TO CHANGE?

The knowledge of the pipe network, and green infrastructure system is particularly important to evaluate since it drives a large part of the urban runoff water quality management plan. It also consists of a set of information that is likely to be inaccurate, incomplete, and obsolete. Sources of information are described as follows:

- **Information from official sources:** It is important to access the municipality's network plan. It is also useful to have access to maintenance data if they are available and pipe material (Tscheikner-Gratl et al., 2019). Information about green infrastructure implementation is rarely available but is important to account for (Cossais et al., 2017; Langeveld et al., 2022). Getting detailed information about a particular infrastructure such as an outlet is crucial. When measurements are available, it is necessary to understand where in the sensors are placed.
- **Information from historical sources:** Data records of change occurring in the drainage network (Fenner, 2000) can help to understand better the urban drainage of the system. To the authors' knowledge, while those databases are regularly used in the literature, there is seldom literature about updates of models with pipe network modification. It can also show if the available measurements of discharge are relevant to the current system, or if the system has changed a lot. Access to other networks can be helpful to analyse possible infiltration in the drainage network. Despite the recent interest in green infrastructure, the use of infiltration trenches, especially on private housing, has been common in some regions. It may be relevant to get access to this information. It may happen that the private owners or that the services of the municipality are not aware of the existence of an infrastructure. These infrastructures may be clogged.
- **Information from field sources:** Verifying information on-site often cannot be avoided since the database may not be always accurate (Okwori et al., 2024; Rokstad, 2012). In particular, the manholes or gully pots may be clogged, the surface water may be diverted to another gully pot than the one suggested by a map. Some infrastructures are critical for the development and calibration of a model. Those infrastructures such as overflow infrastructure and infrastructures with sensors should be visited onsite and investigated in order to ensure more accurate modelling. It is important to note that gathering information in the field can be costly. Especially if it is not possible to inspect each of the conduits without investing a lot of resources. However, it is possible to investigate a possible mismatch between official information and the site itself on site. It can help to assign a reliability to available data.

Box 4: Key message – Area of interest.



AREA OF INTEREST: level of detail, reliability, and likelihood of change

Knowledge of the land-uses and catchment history:

- Hydrological model development,
- Pollutants of interest and sources,
- Likelihood of change within the scale of the URUQ-MAP.

Knowledge of the sewer network and its evolution:

- Hydraulic model development,
- Pollutant pathways,
- Likelihood of change within the scale of the URUQ-MAP.

How and where to get information:

- Municipality
 - Urbanization plans,
 - Network maps,
 - Expert knowledge from field operators
- Archives,
- Community: citizens, news, etc., help to identify:
 - Need for further investigations,
 - Flaws in approaches, etc.



2.2.2 MEASURED INFORMATION

The goal of this section is to determine to which extent available data can be used to guide planning. It does not decide how to use them, it evaluates their suitability for later use (see Box 5 at the end of this section for key aspects). It is important to acknowledge that many data sources with various reliabilities may be considered. Depending on their characteristics, it may be possible to extract relevant information. If the conclusion of the investigation is that available data cannot provide relevant information for the urban runoff water quality management plan, it is still a relevant and crucial conclusion. The aim of this framework is also to help with deciding when to collect more data instead of planning implementation based on unreliable information, which may result in a waste of resources and possible increased risk (e.g., a risk reduction measure acting on a poorly identified risk event may result in a false sense of risk event mitigated, which may not be the case).

(1) CLIMATE VARIABLES

Climate information can be used to represent a direct trigger for the system. For instance, an extreme rainfall event may wash off surfaces, and via an overflow release pollutants into the sewer system. Climate information is also relevant to represent indirect triggers linked to pollutants. Temperature and humidity may affect the development of bacteria or the degradation of pollutants. Several sources and types of sources of information for this topic can be listed as following:

- **Information within the system's boundaries:** Different climate variables may be measured in the catchment. Several key information should be gathered. The period of measurements should be investigated. It includes the periods where the station was under maintenance. The resolution (both of temporal and of the variable). What needs to be assessed is the period of measurement, the type of sensors, the metadata availability, the maintenance information (Bertrand-Krajewski et al., 2021). The main variables of interest are precipitation, temperature, wind, air humidity, etc.

In order to estimate the reliability of information, several pieces of information should be considered and documented. Are there rain gauges in the catchment? Which model was used? Are there several monitoring stations in case the catchment is large? How long have the measurements been recorded. Is the data post-processed and how?

- **Information outside the system's boundary:** Where are the nearest rain gauges? Are the time-series significantly different there? The goal is to evaluate if nearby data (geographically) has relevant information. It can be used to confirm if the rainfall event in the catchment has been measured correctly. It can also help to see if a large change in the event is likely to be observed from one side to the other of the catchment (Cristiano et al., 2017).
- **Information from proxy data:** In some cases, no measured data is available in a relevant location. The use of data from climate models may be considered (with all the uncertainty that it entails). Private weather stations may be considered as a source of information. If it is possible to access this source of data, a larger uncertainty may be assigned to the data. The information on maintenance may not be as reliable as the one in a meteorological institute. Some research aims to extract precipitation from commercial microwave links (*see* Chapter 2, Bertrand-Krajewski et al., 2021). However, those data may require a lot of resources (time and skills) to invest information. Miscellaneous information sources must be evaluated for the information they may provide, the uncertainty we should account for, and the resources required to extract the information. In case of absence of data in the catchment, data from a similar catchment may be considered.

(2) SEWER MEASUREMENTS

Drainage systems are complex systems. The knowledge about the system (including climate condition, topography, hydrology, sewer system state of deterioration, etc.) without measurements, does not allow predicting the outflow of the system. That is why data collection is crucial to study the system's behaviour. Different sources of data are:

- **Monitoring stations:** Some catchments have a single sensor at the outlet measuring, for instance, overflow. Depending on the country's regulation, it may be a requirement to monitor overflow. The available sensors may consist of water depth, discharge and/or overflow occurrence. Evaluating the reliability of the sensors has to be put in perspective with the knowledge in the catchment. Indeed, it is important to know how a sensor is placed (micro-placement) and which type of sensor it consists of to be able to analyse the data collected. In particular, when a sensor is placed in a complex infrastructure, if the only available information is that it is located in this infrastructure, the information is not sufficient. It is then necessary to go on site and document more accurately the location to

be able to analyse if some values are particularly critical (overflow height, offset, baseflow, etc.). It is also important to contextualize the different information that can be extracted from the data collected. For instance, wet weather flow is a small a part of the dataset. It can be analysed with respect to the storm event, but including information from previous days (antecedent rain, occurrence of rain on snow, etc.) may result in a more relevant information. The baseflow, similarly, can be studied with respect to seasonality, weather, population habit (daily and weekly patterns).

- **Short-term measurement campaigns:** In some cases, short-term measurement campaigns can be realized. It can provide useful information to understand the catchment behaviour, especially if it provides information from different locations in the catchment. The spatial information can be relevant to estimate, for instance, if the baseflow is coming particularly from a specific area of the catchment. Such information can be important to plan risk reduction measures for stormwater quality in the catchment.
- **Miscellaneous information:** Data can also be of a different nature and be more qualitative. In particular, during storm events, citizens may record videos. Those videos may contain information that can be relevant for decision, planning of measurement campaigns or model calibration. This information can also come from visual inspection in manholes. In particular, the presence or absence of baseflow in a manhole, may be inspected with a large qualitative uncertainty. Indeed, the data may be "at time 't', in manhole 'm', no baseflow was observed while a baseflow was recorded at the measurement station". It does not allow concluding that this specific manhole never had baseflow. It may have a baseflow only at specific times of the day. If the baseflow comes from wastewater and the manhole is located so far upstream that only a few houses are contributing, the wastewater flow may be very versatile. Using information from miscellaneous sources of information requires putting it in perspective with the knowledge of the system and assigning a qualitative uncertainty according to the level of "trust" in the source of data. This information may however be relevant to planning measurement campaigns. If no information is available, they may be used to guide the design of the monitoring system.

(3) POLLUTANTS MEASUREMENTS

The goal in this section is to identify which level of information we have from the pollutant on site. In practice, it is important to track where the information is coming from in order to assign it a lower reliability where appropriate. For instance, a measurement campaign on-site, is very relevant, in the case of pollutants that degrade rapidly. If the catchment changed since the measurement campaign, they may be completely outdated. Other measurements from persistent pollutants such as PFAS may remain relevant. When no measurements are available in the boundaries of the system, data from another system, similar enough may be considered. However, the applicability of the data from a system to another must be considered carefully in terms of data quality and system similarity. One may trust the data collected in the other system, but the level of similarity between the systems may be considered too low. Alternatively, the two systems may be considered similar-enough, but the data from the other system may be considered unreliable if we are not confident in the data reliability. Data has to be labelled in terms of **applicability**, **uncertainty**, and **reliability**. Information can be collected from:

- Information from internal sources (at local scale): Have there been measurements of pollutants locally? Can we rely on their values? Do we have a long record of measurements (i.e., are the measurements still relevant)? Is the case documented enough? Is there information about the temporal and spatial consideration for those measurements?
- Information from external sources (by proxy): Can the knowledge of the catchment and of the solutions allow identifying an external source of data? Are there relevant data available for a similar case (e.g., similar solution, similar land use, similar climate, e.g., Stormtac, international BMP database?)

It is important, especially in the case of pollutant data, to evaluate if the sources of data consist of relevant information and if they are applicable to the case study. It should be acknowledged that in the absence of local information, finding replacement data (e.g., in Stormtac or the international BMP database) may result in a bias if the data is not evaluated correctly. In particular, for the case of pollutants, the measured data may be site specific depending on the pollutant. If no information about the catchment characteristics and the climate are available, it is important to be able to assign a low level of reliability to this information to avoid any bias in the use of data.

Box 5: Key message – Evaluating measured information.



MEASURED INFORMATION: level of detail, reliability, and obsolescence of available data

Climate data for each **variable:**

- Availability (official, private, etc.),
- Resolution (minute, hourly, daily; single station or several?),
- Location (how close to the area?),

Sewer measurements:

- Availability (official, private, etc.),
- Resolution (minute, hourly, daily; only at the outlet or with several measurement points in the system?),
- Redundancy (other data for comparability),
- Variable (water level, flow, “Yes/no” overflow, etc.)

Pollutants measurements:

- Quantitative or Qualitative,
- Link with land use analysis and archives,
- Link with the receiving water body.
- Literature values, etc.



The **community** is knowledgeable in that stage: they may know about flood paths, type of paints, changes in the system, might have videos during rain events, memories etc.

2.2.3 POLLUTANTS OF INTEREST

The main question that should be answered in this section is: Are the pollutants of interest well-defined, and is the list likely to remain the same? This topic is more largely discussed in Deliverable 4.1 of StopUP. Given a list of pollutants of interest, this section investigates if that list should be revised, and when it should be revised. For instance, it questions if we can exclude those unlisted pollutants (not regulated at the time of the elaboration of the URUQ-MAP) will be added later on, and if the climate will have an impact on pollution pathways. The topic of the pollution of tomorrow, is vastly discussed in one of the final deliverables of the SOLUTION European project (Bunke & Moritz, 2018). They highlight that the anthropogenic changes resulting or manifesting into climate change, population growth demographic change, urbanization legislation and innovation are linked to development in different sectors for instance public health, food, technologies cities, impact the use of chemical in society both in terms of sources and pathways. This section contributes to updating the risks preliminarily identified in step 0 by evaluating the source of pollution to be considered. This is directly linked to Section 6.4.2 Risk identification of the *ISO 31000:2018, Risk Management – Guidelines* (2018). Key aspects are detailed in Box 6 at the end of this section.

(1) SOURCES AND LAND-USE CHANGE

If the different subcatchments are likely to change in terms of land use, we may expect different pollutants. It should be noted that depending on the type of pollutants, a change in land use may not mean a change in pollutant source since they may be persistent. To assign a likelihood and a time horizon of land use change, different sources of information with different level of reliability can be used, they are directly linked to the information collected in section 2.2.1:

- **Information from official sources:** Municipality's urbanization plan may help, for instance, to identify a possible change in road traffic or change of roofs material which may affect pollutants in runoff. Change in the drainage network may redirect runoff from other catchments to the area of interest.
- **Information from historical sources:** For instance, if the catchment is located in a city centre, an already highly dense area, and the building renovation and construction is well documented, it is possible to assign a qualitative high or low likelihood of change of land-use. This likelihood of change informs the stakeholders if the pollutant sources considered are likely to change or not.
- **Information from external drivers:** Several sources of information may come from different official sources from different utilities with different level of governance. Those sources may not always be accurately described at the system's but may also be considered as proxy to evaluate the likelihood of change of sources of pollutants. Non exhaustively:
 - Increase in population and areas susceptible to change (e.g., old industrial area that may turn residential)
 - Change in urbanization strategy (functionalism used in the past may turn area with a single function like an industrial area to an area with mixed functions),
 - If the last urbanization plan is outdated and a new one is expected in the next years.
 - Other drivers (if some area turned into area mapped as flood sensitive, next urbanization may take place in the targeted area).

(2) POLLUTANTS OF EMERGING CONCERN

The development of new technologies and globalization leads to the emergence of new pollutants. In the meantime, increase of knowledge leads to pollutants of emerging concern. This is different from emerging pollutants, since it designates pollutants that may be found in water bodies before awareness about their impact has been risen (Dulio et al., 2018). Therefore, those pollutants are often regulated after they are found in water bodies. To assign a likelihood and time horizon of pollutant emergence, different sources of information with different level of reliability can be used:

- **Information from official sources:** Which pollutants are to be monitored according to official guidelines? Are new pollutants being discussed at institutional level, or academic level? It aims at answering the question if some pollutants that should be considered of interest and are not currently monitored in the study area. (e.g., a neighbouring country with a similar climate may have decided to regulate on some pollutant, it can be expected that those pollutants will become pollutants of interest).
- **Information from historical sources:**
 - If the local monitoring practices in the past show evidence of pollutant emergence in the past, it may be expected to happen again,
 - If the local guidelines are historically "one step behind" in terms of monitoring practice and pollutant of interest compared to other official sources, it can reinforce the likelihood of pollutant emergence.
- **Information from external drivers:**
 - Emergence of new industries in the region or of new technologies on which research has not set a diagnostic.
 - New technology that used to be negligible become globalized: the potential pollutant can emerge as a concerning pollutant.
 - Are environmental protection organization (e.g., NGOs) pledging for regulation of some specific pollutants (linked to neighbouring areas, for instance)?

(3) CLIMATE CHANGE AND VARIABILITY IMPACT

The effect of climate variability, seasonality, and change may influence the processes ongoing in the catchment, including the temporal distribution of pollutant concentration due to modification of weather patterns. It can also influence the occurrence of overflow and the mass of pollutants during overflow. Climate change may lead to the use of pollutants that are not currently used in the region. To assign a likelihood of interaction between climate change and pollutant diffusion, different sources of information with different levels of reliability can be used:

- **Information from official sources:** The local climate may evolve toward the climate of another well-known area. Climate is a driver for the use of pollutants (e.g., snow, drought, etc.). Conversely, climate change may affect the sources of pollutants. For instance, scientific studies show evidence of an increase of some pollutants due to climate change (e.g., bacteria). Therefore, data corresponding to a different climate may be informative.

- **Information from historical sources:** It happened before in the local region that the evolution of climate led to the use of different products, which led to the change in pollutants of interest.
- **Information from external drivers:**
 - Adapting to climate change leads to different practices, which may lead to the emergence of new pollutants of interest.
 - Catchment hydrology and pollutant accumulation may change with climate change. Pollutants historically under the threshold of interest are now likely to become a threat to the environment.

Box 6: Key message – Pollutants of interest.



POLLUTANTS OF INTEREST: Can changes be expected?

Investigate factor affecting change in the pollutants of interest:

- Land-use change impacting sources and pathways,
- Contaminants of emerging concern,
- Climate change impacting diffusions processes.

ISO 31000:2018 – 6.4.1 Risk identification:



- Change in the external and internal context,
- Indicators and emerging risks,
- Biases, assumptions and believes of those involved.

In practice:

- Challenging to account for changes,
- Plan and risk reduction measures should be adaptable,
- Uncertainty in approaches should be accounted for and communicated to stakeholders.

2.2.4 AVAILABLE MODELS

This section is especially linked to Work package 2 of StopUP. Key messages are summarized in Box 7. Models may be used in the planning phase, but their relevance and reliability must be assessed prior to their use. This approach consists in assigning a qualitative weight to a model-based analysis depending on their reliability. Carefully evaluating the reliability of a model is crucial for avoiding confirmation biases (Stark, 2023). Moreover, understanding what is the context of model development and its objective is important to assess its usefulness (Di Fiore et al., 2023). In the context of the URUQ-MAP, the usefulness of urban drainage models and pollutant models is their capability to be predictive, and compatible with the development of scenarios (i.e., that a modification of the system to simulate the implementation of a solution does not affect its predictive property). A useful model should help with estimating the potential impact of a risk reduction measure on the estimated risks. If the models available are not suitable for this task, an alternative approach should be considered.

(1) CLIMATE MODELS

Climate information and climate tools may exist, but it does not ensure that they can be found easily or used easily. In this section, it is necessary to evaluate if it is possible to rely on these data. Similarly, one of the goals of this step is to track misuse of climate tools. In particular, using the output of a complex climate model could create a false impression of confidence in the result that does not align with the result of the climate model itself. It is necessary to be careful in the use of outputs from climate models and to better understand their potential, and the available capability to use them. For instance, there is a difference between the climate's models resolution, and the resolution of their output data.

(2) URBAN DRAINAGE MODELS

Urban drainage models are, similarly to most environmental models, subject to equifinality. It means that different sets of parameters may lead to similar results (Beven, 2006). It emerges in particular in the context of limited data. For instance, when calibrating a hydrological model of a green infrastructure solution that allows both for infiltration and evapotranspiration with only measurements at the outlet, a parameter set may assume a large portion of infiltration, and another set a large portion of evapotranspiration. Assuming that one of the parameter sets is closer to the real behaviour of the roof, basing the decision on the other may lead to wrong results. It is therefore important to make sure that the model developed is aligned with the objective of its use and that the users keep track of the assumptions and hypothesis (V. Pons et al., 2023).

(3) WATER QUALITY AND POLLUTANTS MODELS

Water quality and pollutants models at catchment scale rely on accumulation-wash off processes. It should be noted that due to limited data availability and dataset obsolescence (Müller et al., 2020), both the conceptualization and calibration of those models have several caveats that make their usefulness limited. For instance, even for variables such as total suspended solids or turbidity for which data is relatively abundant in comparison to most other pollutants, it remains complicated to use models reliably at catchment scale (Bonhomme & Petrucci, 2017). In particular, they often do not capture the variability of concentration (Sage et al., 2015). They also don't include non-conventional sources (Zhang et al., 2019), which are crucial in terms of risk management.

It is therefore important to evaluate the possibilities depending on the pollutants to be modelled. The pollutant models are taking as inputs outputs from climate models and urban drainage models. Therefore, the uncertainty conveyed through those input models should be propagated through pollutant models. In the case of large input uncertainty and large epistemic uncertainty in the pollutant model's conceptualization, alternative approaches must be considered. In particular, statistical methods can be used to account for variability and scenario-based methods developed for deep uncertainty (Walker et al., 2013) may be considered. In all the mentioned approaches, models should be used with caution to avoid a false sense of confidence when quantifying. Due to the ongoing difficulties inherent to pollutant modelling, qualitative and scenario-based approach are still strongly advised.

Box 7: Key message – Evaluating available models.



MEASURED INFORMATION: are the models aligned with the objectives?

Climate models:

- Compatibility between model resolution, and resolution needed,
- Awareness about the model's assumptions and scenario development,
- Awareness and framework to manage the uncertainty cascade,

Urban drainage model:

- Is the model conceptualization aligned with objectives?
- Is the calibration and testing tailored for the URUQ-MAP?
- Is the model up to date?

Pollutants models:

- Is there sufficient data for model development?
- Is a reliable model conceptualization available?
- Uncertainty propagation from other models?



The goal is to evaluate if the model is **useful** or if it risks **misleading** decisions. The evaluation should help to identify the **bottleneck** in the approach in order to **distribute efforts** in improving models accordingly.

2.3 STEP 2 – HOLISTIC RE-EVALUATION

2.3.1 HOLISTIC ASSESSMENT: CAN THE AVAILABLE INFORMATION EVALUATED IN STEP 1 ALLOW TO MEET THE OBJECTIVES SET IN STEP 0

At this point, each of the available information has been evaluated individually in terms of alignment with the objectives and requirements of the management plan. Each uncertain information contributes to a total uncertainty when estimating risk level (in terms of level of detail and reliability). Similarly to the concept of total effect indices in sensitivity analysis (Saltelli et al., 2007), this step aims, by combining sources of information together, at evaluating if the level of uncertainty in the resulting risk likelihood and consequences is acceptable or not. If the uncertainty level is not acceptable, it aims at reducing the uncertainty by identifying efficient methods to cut the level of uncertainty. In order to address these possible cases, this step aims at evaluating holistically if the available information is sufficient to progress in the management plan. One of the reasons for that holistic evaluation is that the management plan requires expert knowledge in different fields. It means that different stakeholders (e.g., urban planning expert, field operators, etc.) may not have communicated during the evaluation of individual information. This step ensures that the different knowledge bases (e.g., about the urbanization, the drainage network, the pollutants, the climate, etc.), that may have been collected in silos until then, are put in common to evaluate the applicability of the plan.

In practice, it aims at answering the question: Given the system, boundaries, scales, objectives, and all available information, can the risk analysis in step 3 be conducted?

In step 0 risks have been identified. During step 1, by increasing the knowledge about the system, some other risks may have been identified (e.g., by looking at roofs material, or being aware of change in land-use, or pollutants of emerging concern). In the current step, it is then necessary to evaluate if risks can be identified or disregarded by evaluating the system holistically.

It is also important to evaluate if a method is feasible to assign likelihood and consequences for each of the risk events. It should then be evaluated if it is possible to develop scenarios in order to decide on risk reduction measures.

If information and resources available do not allow achieving the objectives, actions must be taken. The three types of actions must be considered: i) collecting more information, ii) collecting supplementary resources, and/or iii) revising the system and objectives. Key aspects of the holistic re-evaluation are listed in Box 8 at the end of this section.

2.3.2 ACTION 1: COLLECTING MORE INFORMATION

If it is acknowledged that the available information is not sufficient to evaluate the current risks given the available resources, one possible action is to consider collecting supplementary information. The information collected can consist of the information sources discussed in Step 1. It may consist of a monitoring campaign.

The design of a monitoring campaign for investigating urban runoff water quantity and quality is further discussed in Deliverable 4.1 of the StopUP project. Useful resources for designing a monitoring campaign accounting for metrological aspects in urban drainage systems can be found in the recently published metrology book for urban drainage systems Plug and Pray (Bertrand-Krajewski et al., 2021). It should be noted that designing a monitoring system, in particular deciding where it is most relevant to place a sensor, is a complex problem. Further information about sensor placement can be found in the European project PREPARED (see Thompson et al., 2011).

The possible information to be collected must be linked to the ease of data collection (i.e., is it resource-efficient?), and to the information value (i.e., is it informative?) with respect to the system. The notion of information is in this section linked to the concept of sensitivity analysis (Saltelli et al., 2007). By assessing the level of uncertainty in the system considered, one must determine which sources of uncertainty should be targeted to best reduce uncertainty at project level. For instance, if a large uncertainty stems in the hydrological processes, it may be more efficient to increase knowledge about the drainage system than to collect water quality samples since their hydrological processes influence pollutant diffusion. The information to be collected must be a trade-off between information gain and resource efficiency.

2.3.3 ACTION 2: COLLECTING SUPPLEMENTARY RESOURCES

At this stage, it is important to evaluate if the necessary resources are available for conducting the risk assessment and continue with the iterations of the URUQ-MAP. The resources can consist of monitoring or computing equipment, material, skill, operators, time, money, etc. For instance, in order to conduct the risk assessment, it may be required to acquire skills related to risk assessment method or the use or development of hydrological models.

The action linked to collection of supplementary resources is deeply entangled with other actions:

- Under the umbrella of resources falls the set of skills and stakeholders available for applying the URUQ-MAP. Applying step 2 may reveal the need for revising the coordination strategy for implementing the URUQ-MAP. Indeed, it may be concluded that the information required exist but due to a poor communication between utilities, the information cannot be centralized. It may also be identified weaknesses in the coordination strategy, leading to failure in the capability of the stakeholder panel to conduct a holistic assessment. Action to be taken include investing more resources in coordination and stakeholder involvement. In some cases, the poor communication between utilities may be linked to an organisational issue that cannot be resolved under the URUQ-MAP. Resources linked to stakeholders involvement, coordination and organisational structure of the utility in reaction to pollution risk is linked to **action 3** (revision of the system and objectives).
- Designing a monitoring campaign requires specific resources, in terms of equipment, skills, material, time, coordination, and money (Bertrand-Krajewski et al., 2021). Therefore, the planning of action 1 has to be done in concert with **action 2**.

2.3.4 ACTION 3: REVISING THE SYSTEM AND OBJECTIVES

Independently of action 1 and 2, the revision of the system (action 3), consisting in an iteration of Step 0 with a holistic overview of available information, and involvement from experts and stakeholders is a necessity. In particular, as detailed in section 2.3.1, having a holistic overview of the system, boundaries, resources, and information may reveal flaws in the approach. For instance, the level of information available and expected evaluation of the risk may not align with the required objective. A concrete example could be that evaluating the reliability of the modelling results is prohibitive due to the high level of detail, leading to high computational cost. More precisely, if the level of detail of the hydrological model is too high to evaluate its reliability and the accuracy of its prediction, then it might be necessary to re-evaluate the spatial scale considered for the model, or to concentrate efforts on a subpart of the system.

Another reason to revise the system could be that information collected during step 1 hints that major processes are occurring outside the boundary of the system. Therefore, it may be sensible to expand the system. As an example, in the case where available information shows that the area of interest is a minor source of pollution for the receiving water body compared to a neighbouring area, it might be necessary to reconsider the system itself and act on the neighbouring one in order to reduce the impact in the water body in a more efficient way.

Box 8: Key message – Holistic re-evaluation.



HOLISTIC RE-EVALUATION: Can the risk analysis be conducted?

Holistic assessment of the system, its boundaries, scales, objectives, and each available information:

- Can new risks be identified?
- Feasible risk assessment method to:
 - assign likelihood, consequences,
 - quantify uncertainty,
 - develop scenarios.

Action 1: Collecting more information.

- Directly linked to Deliverable 4.1,
- Identification of crucial information,
- Decision making based on resources available.

Action 2: Collecting supplementary resources.

New resources may consist in monitoring or computing equipment, material, skills, time, money, etc.
Such action can be used to remediate poor information flow or stakeholder coordination.

Action 3: Revision of system and objectives.

- Mandatory during the iterative process,
- Aims at revealing and correcting flaws through a collective assessment,
- Avoid waste of resources.

2.4 STEP 3 – RISK ASSESSMENT

To assess and update the risk levels, a methodology for risk assessment is to be applied. To keep this report concise the reader is referred to the *ISO 31000:2018, Risk Management – Guidelines* (2018) section 6.4 – *Risk assessment*, with the Risk analysis and Risk evaluation. Hence, it is advised to produce risk matrices to visualize risk mitigation measures. In the context of risk management applied to the water quality of urban runoff several aspects described below must be listed (see Box 9 at the end of this section for key messages).

2.4.1 RISK MAPS

In the context of risk assessment with a spatial dimension, risk maps must be produced. Those maps enable visualization of pollutants sources and pathways. Depending on the level of information available and the objectives defined, they can be qualitative or quantitative. In particular, those risk maps can be used as support for communication and stakeholder involvement. The detail on how those risk maps should be produced and which level of detail should be considered is context dependent. Based on the work to be produced by the case studies, there will be updated recommendations (in accordance with the principle of continual improvement of

the ISO 31000:2018). They aim to convey information about major pollution sources in the catchment, as well as pollution pathways and release in the recipient water body.

Risks maps refer to maps used in the URUQ-MAP to help with the implementation of the framework. As such, several types of risks maps may be produced:

- **Expert-based mapping of sources of pollutants for prioritization of actions:** Based on the experience in case study 2 in Bologna, we acknowledge that one challenge is the combination of information. Indeed, from a communication point of view, it may be needed to have a map combining different groups of pollutants, and different sources to help to prioritize where to act. It should be noted that such information may come from different sources of information such as measurements in the sewer, land-use maps, maps related to the use of specific construction material, presence of anthropogenic activities. Those sources of information may be associated with different level of detail, and different level of accuracy. While there is no standard procedure for combining those sources of information, we recommend the use of expert and or stakeholder opinion to develop a map for prioritizing actions. It should be noted that such maps may be used as a screening tool, and depending on the level of consensus they rise among experts, supplementary information may be required.
- **Model-based mapping of catchment contribution to overflow load:** In case study 5 a method based on a hydraulic model has been tested for mapping the volume of overflow coming from different subcatchment during the time of overflow. Such an approach is subject to the uncertainty associated with the model, but may help with identifying which subcatchment are considered both as a source of pollutants, and contribute hydraulically to the CSO discharge.

Particular attention should be given to the representation of variability (aleatory uncertainty). For instance, a risk mitigation objective defined by a maximum duration of overflow per year, should include the inter-annual variability both in the formulation of the target and mitigation of the risk. It should therefore also be presented in risk maps. Presenting the natural variability is also necessary to bring the notion of uncertainty in the public debate and interaction with stakeholders (Pappenberger & Beven, 2006).

2.4.2 UNCERTAINTY MAPS

It is strongly advised to produce, along with risk maps, uncertainty maps. Uncertainty maps have to be understood here as epistemic uncertainty maps or “reliability” maps. In that sense, it differs from including the natural variability in the risk maps. Indeed, in the context of pollutants in urban runoff where models do not reproduce the variability of pollutants accurately (Sage et al., 2015), it is important to acknowledge sources of uncertainty and how they impact the risks. The URUQ-MAP aims at evaluating the current level of pollution through urban runoff and mitigating risks. Since the first steps consist in evaluating the level of information and level of knowledge, representing the epistemic uncertainty is crucial. Indeed, some mitigation measures, or actions such as the one described in section 2.3.2 aim at increasing the level of knowledge to reduce uncertainty and therefore should be visualized. Knowing the sources of pollution and their pathway is a major step toward risk mitigations. It should be acknowledged, again, that risk mitigation measures may also aim at uncertainty reduction in the context of a risk assessment.

As mentioned in the previous section about risks maps, the methods, and specificities of uncertainty maps require testing in the different case studies. Within the frame of the StopUP project, and following the two types of risk maps previously introduced, two types of uncertainty maps have been identified:

- **Expert consensus:** the mapping of the source of pollutant based on expert judgement may be used to collect their opinion. In particular, for case study 2 we have grouped experts to realize the same exercise, which allows identifying intragroup consensus (do expert discussing together agree on a risk level), and intergroup consensus (do different groups of experts reach the same conclusion). Those levels of consensus can help to identify a level of uncertainty on the expert assessment.
- **Model-based uncertainty:** In case study 5 the mapping of the contribution of catchments to the overflow can be linked to a level of uncertainty. We recommend using a set of models to account for equifinality. This set of models can consist in model with the same structure but different parametrisation, but it is also recommended to explore the possibility to account for structural uncertainty.

2.4.3 RISK DYNAMICS AND BOUNDARIES

As highlighted in *ISO 31000:2018, Risk Management – Guidelines* (2018), risks are dynamic, and risk management should follow a continual improvement. Indeed, knowledge about specific pollutants (both scientific knowledge, and site-specific information) may increase over years, requiring a re-evaluation of risks events. Similarly, factors affecting the pollutant pathways dynamics may require a re-evaluation of the risks. The characteristics of pollutants themselves may also affect the frequency of evaluation. It means that an event initially classified as unlikely with minor consequences may need to be classified differently due to change in the internal or external context, as well as change in the level of knowledge.

The differentiation between short-term risk and long-term risks, related to pollutant accumulation in receiving water bodies, should also be acknowledged (Brudler et al., 2019). The reflection on the timescales may also be expanded to the spatial scale with respect to the system's boundaries and the intra-system spatial variability. As a result, clear plans of reassessment of risks must be established.

Box 9: Key message – Risk assessment.



RISK ASSESSMENT

Risk maps:

- Communicate risk (likelihood and consequence),
- Useful for stakeholder involvement,
- Visualization of sources and pathways,
- Must account for variability (aleatory uncertainty).

Uncertainty maps:

- May be qualitative,
- Communicates current state of knowledge (epistemic uncertainty),
- Risk reduction measures may aim at uncertainty reduction.

Risk dynamics and boundaries:

- Knowledge increase and risks are dynamic and should be regularly re-assessed,
- Long-term and short-term risks must be considered,
- Barrier related to management plan's timeframe and spatial boundaries.

2.5 STEP 4 – RISK REDUCTION MEASURES

When it is necessary to act on the risk, risk reduction measures may be considered for implementation. This section details specificity within the context of the URUQ-MAP (see Box 10 at the end of this section for key messages), but the reader is referred to the *ISO 31000:2018, Risk Management – Guidelines* (2018) and in particular section 6.5 – Risk treatment for additional information.

2.5.1 COMPARISON OF ALTERNATIVES AND DECISION SUPPORT SYSTEM

The selection of measures in terms of applicable treatment technologies will be accounted for in deliverable 4.4 of the StopUP project “Decision support method for treatment technologies”. However, it should be noticed that risk reduction measures can consist in measures of a different nature as well, such as monitoring solutions or uncertainty management methodologies that may help to characterize risks more accurately.

2.5.2 INTERNAL ASSESSMENT OF RISK REDUCTION MEASURES

The risk reduction measures should go through an assessment similar to the URUQ-MAP itself. It means that they should be defined (in terms of system, boundaries, and objectives) and information available about them should be evaluated (in terms of performance, and applicability to local conditions). The potential measures should then be evaluated. First at a local scale, and then if the measure is considered relevant, at system scale. It means looping to step 3 to evaluate the potential updated risks of the updated system.

For each of the measures that are chosen for implementation, it is necessary to iterate to step 0 and update the system, collect information, etc. In particular, the solutions should be monitored to verify that risk mitigation is achieved. A crucial aspect of this practice goes also through stakeholder involvement. Especially green infrastructure, which is surface infrastructure, may benefit from citizens involvement. The monitoring plan is a crucial aspect of the iteration of the URUQ-MAP.

2.5.3 ACTING ON PROBABILITY, CONSEQUENCE OR UNCERTAINTY

Risk reduction measures most often act on the probability, and/or the consequence associated with a risk event. As an example, one can consider a combined sewer overflowing during rain events in a natural water body where citizens are bathing a health hazard. Possible risk reduction measures may act on the probability associated with the risk event by acting on the system's design to reduce the frequency and magnitude of overflows. Another solution is to act on the consequences of overflows. This could be done by the implementation of treatment technologies to discharge cleaner water for reducing the health consequences of bathing. It could also be achieved by communication campaigns to warn the citizens to not bath after rain events. In the case of a communication campaign, it should be noted that it has an effect on the health dimension of the risk management but not on the environmental dimension. It remains important to visualize in risk matrices for each of the dimensions the effect on probability and consequences of each risk reduction measure.

Another aspect that is especially important in the context of the water quality of urban runoff is that the estimated risks and consequences are highly uncertain. Conversely, the effects of the risk reduction measures are also uncertain. In that sense, it should be acknowledged that the risk management framework is acting on estimated risks, but aims at true real risks in terms of likelihood and consequences: there is a difference between estimations and true values. It should be therefore again emphasized that risk reduction measures can target uncertainty and estimation directly. For instance, considering the annual time of overflow per year in a system, the effect of risk reduction measures for water quality and quantity improvement may be complex to evaluate due to high uncertainty in the urban drainage model. Therefore, a monitoring campaign could be planned to improve the model's reliability and increase the chance of adequately quantifying risk reduction measures.

Box 10: Key message – Risk reduction measures.



RISK REDUCTION MEASURES

Selection of alternatives:

- Decision support system,
- Action on likelihood, consequence, or uncertainty associated with a risk event,
- Internal risk assessment for each alternative.

At risk reduction measure scale:

- Definition,
- Information,
- Evaluation.

At system scale:

- Scenario analysis (loop to Step 3),
- Selection of alternative (loop to step 0),

URUQ-MAP Iterations, monitoring, and community inclusiveness:



- A plan must be established evaluating the effectiveness of implemented solutions,
- Community must be involved for maximizing efficiency and failure detection.

3. FAQ – FREQUENTLY ASKED QUESTIONS, HOW TO APPLY THE URUQ-MAP

The goal of the current section is to increase the applicability of the URUQ-MAP for end users. Figure 3 presents the timeline leading to the development of the current deliverable, which has a focus on the applicability of the URUQ-MAP. The development has been divided into two phases: the development phases – reported in the interim deliverable, and the testing phases – reported in the current and final deliverable.

The development phases, focussed on the alignment between the URUQ-MAP and the ISO 31000:2018. It also, based on feedbacks from stakeholders during the workshop at the General Assembly in Utrecht, helped to identify preliminary key aspects and challenges for the applicability of the URUQ-MAP. Those key aspects were used to help each case study to identify their contribution to the URUQ-MAP through storylines. Indeed, none of the case study can completely apply the URUQ-MAP since it is an iterative plan meant to be applied over several years, from the collection of information and risk evaluation to the evaluation of mitigation measures, their implementation and monitoring.

The testing phase is based on several workshops organized with StopUP partners, with stakeholders, as well as individual interviews to collect useful information for the development of the FAQ.

- The workshop at the General Assembly (GA) in Basel focussed on the key components of the URUQ-MAP: i) The definition of pollution maps, ii) the involvement of stakeholders, iii) the development of scenarios and the use of technical tools, and iv) the impact of tools for managing urban runoff quality. The workshop was organised as world café, a type of workshop meant to facilitate discussions in large groups of stakeholders. Different tables are assigned a topic and a host. The stakeholders, by subgroups, spend time to each table for discussions.
- The stakeholder workshop organized in Trondheim with stakeholders from different departments of the municipality was meant, based on a green infrastructure implementation scenario developed by the NTNU team, to discuss the applicability of the URUQ-MAP from municipality stakeholder perspectives. They helped to identify practical issues with the scenario developed and commented in challenges and opportunities to apply the revised European Wastewater treatment directives.
- The individual interviews were organized toward the end of the StopUP period in June 2025, at a period where the StopUP partners were expected to have sufficient experience and feedback for revising the URUQ-MAP. One interview was organised per Case Study, with one to three interviewees. The goal of the interview was to avoid biases emerging if all case study partners were providing feedback in a group discussion (e.g., biases in mentioning difficulties and challenges). It also helped to direct their feedback on the experience in their case study. The interview was semi guided. A first part of the interview, after summarizing the URUQ-MAP, was directed to make CS partners identify challenges in applying the URUQ-MAP, and question they wish would be answered in D4.5. The 2nd part of the interviews focussed on their specific case studies to identify their added contribution to the URUQ-MAP. A time at the end of the interview was left to let the interviewees add comments that were not mentioned during the interview.
- The workshop at the General Assembly in Trondheim was meant to help to identify with stakeholders how to combine information on pollutant sources. Indeed, the application of the URUQ-MAP require putting knowledge from several stakeholders and expert in common, which means that simple rules for aggregating information may not be relevant. During the workshops, the stakeholders were in groups of three. They either had to fulfil task 1 (combination of different sources of the same pollutant), or task 2 (combining the presence of several pollutants).

PROTECTING THE AQUATIC ENVIRONMENT FROM URBAN RUNOFF POLLUTION

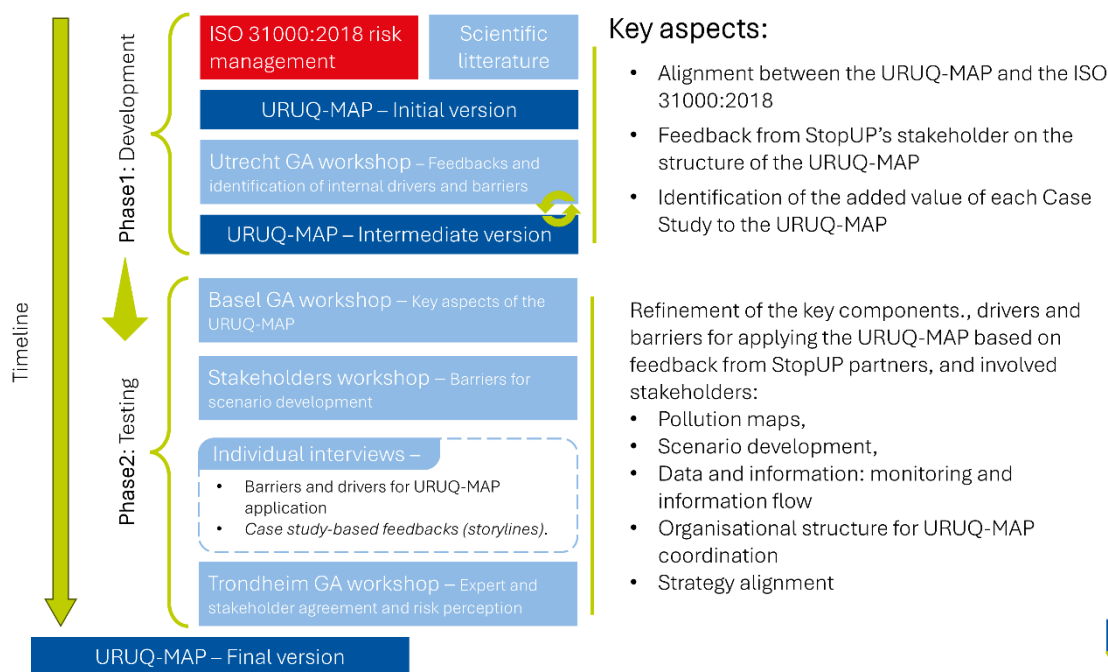


Figure 3: Timeline for the development of the URUQ-MAP with a focus on increased applicability and impact.

Based on the workshops and the interview, we structure the frequently asked question around several key topics:

- **General questions:** questions about the URUQ-MAPs principles and where to start
- **Pollution maps:** This is a key element for decision-makers as it may help to map risk sources, as well as the potential effect of strategies for mitigating risks.
- **Stakeholder involvement:** it is the bottleneck of applying the URUQ-MAP. This section addresses the topics of stakeholder involvement, organisational structure in institutions, and the coordination of a risk management framework.
- **Scenario development:** It is a key concept in the URUQ-MAP. It may be used, at a tactical level, to compare different strategy for risk mitigation, or at an operational level to compare different risk mitigation alternatives.

It should be noted that the question of monitoring and modelling, which are tools for applying the URUQ-MAP are referred to in the general question section as they are linked to the available resources, the information needs, and the uncertainty associated with information.

The answer to some questions may overlap. This redundancy is intentionally and based on the interviews. In order to keep the deliverable concise, only 20 questions were selected, either based on how often they were brought up during the interviews or based on expert opinion on their importance.

3.1 GENERAL QUESTIONS

3.1.1 WHERE TO START?

Developing a plan for managing urban runoff water quality might seem overwhelming. There are a lot of information to collect and put in common. Monitoring requires a lot of resources, and unfortunately it is often not straightforward how to evaluate the impact of urban runoff on receiving water bodies. To start applying the URUQ-MAP, it might be easier to work at a coarse scale and identify the major sources of pollution. For instance, prioritizing the mapping and identification of the worst CSOs, or identifying heavily polluted areas.

We recommend, before planning any action to identify key stakeholders, resources and data available in order to evaluate what the possibilities are for managing water quality. We also recommend identifying ongoing effort in the municipality that may need to be aligned with the implementation of the URUQ-MAP (e.g., development of specific areas, climate adaptation effort, Zero Pollution cities, etc.).

3.1.2 HOW TO SET ACHIEVABLE OBJECTIVE AND REACH THEM?

The problem of managing urban runoff quality is definitely complex. It came out of the interviews and workshops with stakeholders, that there is a mismatch between some technical solutions to manage stormwater at city scale and the actual feasibility of it. Indeed, before reaching the technical barriers, municipalities have to deal with some more structural barriers. For instance, their organisational structure may not be fit to apply some technical solutions. Another example is limited available resources. Some municipalities have reported that some technical guidelines or recommendation are simply too complex for their context. On the other hand, some technical guidelines may be designed to comply with regulations but not guaranty a low impact on water bodies.

For that reason, the URUQ-MAP is a risk management framework. It means that it requires municipalities to formulate their objectives, with respect to the feasibility and the regulations. We put a strong focus on information, uncertainty and adaptability, because in a context where there is a lot of unknown and where we expect the context to evolve, we need to make sure to plan for the long-term.

In a municipality where close to no data would be available, we recommend collecting information at the larger scale (strategic level), by evaluating the status of the main overflow infrastructures in order to prioritize. Once critical subcatchment have been identified, they have to be put in perspective with the municipality's master plan to identify opportunities for reaching the targets set (tactical level) and identifying mitigation measures to be implemented and monitored (operational level).

3.1.3 WHAT ARE THE MAIN BARRIERS IN APPLYING THE URUQ-MAP?

In deliverable 4.1 regarding monitoring campaigns, and in deliverable 2.5 regarding modelling tools for stormwater quantity and quality, major technical barriers have been identified. In deliverable D4.1 we highlight the complexity of the task to monitor urban runoff quality (because of the number of substances to be followed as well as the difficulty to measure their impact). In deliverable D2.5 we highlight the limitations of water quality models as well as the difficulty to ensure the development of models aligned with their use. Those limitations are directly connected to the application of the URUQ-MAP and are considered as technical barriers, even though solution to

overcome those barriers may not be technical (e.g., there is a limit to the information that can be collected, and by involving stakeholders accordingly it is possible to prioritize data collection to design a monitoring campaign).

When it comes to the URUQ-MAP itself, it came out of the workshops and the interviews that the main barrier to overcome may be non-technical:

- When it comes to collecting information about the system, all interviewees mentioned difficult data or information flows between different utilities and or stakeholders involved. Difficult data flow encompasses, difficulty to obtain existing data and/or poor documentation (metadata) and quality of data.
- It came out from the workshops, as well as from existing literature, a challenge linked to governance. Governance challenges include the question of public and private property (for implementing solutions), and the question of ownership of infrastructure and water. The responsibility for the implementation and maintenance of infrastructure may lead to managerial issues.

3.1.4 HOW TO OVERCOME THOSE BARRIERS?

The technical barrier linked to the complexity of stormwater monitoring can be tackled by prioritizing critical information based on available resources and system knowledge (see next question or deliverable D4.1). The technical barrier linked to models' limitations can be accounted for by ensuring good and transparent modelling practice in order to avoid misuse of models.

Regarding non-technical barriers, solutions involve a diagnosis of the different utilities involved to identify how to make a more robust organisation. It should be acknowledged, that utilities have to adapt their structure to the current challenges. Municipalities must use the citizens support to drive those changes. Many European cities facing heatwaves in the summer manage to implement solutions that put in common information from several services under the umbrella of climate change adaptation. The environmental protection of receiving water bodies can be similar. We cannot wait for visible damage on the environment. Urban water system has long been buried and become visible upon failure. In particular, citizens are often unaware of issues such as CSO. Bringing awareness on that topic may be seen as controversial, since citizens may consider that the utility does not fulfil their mission. On the other hand, it is needed that citizen become aware of these challenges in managing wastewater in order to be a driving force for change and improvement of the systems.

3.1.5 HOW MUCH INFORMATION IS “ENOUGH”?

Information is the cornerstone of risk management, in particular in the URUQ-MAP. In order to apply the URUQ-MAP, data from different utilities have to be collected. Collecting this data, and extracting relevant information out of it, requires resources. Available information may be limited due to lack of coordination, lack of skills, lack of material, and/or lack of money. This lack of resources may be manifested in poor data flow (between and within utilities), poor documentation of data (the data do not follow the FAIR principles and are not usable), poor prioritization of data collection (critical data have not been collected while data with limited use have been collected), and finally lack of data in general (the amount of data is not sufficient for the objective of the plan).

The challenges in collecting data may lead to insufficient information available. The information may be insufficient in amount, resolution, and reliability. This aspect is treated in step 2 of the URUQ-MAP. In case of insufficient information, the user must consider different options which are collecting more information, collecting more resources and revising the plan objectives. The definition of resources including the organisational structure, it should be mentioned that collecting more resources, may include a modification of the data flow, to ensure the accessibility of data.

3.1.6 WHY ACCOUNTING FOR UNCERTAINTIES?

Uncertainties are sometimes considered difficult to quantify and to communicate. However, in the context of the application of the URUQ-MAP we recommend accounting carefully for uncertainties as failing to account for them may result in a waste of time a resource. For instance, planning a solution, such as separating sewers, based on a poorly calibrated model may result in applying an insufficient solution to meet requirements. It is also possible that the solution designed ends up oversized.

3.2 WHAT IS A POLLUTION MAP AND HOW TO DEVELOP IT?

3.2.1 WHAT IS A POLLUTION MAP?

Applying the URUQ-MAP involve the production of pollution maps. A pollution map can take different shapes depending on the context of the application of the URUQ-MAP. Through a workshop, our group of experts identified several key aspects.

Pollution maps in the URUQ-MAP correspond to a set of tools for visualizing spatial information for supporting risk management. Our group of experts identified that several types of pollution maps may be needed. Those different types of maps may be identified to support different levels of action (strategic, tactical and operational). As such, it should allow presenting to stakeholders an overall status at city scale to help prioritizing critical area (pollution map as support for strategic management). In area that are prioritized for intervention, it should help identify sources of pollutants, in order to select a relevant mitigation measure (pollution maps as support for identifying implementation pathways and scenario development).

Pollution maps as support for strategic management may contain the main overflow location, as well as their status (monitored, unmonitored, annual overflow duration, etc.). It also may include major pollution sources, in particular if there is a large discrepancy within the city. The goal of such a map is to provide a synthetic indicator to evaluate the status of the city and help to prioritize areas in the city for action. Such a map should be a tool for aligning the different goals of the municipality. For instance, an area of the city that is under development despite not critical may be targeted as an opportunity to share costs.

Pollution maps as a support for scenario development may map the sources of pollution in order to perform targeted interventions. It should be noted that the development of such pollution sources maps, based on landuse for instance, remains complex and subject to uncertainty. Indeed, it requires merging different types of information and is bound to our understanding of the relationship between landuses, pollution sources, and pollutant transport. Research has shown that pollution sampled in gully pots cannot be solely explained by landuse (Wei et al., 2023). The use of such pollution maps can help with the design of scenarios and the selection of an alternative relevant for the situation. A catchment with diffuse sources of pollution may favour the use of decentralized solution, while a catchment with disparities in pollution sources level may rely on

targeted interventions. Through the development of scenarios and the use of model, alternative pollution maps may be used to compare the estimated efficiency of the implementation scenario.

3.2.1 HOW TO DEVELOP A POLLUTION MAP?

The development of pollution maps is based on four pillars:

- **Information collection:** those maps require an efficient data flow between utilities to collect all the necessary information for the development of the maps. Not all information has the same value: it is important to prioritize (e.g., monitoring the flow in overflow structure or retention tanks may be easier to collect and more insightful than measuring pollutants concentration from the subcatchments).
- **Tools and scenario development:** Pollution maps representing the projected effect of a scenario can be generated by the use of models. It is then critical to be aware what the model can do and what it cannot. For instance, the model may not be reliable enough to include pollutant transport dynamics. In that case, the model will focus on the hydrological aspects, and external knowledge will be combined to the modelling results to discuss the scenario performance.
- **Stakeholders and expert involvement:** In many cases, monitoring data alone or tools cannot help to estimate risks level. A panel of experts and stakeholders can help to combine different sources of information in order to prioritize areas based on risk acceptability.
- **Communication and uncertainty:** Pollution maps are used to plan the future under deep uncertainty. As such, they should be visual and simple and allow visualizing more details if required. Communicating the uncertainty of information is critical to help decision-makers planning a strategy (e.g., to avoid black swans).

3.2.2 HOW TO COMBINE INFORMATION FROM DIFFERENT SOURCES IN A POLLUTION MAP?

Combining information for the creation of a pollution map requires putting together information and knowledge from different experts and stakeholders. It is also related to the perception of risk. In order to identify the adequate solution, we tested a solution by organising a workshop (Figure 4). We asked experts to combine information in order to identify the thinking process for prioritizing subcatchments in terms of presence of pollutant based on: i) combining different sources of the same pollutant in a subcatchment, and ii) prioritizing catchment with different level for several pollutants. Our findings suggest that the task remain complex for experts, they often require supplementary information. Most groups of experts reached a consensus within their group, but different groups used different strategies. It suggests that there is no consensus in how to combine information. Based on that, we suggest using that methods to identify if there are within a catchment area of high priority (which reach a consensus between groups) or if there are areas with too limited information. It should be noted that difficulty in prioritizing between subcatchment may also suggest that a strategy should treat the entire catchment instead of prioritizing a specific area.

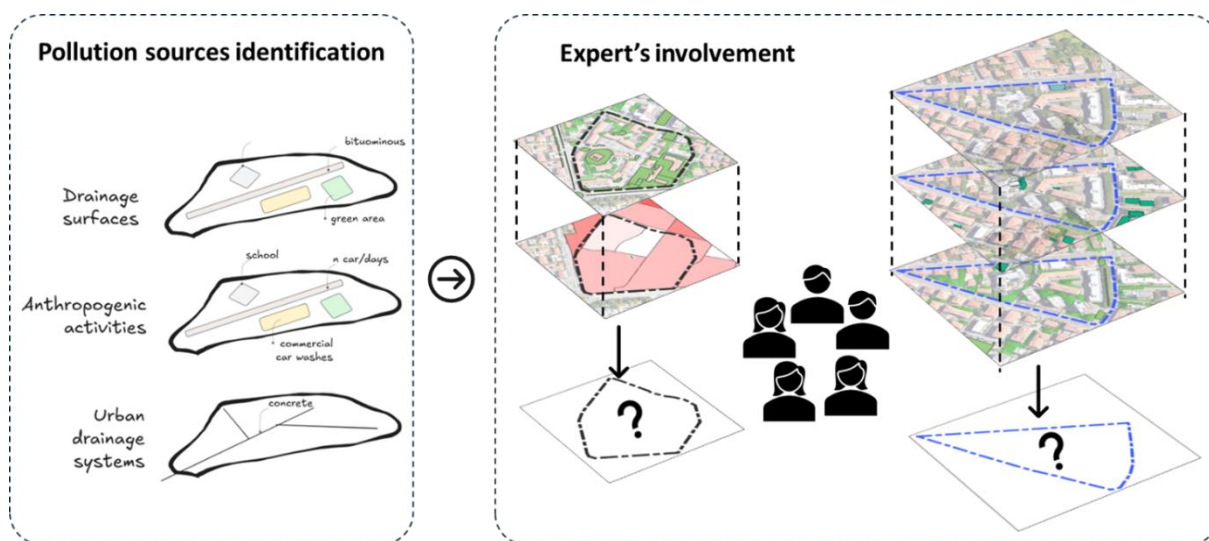


Figure 4: Example of framework for developing pollution maps for prioritizing actions in subcatchments based on expert opinion. This example was used during a workshop in the GA meeting in Trondheim with a link to case study 2.

3.2.3 HOW TO CONVEY UNCERTAINTIES IN A POLLUTION MAP?

Uncertainties are often considered as difficult to convey (van der Bles et al., 2019). In the context of urban runoff quality, a pollution map is subject to large sources of uncertainty, it is important to communicate those sources of uncertainty. Conveying uncertainty on pollution maps is important to prioritize monitoring for collecting critical information.

We recommend associating the prioritization of information collection based on the risk associated to the uncertainty. It means that large uncertainty on a component of the system that do not influence the risk level is not to be prioritized. Similarly, conveying uncertainty must be aligned with the management strategy. For instance, it was reported in case study 5 as well as case study 3 that the main strategy for pollution control used is volume control:

- In case study 3 the different catchments linked to a retention tanks are considered as mostly similar. While uncertainty may subsist in the quality of urban runoff, efforts are currently put in controlling the volume discharged by those tanks. Reducing uncertainty associated with operation of the tank may have a bigger effect than reducing the uncertainty associated with the urban runoff quality: efforts must be put in priority on sensitive parameters.
- In case study 5, the strategy for controlling urban runoff quality consists in limiting the number of hours of overflow per year. The difference in pollution sources associated to each subcatchment is uncertain, but as the catchment is relatively homogenous (mostly residential, and dense urban city centre) it was deemed more relevant to quantify uncertainty in the contribution of individual subcatchment to the overflow. Figure 5 shows a pollution map associated to case study 5. The darkest catchments are the ones contributing the most to the overflow, assuming that the water quality from those catchments is relatively similar. The darkest catchment is highly impervious and is placed in the catchment in such a way that the model predicts a higher hydrological contribution

to the overflow than other subcatchments. Uncertainty is then conveyed by showing if different models predict a similar map (map of variability using a set of models).

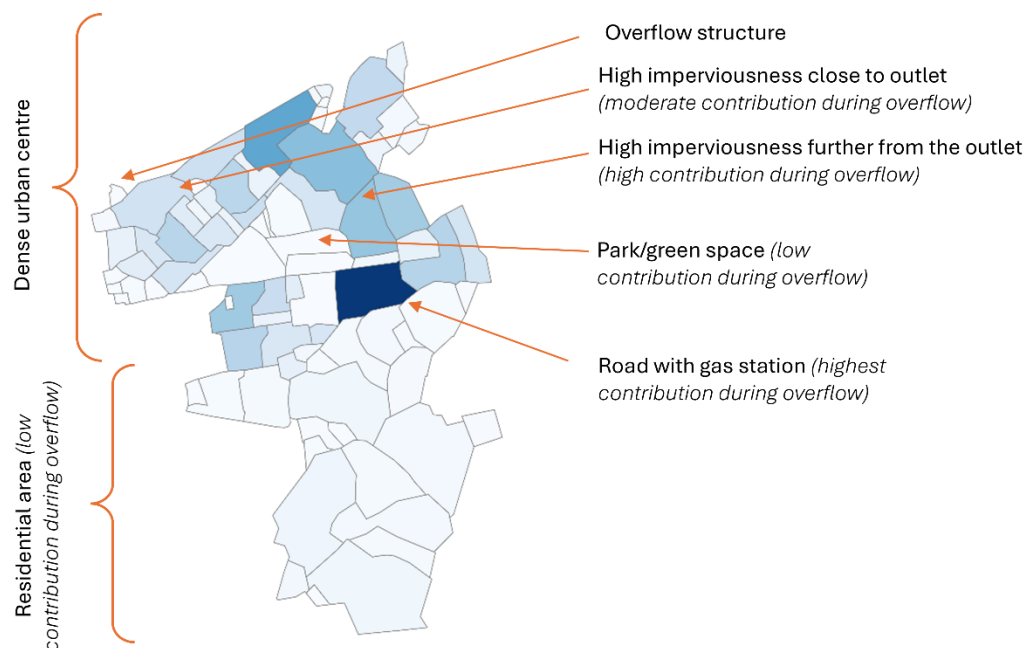


Figure 5: Pollution map for case study 5. The shades of blue from clear to dark indicate low to high contribution to the overflow. The map is based on water quantity simulation over a period of 5 years. The results are influenced by the type of events in Trondheim that tend to be long with low intensity, and the parametrization of the model. A different climate and model parameterization would have led to different results (e.g., a climate with more intense rain could lead to higher contribution from the subcatchment close to the outlet).

3.3 HOW TO COORDINATE THE URUQ-MAP AND ENSURE SUCCESSFUL STAKEHOLDER INVOLVEMENT

3.3.1 WHO IS GOING TO BE RESPONSIBLE FOR APPLYING AND COORDINATING THE URUQ-MAP?

While the European regulation points at the municipal level for applying a plan such as the URUQ-MAP, it remains unclear who will coordinate to apply the plans. In that sense, there may be a difference between the responsible utility and the utility developing the plans. Through the series of interviews, we identified the diversity of organisations in the different countries. For instance, in Bologna private companies – with a public participation – are hired for a period of 12 to 30 years, after which another public call opens. The structure of organisations needs to be individually assessed to identify conflict with the application and the development of a long-term plan such as the URUQ-MAP. Similarly, as it was identified in Aachen, that it is likely that consulting companies are hired for coordinating the development of such a plan. Those practices, while common, need to be integrated in the coordination aspect of the plan to make sure to avoid knowledge loss over the years, in case of change in stakeholders.

3.3.2 WHY TO ESTABLISH AN INTERDISCIPLINARY PANEL OF STAKEHOLDERS AND WHO TO INCLUDE?

The management of urban pollution and its transport in urban runoff is deeply entangled with every infrastructure and anthropogenic activities in cities. It means that identifying pollution sources as well as pathways and impact require the collaboration of several services within and between utilities. Likewise, to treat the risk identified, it is crucial to achieve synergy between the different goals and strategy of the municipality (e.g., toward biodiversity protection, social equity, mobility change, flood prevention, etc.). Such synergies are complex and need a strong coordination to happen. Achieving it successfully may require organisational changes.

In order to apply the URUQ-MAP, it is necessary to involve:

- Stakeholders related to activities generating pollution sources.
- Stakeholders related to the data management, ensuring the link between different institutions collecting data.
- Stakeholder related to the strategic city planning and zoning, to ensure that the URUQ-MAP is integrated in the municipality's general strategy.
- Stakeholders involved in the operation of infrastructure, to ensure that their feedback help with the selection of mitigation measures as well as their maintenance and monitoring.

3.3.3 HOW TO INVOLVE STAKEHOLDERS?

The involvement of stakeholders on such multidisciplinary topics, is not automatic. For instance, for the case of the implementation of Green Infrastructures which are multifunctional by nature, it has been shown in several cities that the organisational structure of the municipality was not suitable for coordinated actions. It means there must be dedicated personnel for coordinating actions and the development of the URUQ-MAP (it may be the stakeholder panel, or personnel supporting the stakeholder panel in its task) for involving the other stakeholders. Those actions may require a revision of the organisational structure of the municipality. Involving stakeholders also requires their identification, which is a challenge in a growingly multidisciplinary field. In case study 6, participatory mapping, a process where stakeholders help to further identify other stakeholders, has been used as a solution for that aspect.

Solutions for involving stakeholders are multiple and must target different type of stakeholder. The system's operators, often on the field, must be involved, for instance during technical visits to learn from their experience. The organisation of workshops (e.g., for the co-development of pollution maps Figure 4) can help stakeholders from multiple horizons to identify synergies and strategies. Political interaction is also essential. It can be done by regular presentations and communications. It is important to understand the drivers and other priorities of those stakeholders (e.g., cost, carbon footprint, flood damages, etc.) in order to trigger involvement and help them to align multiple goals. Such interactions should also use energy or inertia from recent events (e.g., the recent flood events in Bologna, the quality of bathing water in Trondheim, etc.), as well as citizen involvement (e.g., environment interest groups). It is important to understand stakeholder involvement as a long-term strategy. Using specific events, it is possible to trigger political interest, but without ensuring long-term engagement, it may not be useful. The strategy should be embedded in the local culture and be pedagogical to involve citizens in the long-term.

3.3.4 WHAT ARE DRIVERS AND BARRIERS FOR STAKEHOLDER INVOLVEMENT?

Among the drivers and barriers identified during our workshops, we identified:

- **Awareness:** the question of urban runoff water quality is not always well-known, which lead to an issue in involving stakeholders. Such a barrier may be an opportunity to organise information campaigns, to involve citizens.
- **Innovation landscape:** the options available for municipalities are not always well known. Similarly, known options tend to be favoured, which lead to a continuity bias (tendency to favour a scenario extrapolated from the current status).
- **Legal obligations:** it may be both a driver and a barrier. Indeed, while regulations will force stakeholders to adopt measures, the way the regulations are formulated can have unforeseen effects. They may not go toward the goal of improving water quality, as it may mobilize extensive resources without achieving a set goal.
- **Inertia and turnover rate:** as mentioned earlier, the question of urban runoff water quality may require bringing awareness regularly as there might be a high turnover rate in stakeholders. On the opposite, some stakeholders may prioritize outdated methods and may be slow to accept new solutions.

3.3.5 HOW TO OVERCOME THOSE BARRIERS AND UTILIZE THOSE DRIVERS?

Several of the barriers and drivers mentioned are linked to awareness. In order to overcome those barriers, we suggest relying on communication campaigns to bring awareness among stakeholders and increase the citizen participation. The local context, culture, and democracy influences the willingness of citizens to engage in the topic. In particular, the impact on the local area may generate interest for the citizens to get involved. For instance, citizens complained about smells and the presence of mosquitoes in the receiving water body in CS6. The impact of the degradation of the environment can be a driver for action for citizens, leading to a political interest. Another example is the water quality in the harbour nearby the CS5 in a place where some citizens swim. A recent news article may be utilized as a driver to bring citizen awareness.

While knowledge about the innovation landscape has been mentioned as a barrier, it should be noted that when new regulations are coming, stakeholders may be more interested to learn about alternatives. When such opportunity comes, the knowledge about an implemented solution may play a role in the decision (e.g., if it has been implemented in a nearby city, or a contractor has experience implementing it).

Large meetings with very diverse groups are not always very productive, it may be more relevant to target more regular meetings with a smaller number of stakeholders. It is important to understand the individual concerns/barriers of stakeholders to overcome those barriers. Those concerns are not always aligned together. The decision-makers at the municipality may be concerned by cost, while the operator may first think about who and how they are going to maintain and operate the solution.

3.4 HOW TO DEVELOP SCENARIOS FOR MITIGATING STORMWATER RISK?

3.4.1 HOW TO DEVELOP SCENARIOS?

The development of scenarios starts from the current context that may be informed by a pollution map as well as data and or estimation of annual loads, and ends at a set target or objective. In the context of the URUQ-MAP the type of scenario that aims to be developed are scenarios to identify a pathway from the current condition toward a set target. The development is based on the strategy set by the municipality on different topics. It is iteratively refined through stakeholder involvement and uses models, data, and tools to visualize the effect of the scenario. There is a need to translate discussions with stakeholders into hypotheses that can be implemented in the model. There is also a need to develop several scenarios for comparability.

For instance, in case study 5 we developed a scenario based on the use of Bioretention cells for reducing annual overflow duration. The scenario is based on an alignment between the municipality's goal to reduce traffic in the area. In practice, the municipality aims at reducing the car traffic and plan to reduce the number of parking place available. Our scenario utilizes the place available for implementing bioretention cells. It has been modelled using a hydrodynamic model, and we presented a comparison of a baseline scenario (business as usual), of a green space retrofit scenario (low impact), and the scenario showing a synergy between the mobility plan and the urban runoff quality target. The scenarios were used for discussion in a workshop with stakeholder in order to identify the limitations and the potential of the scenarios. For instance, unforeseen limitations linked to the use of private space for managing stormwater were identified. Similarly, difficulties in identifying which department at the municipality may be in charge of maintenance may limit the efficiency of the scenario. Such feedback was initially not considered in the scenario and are outside the scope of the model's capabilities. It shows the need to include iteration when developing a scenario. It also shows that the biggest limitations to the implementation of a scenario may not be included in the model used as support for scenario development. A scenario must not be confused with the modelling results following a scenario.

3.4.2 HOW DOES THE TOOLS AVAILABLE TO SUPPORT THE SCENARIO DEVELOPMENT (E.G., NUMERICAL MODELS) INFLUENCE THE POTENTIAL FOR SCENARIO DEVELOPMENT?

As mentioned in the previous question, the tools available for supporting the development of scenarios cannot include all the aspects of the scenario. The user mustn't confuse the scenario with its modelled results.

The tools available as well as the data available may constrain the development of scenarios. If it is not possible to model a solution, then it may not be feasible to model the impact of its implementation. In that case a compromise must be reached, it may be accepted that some aspects of the solution will not be accurately modelled. For instance, in case study 5 it was acknowledged that the filtration function of the bioretention cells could not be modelled accurately by the SWMM model due to both data and conceptual limitations. In that case, knowledge about the behaviour of the solutions will be used when analysing the model results. It is possible in that case, as the main function modelled is the hydraulic function, resulting in reduced overflow duration.

The tools may also be developed for the purpose of developing a scenario. For instance, in case study 1, a model is developed for estimating the inflow into the retention soil filter. Since the retention soil filter is a solution located downstream the sewer, a model with a lower spatial

resolution, or a data driven model would have been sufficient. However, it was chosen to develop a tool that may exceed the requirements of the current scenario as the scenario may be adapted in the future. Indeed, while the current scenario considers an end of pipe solution, it may be considered to put intermediate solutions further upstream in the catchment. Those solutions would require a more detailed model.

We recommend the development of explanatory models, i.e., models that represent the physical processes and well as the system (e.g., a digital twin) instead of a purely data driven approach. Indeed, those models may be more challenging to develop, but they are more adaptable, and may meet the changing requirements of the municipality. It does not mean that no data-driven or machine learning based approach can be used, but that the focus should be put on a model designed to handle modification of the system. Changing conditions in the system include climate, traffic load, pollutant sources, implementation of green infrastructure, and land use change.

3.4.3 HOW TO INCLUDE QUALITATIVE INPUTS, PART ON THE SCENARIO DEVELOPMENT, INTO MODELS?

Models and tools are limited in terms of capability. The task of developing a scenario together with a model as a support for discussion involves translating some assumptions into modelling choices. It may happen that some assumptions cannot be included in the model, in that case it should be included in the discussion about the models result in a form of supplementary uncertainty. For instance, in the scenario developed in case study 5, the impact of traffic reduction on pollution loads was not included since it was considered not doable to include it in the model. Instead, it was included a qualitative factor together with the models' results. It means that the scenario including a change in the mobility plan in the catchment both reduce overflow duration (modelled) and the pollutant loads (qualitative assessment).

3.4.4 WHAT ARE BLACK SWAN EVENTS AND CONTINUITY BIAS, AND WHY WE SHOULD CARE ABOUT THEM?

Black swan events are unforeseen future with possibly dramatic consequence. It is unforeseen in the sense that it is not included in the development of scenarios. Dealing with black swans require either to develop a robust scenario or an adaptable scenario. A robust scenario is a scenario that may hold toward a large range of future (i.e., even under a black swan event). An adaptable scenario is a scenario that can be modified or altered to adapt to a new situation (e.g., presence of a black swan). In both cases, while it is acknowledged that by nature there may always remain black swans (in the case of a truly unpredictable event), it is possible to avoid some black swans by accounting for uncertainty and making sure to involve stakeholders.

For instance, in the scenario developed in case study 5 with the implementation of bioretention cell, failing to consider maintenance issues could result in a black swan if all the measures end up malfunctioning due to poor maintenance.

It should be noted that black swan events can also occur in the case of continuity bias. Continuity bias is the tendency to favour scenarios that unfold naturally from the current situation. For instance, in case study 5, favouring a separation of stormwater and wastewater sewers could be associated with several black swans. One could be that untreated stormwater may lead to the release of pollutants in the receiving water body. Another one could be due to failure in considering

infiltration inflow in the wastewater pipes that may be undersized after separation, which could lead to flooding of wastewater. A last possible consequence is that the separated stormwater network would fail to prevent flooding due to change in weather patterns.

Continuity bias is linked to the barrier of awareness of the innovation landscape. The use of the current solution to stormwater and wastewater management may not be the ideal solution, History has showed several changes of paradigm in stormwater management (e.g., from no sewer to combined sewer, from combined sewer to separate sewer, the use of large retention basin, the implementation of green infrastructure, etc.). While it is acknowledged that known solution may be considered as more efficient in the short term as the municipalities may be used to them and more confident about them. It is necessary to help municipalities consider alternatives. Those alternatives may be linked to the implementation of demonstration sites, where the results also help stakeholders to consider those solutions.

Box 11: Key message – Frequently asked questions.



FREQUENTLY ASKED QUESTIONS

- Improving the organisational structure within and between utilities is the **bottleneck** of the URUQ-MAP application
- Improving data flow between utilities for extracting information,
- Coordination of risk management for improving involvement, management and maintenance,
- Raising awareness about challenges and solutions,
- Prioritization of actions (from strategic scale to operational scale).
- Models are a support for discussing scenarios, they do not include all of the scenario's assumptions.

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APPENDIX A – ALIGNMENT BETWEEN THE URUQ-MAP AND THE ISO 31000:2018

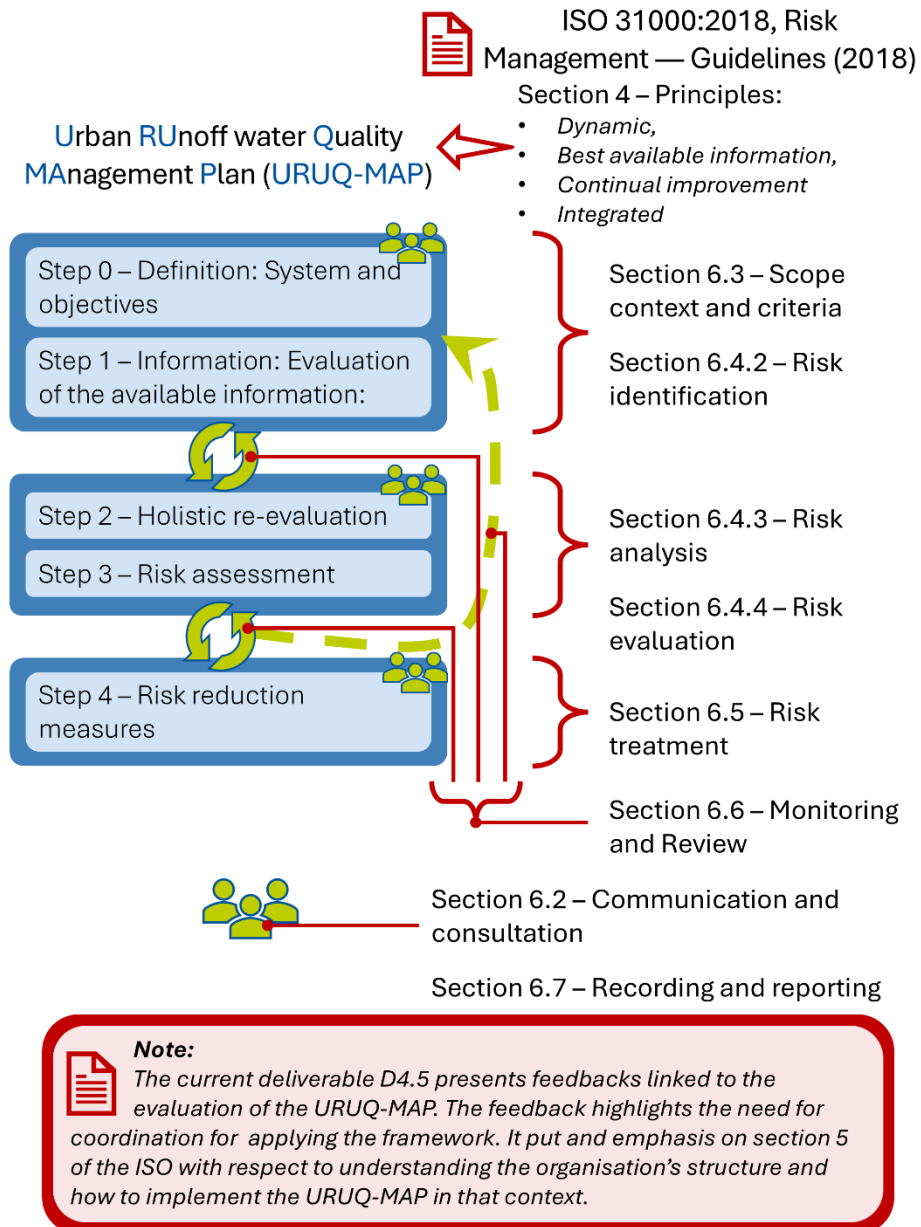


Figure 6: Alignment between the URUQ-MAP and the ISO 31000:2018.

APPENDIX B – KEY MESSAGE PER CASE STUDY

In the following section, a key message per case study was selected based on their experience in applying the URUQ-MAP. This short summary per case study refers to other deliverables for more insights. The key message is selected by the interviewer for information purpose for the reader based on the individual interview and on the overview with other case studies. It may not be considered as the key message by the interviewee.

4.1 CASE STUDY I – RETENTION SOIL FILTERS IN URBAN CATCHMENTS – AACHEN (DE)



MAIN STORYLINE WITHIN THE URUQ-MAP

In Case Study 1 (CS1), the risk mitigation measure studied is a Retention-Soil-Filter (RSF) operated by the local Water Board (WVER). Since the RSF was already planned and built before StopUP started, the focus was on monitoring the RSF's effectiveness in risk reduction and disseminating the results to the Stakeholder panel.



KEY MESSAGE AND LEARNING

- The RSF is working as intended, heavily reducing the pollution load of CSOs
- Every technology has its limit, and holistic approaches need to be considered
- Indirect measures delaying the runoff concentration also aid in risk reduction

APPLICATION OF THE URUQ-MAP

Step 0: Definition: system and objective

In CS1, the objective was to monitor the RSF Aachen Soers, which is operated by the local water board (Wasserverband Eifel-Rur, abbreviated as WVER). The RSF is located in the northern part of Aachen at the city's lowest elevation, directly beside the wastewater treatment plant (WWTP) Aachen Soers, which the WVER also operates. The RSF was planned and built to mitigate the immense risk of combined sewer overflows from the WWTP inlet into the small tributary river Wurm, stemming from its hydraulic and pollution loads. The initial goal was to minimize the spills to one event per year, coming from 30 – 60 events causing a CSO annually. Nevertheless, although the RSF is now the largest of its kind in Germany, it remains insufficient compared to the actual size required, as the available area beside the WWTP inlet was insufficient compared to its initially calculated required size. Therefore, the RSF is expected to spill ten times a year on average. However, the total spill volume is unknown. As the spill volume and concentration of pollution define the risk associated with the CSO, ISA RWTH monitored the start-up phase and several events mitigated by the RSF to evaluate its performance, as well as the risk reduction caused. Furthermore, the gathered information was disseminated to the stakeholder panel and on several occasions to demonstrate the usefulness of these systems and their application beyond North Rhine-Westphalia (NRW), which is known for its already frequent implementation of these systems.

Step 1 – Information: evaluation of the available information

As the CS1 and StopUP partner ATD GmbH planned the RSF for the WVER, in-depth knowledge of almost every aspect was available, and stakeholders were already involved from the very beginning of StopUP. In the planning of ATD, the greatest possible retention volume of the RSF, completely covering the only available empty plain besides the WWTP, was realised, thereby excluding the realisation of any additional end-of-pipe solution for a possible optimisation of the system. However, this end-of-pipe solution had yet to be modelled, particularly in relation to climate change scenarios. To cope with this issue, the Regionetz GmbH (100% linked to the City of Aachen) supplied the ISA RWTH with sewage system data. Combined with climate change scenarios and additional data, a model was established to investigate the impact of climate change and changing precipitation patterns on the RSF.

Step 2: Holistic re-assessment

Thus, the risk associated with climate change for the Wurm could be approximated, a factor not included in the planning phase. Since additional end-of-pipe solutions can be neglected, a holistic evaluation of the required retention volume throughout the sewage network can be derived, and stakeholders, namely the City of Aachen and Regionetz GmbH, could be included in these investigations.

Step 3: Risk evaluation

Yet, the focus of the Case Study was on the monitoring, which was also planned to serve as a validation option for the numerical model. The monitoring results indicate that the RSF is functioning as intended, and the pollution reduction is increasing with operational time (Figure 7). Hence, the predominant risk of direct CSO discharges once the retention basins are filled was drastically reduced. Therefore, the remaining risk is mainly caused by the residual concentration of pollutants and hydraulic load of the RSF effluent, as well as, especially, by CSO events that exceed the RSF's capacity.

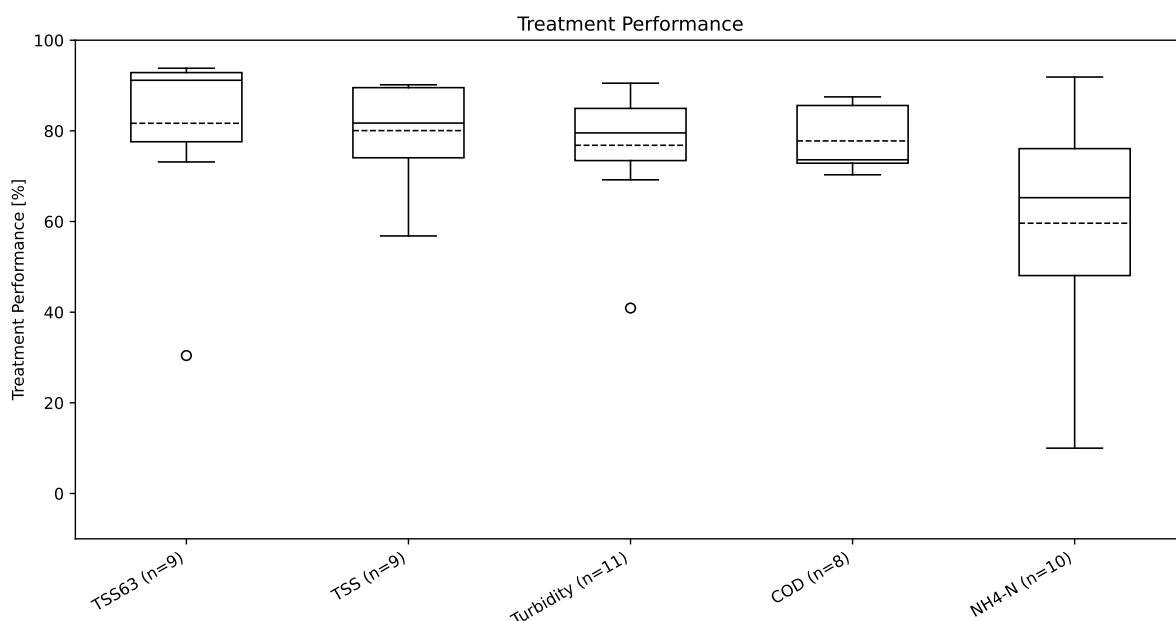


Figure 7: Treatment Performance of the RSF AC Soers for Standard Parameters. Further Data in D3.4.

Because evaluating the remaining risk of the CSO exceeding the RSF capacity was not initially planned in StopUP, it remains a difficult task, as the WVER does not robustly measure the volume discharged into the Wurm. This can therefore only be approximated roughly. Although the concentration of pollutants is reducing with increasing precipitation intensity, the overall mass of pollutants entering the river is still significant. Additionally, the hydraulic load in itself can be a challenge for the receiving river.

Step 4 Risk reduction measures

As increasing the retention volume of the RSF is not possible, ISA RWTH developed an idea for a new technology that aimed to increase the throttled effluent of the RSF while maintaining the removal efficiency. The so-called RSF-compact utilises flocculants to enhance the filtration efficiency of the RSF, thereby allowing for an increase in throughput. As this technology is currently being investigated, it remains to be seen if it will be applicable. However, every technical solution has its limits, and optimising a single measure can only be part of a holistic concept. Generally, the runoff concentration time in urban areas must be reduced to mitigate stress on the sewage network by increasing local storage, which can be integrated into blue-green infrastructures, such as small RSFs beside roads and impervious areas. These measures would also mitigate additional impacts, such as thermal stress, which are likely to arise from climate change in the upcoming decades.

All these measures should be investigated and planned to employ the URUQ-MAP, ensuring a holistic approach that encompasses all relevant aspects and stakeholders.

KEY FOCUS AND STORYLINE

In Case Study 1, ISA RWTH monitored and modelled the RSF AC Soers to a) gather valuable information on its performance, which is barely available in literature, b) evaluating the risk it is reducing, and c) include the data into a numerical model which enables a climate change scenario base extrapolation of the RSF performance and time wise risk mitigation development.

These results were disseminated to the local stakeholders and experts in two RSF workshops as well as several smaller meetings. We further aim to inform local authorities and responsible institutions that the RSF and RSFs in general are a significant factor in reducing the risk of events that lead to CSOs. Additionally, further, smaller, and indirect measures should be considered, thus culminating in a holistic risk reduction concept stemming from StopUP in Aachen as the nucleus for out-of-the-box solutions.

Further details concerning this case study can be found in Deliverable D3.4 “Treatment technology assessment for the CSO technology treatment options”.

4.2 CASE STUDY 2 – SEWER OF BOLOGNA (ITALY), AND PILOT PLANT
INSTALLED AT THE BOLOGNA WWTP CSO – BOLOGNAT (IT)

MAIN STORYLINE WITHIN THE URUQ-MAP

In Case Study 2, an integrated approach was developed for runoff and pollution management through the creation of pollution maps based on pollutant source proxies derived from heterogeneous datasets. A multidisciplinary group of experts collaborated to combine information and prioritize the most critical subcatchments. The analysis revealed that a source-based approach alone is not sufficient and must be integrated with targeted monitoring campaigns.



KEY MESSAGE AND LEARNING

- Need for synergies between stakeholders for a holistic view of the problem.
- Pollution maps alone are not enough, targeted monitoring is essential to validate findings and prioritize interventions effectively.

APPLICATION OF THE URUQ-MAP

Step 0: Definition: system and objective

The modelling exercise set-up in Deliverable 2.5 and developed in Deliverable 2.7 revealed that the management of runoff is a crucial challenge in Bologna municipality: the activation of numerous overflows impacts the urban streams. However, the results also showed that, on an annual scale, a limited number of CSOs are responsible for more than 50% of the total TSS load discharged by all 123 CSOs. This finding suggests that targeted interventions on the catchments connected to the highest-contributing CSOs could significantly mitigate pollutant loads. Ideally, we can then shift from a broader, city-wide perspective to a more localized, small-scale approach for runoff and pollution management. The application of the URUQ-MAP has as objective the evaluation of which sites should be prioritized for actions in order to mitigate stormwater pollution most effectively.

A small neighbourhood of Bologna municipality was selected, for research purposes, for the application of the framework. The catchment, of approximately 50 ha, is a densely urbanized residential area with about 11,000 inhabitants (ISTAT, 2021). Dominant land uses are residential and commercial; the percentage of green areas in the catchment (public and private green areas) is around 22%. The catchment is drained by a combined sewer system of a total length of 5 km.

Step 1: Information: evaluation of the available information

The available information belongs to different areas and involves different stakeholders:

- **Sewer measurements: hydraulic and pollutant measurements:** Monitoring station located in the final pipe of the Fossolo sewer system involved sensors that measured continuously and an automatic water sampler, that collects samples during wet periods. Inline sensors measure electrical conductivity, turbidity and water level every 5 minutes, allowing a comprehensive temporal characterization. On the other hand, the aggressive

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sewer environment makes turbidity measurements low reliable, caused by the frequent dirt and toilet paper that occlude the optical sensor.

- **Asset data:** Sewer network maps, including information on pipe materials were provided by the water utility that manages the water and wastewater in Bologna municipality.
- **Climate variables:** Precipitation data, openly accessible, are available from the two nearest rain gauges (Bologna Idrografico and San Ruffillo Savena weather station) managed by the Regional Environmental authority (<https://simc.arpae.it/dext3r/>). The distance of the weather stations to the area of interest is approximately between 3.5 and 5 km.
- **Traffic load:** Vehicular traffic data at hourly time resolution are available from 2019: the measurements provide an indication of the roads with high number of vehicles. The data are provided by the municipality of Bologna and is openly accessible (<https://opendata.comune.bologna.it/pages/home/>).
- **Land use:** A first dataset provided by the municipality distinguishes the area in main roads, buildings and public/private green areas: the dataset is openly accessible (<https://opendata.comune.bologna.it/pages/home/>). More detailed, is the dataset provided by the Geomatic group of the University (Trevisiol et al., 2022): the dataset provides the classification of roof materials. Six macro-classes were identified, the most widely used in the city: clay tiles, sheaths, metal sheets, gravel tiles and other material.
- **Population density:** Ultimately, information on the population resident in the catchment is available from the national institution of statistics (<https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/>).
- **Satellite images:** To recognize the absence/presence in the catchment, satellite images were used, useful also to assess the evolution of the area during the years.

The datasets presented are not strictly related to a quantitative measurement of pollutant concentration but rather serve as indicators for detecting their possible presence. In this sense, the collected datasets act as proxies: representing influential factors that can directly impact pollutant presence or to factors that are indirectly related to them. For each pollutant source category identified by (Müller et al., 2020) an ensemble of influential factors have been considered.

Table 1: Pollutant sources and how to evaluate them: the use of proxies.

Pollutant Source Category	Motivation	Proxy used to account for
Anthropogenic activities	Human and pets living – related to littering, deposition of pet faeces.	Population density
	Vehicular transportation – related to PAH, Heavy Metal and TSS emission,	Traffic intensity

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	Hotspot of pollutant emission (construction activities, gasoline station)	Satellite images
	Gardening, use of pesticides	Land use
Drainage surfaces	The pollutant released is connected to the material type of the drained surface.	Land use data and roof material classification
Urban drainage systems	The pollutant released is connected to the material type and the age of the pipe.	Asset data
	Green Infrastructure	Asset data

Pollutant source categories identified involved: anthropogenic activities, drainage surfaces and urban drainage systems. Even if atmospheric deposition remains an important pollutant source, the complexities in defining boundaries for air transport processes make this source hard to related.

Step 2: Holistic re-assessment

Each of the proxies on pollutant sources have been evaluated individually, considering their level of detail and their level of accuracy. As mentioned before, the datasets are heterogenous and belong to different fields (e.g. land use data, asset data, hydraulic and water quality data) but the information needs to be combined, since a pollutant (e.g heavy metals) can be released from drainage surface (e.g roof in zinc) but also from anthropogenic activity (e.g during vehicular transport). The way for combining information from different levels in order to have a comprehensive map to help to prioritize where to act is challenging since no standard procedure is available.

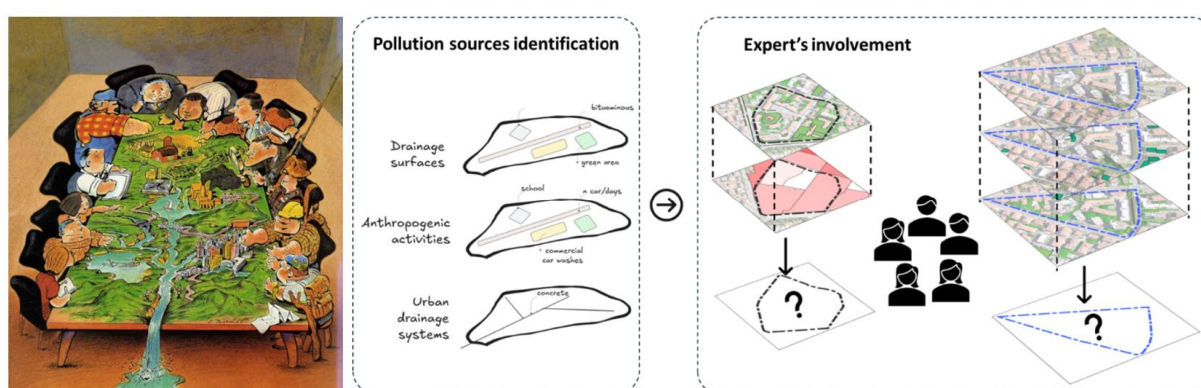


Figure 8: Source (Loucks & Van Beek, 2017) – stakeholders involved in river basin planning and management, each having different goals and information needs.

In this sense, the holistic re-assessment was done through the involvement of a group of experts (e.g urban planning experts, wastewater experts, researchers, water utilities), who was asked to combine information in order to identify the thinking process for prioritizing subcatchments in terms of presence of pollutant based on: i) combining different sources of the same pollutant in a

subcatchment, and ii) prioritizing catchment with different level for several pollutants (Figure 8). Belonging to different fields and areas of expertise, it is logic to deduce that they also have different perception of the problem and different ways to address it. The findings suggest that the task remains complex for experts, they often require supplementary information. Most groups of experts reached a consensus within their group, but different groups used different strategies. For most of the groups, the consensus was not reached since the available information was not sufficient to evaluate the current risks given the available resources.

This led us to take collect more information, through monitoring campaign set-up ad hoc. Starting from the water quality data measured in the final pipe of the drained catchment, the possible pollutant contributors are identified: the next phase explores a range of **scenarios** for setting up targeted monitoring campaigns, with the aim of pinpointing the critical areas.

Step 3: Risk evaluation

The risk evaluation phase is developed according to the methodology depicted in Figure 9. To be more pragmatic, the approach is introduced through a real-world case study based on observed data. The water quality dataset, collected at the outlet of Fossolo catchment, revealed significant peaks in zinc concentrations during most monitored rainfall events. To mitigate these

PROTECTING THE AQUATIC ENVIRONMENT FROM URBAN RUNOFF POLLUTION

contributions, which may eventually be discharged into downstream urban streams, potential zinc sources within the catchment are systematically investigated.

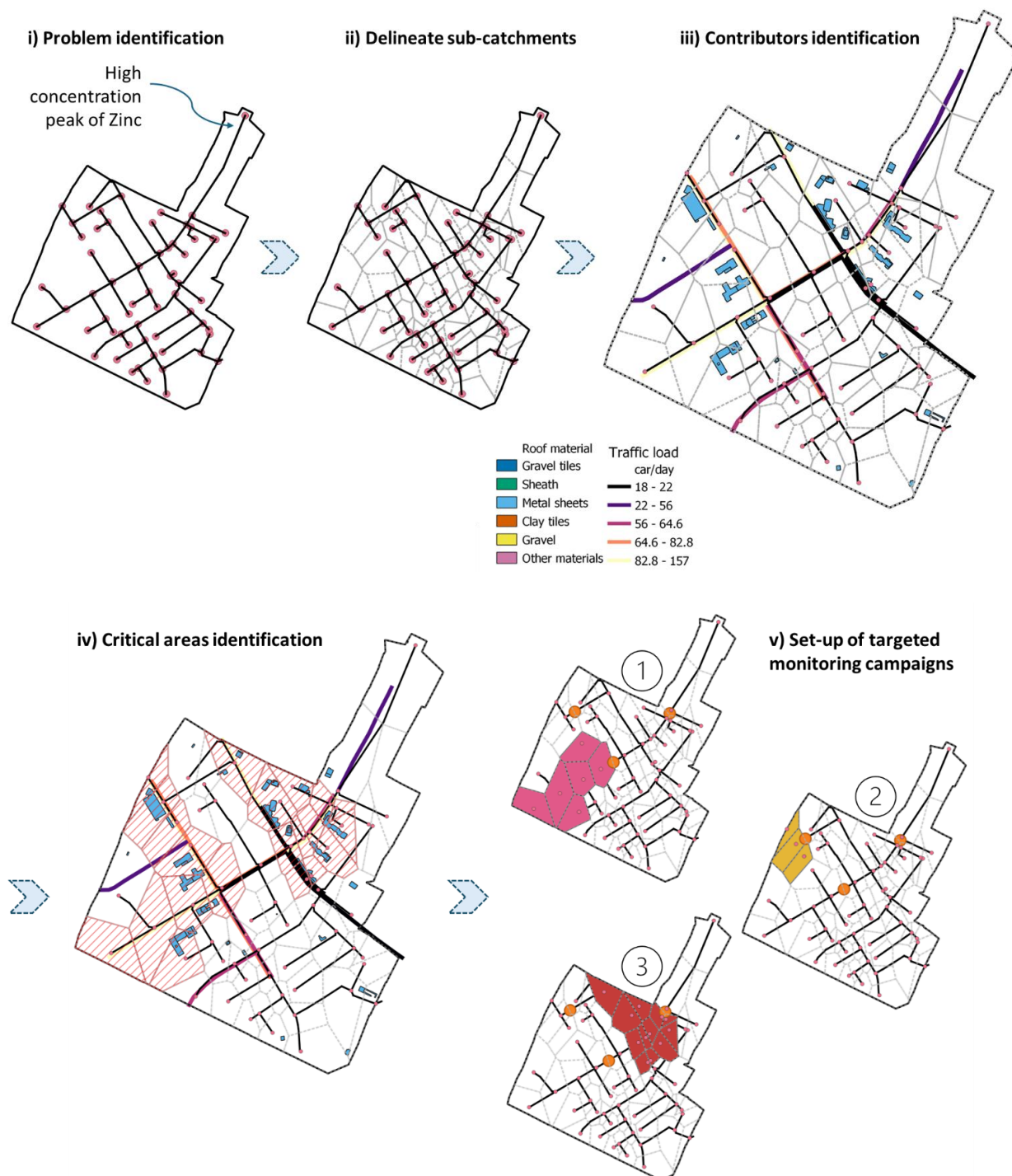


Figure 9: Risk evaluation step: (i) problem identification, (ii) delineation of sub-catchment, (iii) pollutant contributors' identification, (iv) critical areas identification and (v) scenarios of targeted monitoring campaigns.

The subsequent step involves the delineation of sub-catchments with a gis-based approach (Voronoi delineation), followed by identification of potential zinc contributors. Metal sheets are an

important source of zinc (Gromaire et al., 2001), but additional contributions are associated with tires and brake wear, which are directly link to vehicular traffic (Huber et al., 2016). Even if the number of vehicles should not be used as a sole predictor for runoff concentrations, limitations in available resources necessitate its use as a primary indicator. Based on the spatial analysis of the main proxies, the areas that have the highest likelihood of being zinc sources during a rainfall event are identified. Finally, targeted monitoring campaigns are designed for these critical areas to validate the guesses refine source attribution. Turbidity sensors, calibrated before to correlate zinc concentrations, can be installed. Alternatively, passive sampling devices (Birch et al., 2013) can be easily set-up, offering the advantages of low equipment costs and no need for an external power supply. This iterative “guess-and-test” approach can then be applied at finer spatial scales, enabling the identification of critical zinc source areas, facilitating the implementation of mitigation actions.

Step 4: Risk reduction measures

The measures to be implemented in the critical zones of the catchment depend on the specific pollutant group targeted for mitigation. Within the URUQ-MAP application, this step was not explored in detail; however, considering runoff volumes, for instance, through a hydrological-hydraulic model as developed in Case Study 5, is essential for designing effective mitigation strategies.

KEY FOCUS AND STORYLINE

Pollution map and scenarios

In Case study 2, pollution maps were developed by creating pollutant source proxies using diverse datasets from multiple domains (e.g land use data, roof material, asset data and sewer measurements, vehicular traffic data). A holistic re-assessment of the available information was done in collaboration with a multidisciplinary group of experts to identify which subcatchment should be prioritized. The study revealed that source-based analysis alone is not sufficient and must be integrated with targeted monitoring. Scenarios of targeted monitoring need to be developed.

Stakeholder involvement

Stakeholders participated in discussions on the development of the hydrological-hydraulic model and the sharing of available datasets. In addition, dedicated meetings with the municipality were organized to engage them in evaluating potential CSO mitigation measures and to incorporate their perspectives into the decision-making process. A final stakeholder session was conducted at the end of the project to present the results and highlight opportunities for potential replication of the approaches and strategies developed.

Further details concerning this case study can be found in Deliverable D3.4 “Treatment technology assessment for the CSO technology treatment options”.

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CASE STUDY 3 – USE OF RAIN RADAR AND ADAPTIVE WWTP OPERATION TO MINIMIZE CSO SPILLS IN THE BIRS CATCHMENT – BIRSFELDEN (CH)

Case study 3 focuses on the operation of retention tanks along the sewer. This perspective is especially important to highlight with respect to the URUQ-MAP. From a management perspective, it consists in better operating existing infrastructures that are semi centralized.

Based on their experience in StopUP, they identified, that reducing volume overflowing may remain a more efficient solution than treating increasing volumes. This holds also for monitoring: continuous monitoring of water level in tanks may remain relatively cheap and low maintenance. In comparison, monitoring water quality parameters continuously may be too ambitious in terms of cost and maintenance. Targeting shorter monitoring campaigns of each of the individual subcatchment to characterize them is a more efficient use of resources. Case study 3, from a URUQ-MAP perspective, promotes the use of an adaptive system for managing stormwater.

Further details concerning this case study can be found in Deliverable D3.6 “Improved operational concept for urban drainage system in Case Study 3”.

CASE STUDY 4A&B - TREATMENT OF HIGH TRAFFIC ROADS AND RESIDENTIAL AREAS I– WOLVENBERG & WETTEREN (BE)

In case study 4 several infiltration solutions were investigated (sand filter and the urban rain shells). The investigation of the sand filter got delayed due to administrative barriers. Those barriers may be linked to some political timelines and link with election. Such event can delay implementation of solutions and have to be accounted for when applying the URUQ-MAP. Due to those unforeseen delays, it was decided to investigate through column test several materials. Such initiatives are crucial to bring practical information for designing a solution. This type of action can also help building confidence in new solutions for stakeholders.

The solutions considered in case study 4 are decentralized solutions. Those solutions constitute a management challenge for utilities: they may be lost or left unmaintained. For implementing those

solutions, it is necessary to ensure that they are clearly identified and maintained. Regarding the monitoring, it may not be affordable to monitor all of them, but it might be more efficient to investigate in detail some of them and build knowledge and awareness based on those monitored sites. The responsible for data collection may not be the main data user. It may be more efficient to delegate monitoring and data management to a specialized utility with a higher level of service. Universities or research institutes may benefit from those datasets, generating new knowledge that help municipalities to further improve the system.

Further details concerning this case study can be found in Deliverable D3.8 “Final evaluation of sustainable urban drainage systems / decentralised (infiltration) approaches”.

CASE STUDY 5 – NATURE-BASED SOLUTION RETROFIT IN AN URBAN CATCHMENT – TRONDHEIM (NO)

CASE STUDY 5 – SCENARIO FOR CSO REDUCTION BY BIORETENTION CELLS IMPLEMENTATION



MAIN STORYLINE WITHIN THE URUQ-MAP

In case study 5 (CS5), the risk mitigation measure studied is a Bioretention cell (BRC). The application of the URUQ-MAP focuses, through the development of stakeholder-informed scenarios, on investigating the potential of decentralized solutions such as BRC for reducing overflow duration in a small urban catchment. Additionally, the simplified pollutant modelling is used to target subcatchments in which implementing measure will give more than one benefit.



KEY MESSAGE AND LEARNING

- Use of scenarios as a tool for stakeholder involvement.
- Strategy alignment for CSO reduction
- Model-based pollution maps and visualisation of uncertainty

APPLICATION OF THE URUQ-MAP

Step 0: Definition: system and objective

In CS5, the study area is a small urban catchment including a combined sewer system and an overflow structure. The catchment contains dense urban area, sparser residential area and a park. The choice of this area within StopUP does not result from prioritization linked to the application of the URUQ-MAP as it would be done in a formal application of the plan at city scale. This area was chosen for research purposes by opportunity, as the area is currently under development by the municipality.

The objective within the study area is to reduce the overflow (CSO) duration. The threshold recommended by the municipality is a maximum of 50 hours of CSO per year. This objective, focusing on CSO duration rather than volume, has been set in concert with step 1 based on available data and information: the discharge is not measured. The use of a hydrodynamic model could be

used to infer a discharge or volume based on the water level but due to high uncertainty it was decided to focus on CSO duration.

Step 1: Information: evaluation of the available information

The information available was collected in interaction with the municipality's stakeholders. A MIKE model was obtained from the municipality and transferred to SWMM. The model was calibrated using water level measured at the CSO structure for 5 years. We used statistical downscaling to generate high resolution timeseries of precipitation and temperature. This data can be used for evaluating the impact of climate change on the catchment. The GIS database of the municipality was used to identify land uses within the catchment (public, private, green spaces, roads, parking lots, etc.).

Step 2: Holistic re-evaluation

Knowing our aim to use the model to evaluate different scenarios at city scale, we evaluated the suitability of the model for estimating CSO. Since only water level is available the model is not considered reliable for estimating CSO volume. In a context with a longer timescale, and sufficient fundings available for the study, an investigation could have been performed to estimate a function linking the water level to the overflow discharge. In the context of the study, we decided to define the objective of reducing annual overflow duration. We selected an ensemble of parameter sets to account for uncertainty in the model.

Step 3: Risk evaluation

Pollution risk is evaluated as annual overflow duration from the combined sewer. Figure 10b shows the difference between the measured performance and the modelled performance. Different scenarios corresponding to different implementation strategies of bioretention cells have been developed based on inputs from municipality stakeholders. S1 corresponds to a scenario where the municipality works in silos on its different objectives (i.e., strategies for stormwater management are not aligned with mobility plans). In that scenario 25% of existing green space are retrofitted into BRC. In scenario S2, following the ambition of the revised wastewater treatment directives, the municipality manages to align different strategies (mobility plan and public transport, road toward zero pollution cities, green deals, biodiversity and green corridors, etc.), 50% of the parking spaces into GI additionally. In future conditions, and from a hydrological point of view, both scenarios perform similarly (Figure 10a), but scenario S2 is more robust as the infrastructures are better integrated and pollution sources may be reduced through goal alignment.

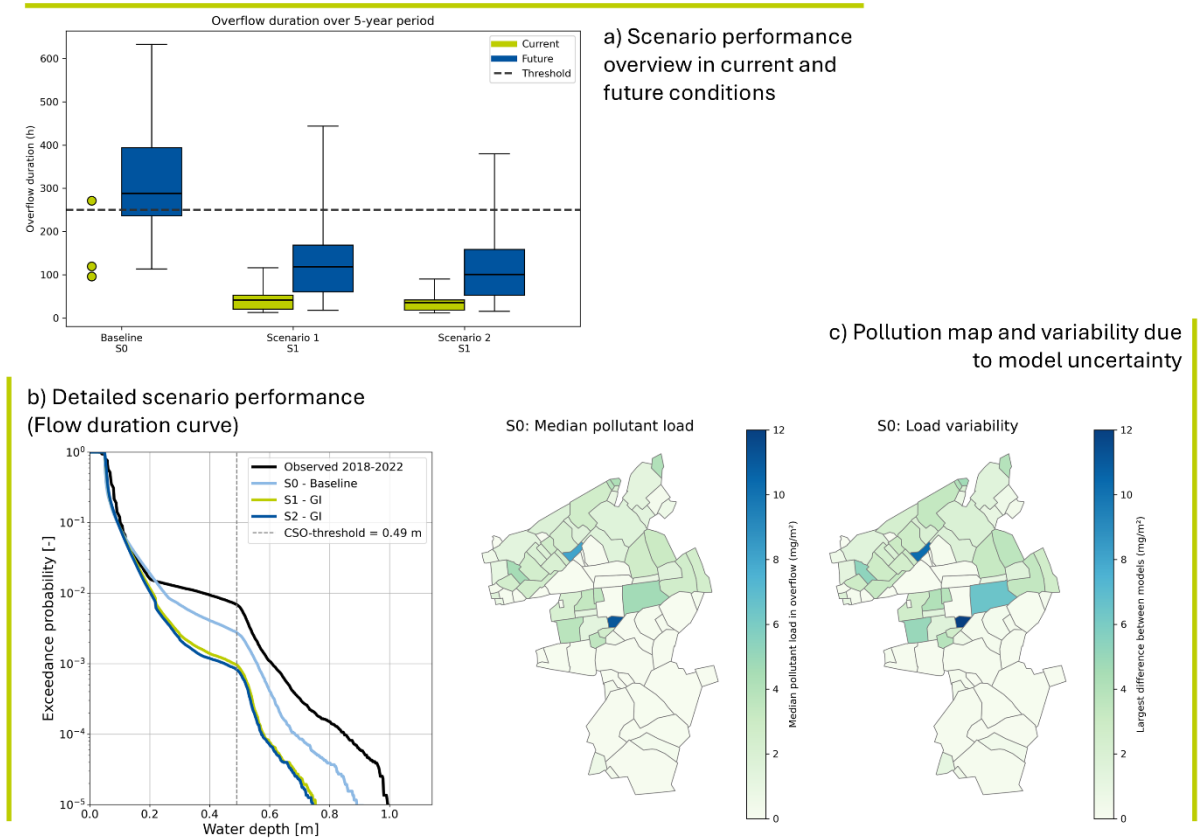


Figure 10: Overview of the application of the URUQ-MAP in CS5.

Step 4: Risk reduction measures

In this step, case study 5 does not consider the comparison of alternative solutions at site scale. The different scenarios are implemented at system scale and involve different levels of implementation of bioretention cells.

KEY FOCUS AND STORYLINE

Pollution map and scenarios

In Case study 5, we used the hydrological model to estimate which catchments contribute more to the stormwater pollutant loads during overflow. Based on this, it was possible to develop a map that can help to identify which catchments are more critical. Targeted subcatchments that can be seen in Figure 10 c) shows which areas that can be used as a starting point for municipalities to get both benefits of reducing CSO and targeting areas with high pollutant loads that are discharged during overflow. Making a valuable input for integrated stormwater management plans. We used three different parametrizations for the hydrological model and two different GI parameter sets to account for uncertainty and more specifically equifinality. We used this ensemble of models to visualize the uncertainty associated with the catchment’s contribution and display the variability between these models to represent uncertainty in models with low data availability (Figure 10c).

Stakeholder involvement

In Case study 5, we used scenarios as a support tool for involving stakeholders. After having met several stakeholders for developing the model and understanding the municipality’s strategy, we developed scenarios that we used as support for discussion. The workshop for discussing scenarios

helped the stakeholders to identify what was not accounted for in the scenarios, which made it possible to improve them and to better analyse the modelling results and their limitations.

Further details concerning this case study can be found in Deliverable D3.8 “Final evaluation of sustainable urban drainage systems / decentralised (infiltration) approaches”.

CASE STUDY 6 – SCENARIO FOR POLLUTION RISK MITIGATION AT SEBKHA SIJOUMI THROUGH HYBRID CONSTRUCTED WETLANDS



MAIN STORYLINE WITHIN THE URUQ-MAP

In case study 6 (CS6), the risk mitigation measure studied is a hybrid constructed wetland (CW) pilot implemented in the Sebkhha Sijoumi catchment. The application of the URUQ-MAP focuses, through the development of stakeholder-informed and data-driven scenarios, on evaluating the potential of nature-based treatment solutions to reduce pollutant concentrations and safeguard the sensitive lagoon ecosystem. The modelling activities support both the scientific understanding and the local stakeholders' decision-making by providing evidence on treatment performance under different environmental and operational conditions.



KEY MESSAGE AND LEARNING

- Use of data-driven modeling and scenarios as a tool to inform stakeholders on pollutant dynamics and treatment performance.
- Evaluation of operational strategies (e.g., different hydraulic retention times, flow rates) for optimizing pollutant removal in the CW pilot.
- Visualization of uncertainty in pollutant predictions across seasons and operational periods, highlighting the influence of environmental and hydraulic factors.
- Identification of key drivers of pollutant removal to support decision-making for scaling up or replicating CW systems in similar urban catchments.

APPLICATION OF THE URUQ-MAP

Step 0 – Definition: system and objective

In CS6, the study area is the Sebkhha Sijoumi catchment (Tunis, Tunisia), where a hybrid constructed wetland (CW) has been implemented at pilot scale. The system combines a Vertical Flow Constructed Wetland (VFCW) followed by a Horizontal Flow Constructed Wetland (HFCW). It was designed to treat stormwater runoff and sewage overflow from the catchment before discharge into the Sebkhha.

The primary objective within this study is to develop data-driven models that estimate pollutant concentrations at the inlet of the pilot plant using environmental and operational variables. In contrast to CS5, which focused on overflow duration, the target here is pollutant dynamics (e.g.,

COD, NH_4^+ , NO_3^- , NO_2^-), aiming at a transferable framework for predicting treatment performance under varying hydraulic and seasonal conditions.

Step 1: Information: evaluation of the available information

Information was gathered through continuous monitoring of the CW pilot plant during two operational seasons:

- Summer (May–August 2024)
- Winter (December 2024–January 2025)

Key variables include:

- Environmental drivers: precipitation, daily average/maximum/minimum temperature were collected from Institut National de la Météorologie (National Institute of Meteorology) Tunisia.
- Water quality indicators: COD, ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), turbidity, fecal coliforms, and E. coli.
- Operational conditions: varying hydraulic retention times (HRT: 18–48h) and flow rates, with a constant recirculation ratio of 0.5.

To identify relevant model inputs, cross-correlation analysis was performed between environmental/operational variables and pollutant concentrations. This enabled the selection of drivers most strongly influencing pollutant dynamics.

Step 2: Holistic re-evaluation

Given the available dataset, the modeling framework was designed as a data-driven approach rather than a mechanistic hydrodynamic model. The goal is to reproduce pollutant dynamics based on correlated variables. Due to limited and incomplete measurements (notably for fecal bacteria), the modeling effort was restricted to COD, ammonium, nitrate, and nitrite. Input variable selection differed across seasons, with drought season (periods 1–3) being better suited for model development compared to wet season (periods 4–5). The models account for seasonal variability and uncertainty by separately analyzing the five operational periods, each defined by specific HRT and flow conditions.

Step 3: Risk evaluation

Pollution risk in CS6 is interpreted as the potential for elevated pollutant concentrations at the CW inlet, which directly affects downstream treatment performance. Different operational scenarios were indirectly evaluated through the five monitored periods, representing changes in flow rates and HRT:

- Longer HRTs (18–48h) were associated with stronger correlations between environmental drivers and pollutant removal, particularly for COD and ammonium.
- Shorter HRTs revealed weaker predictive performance and less stable pollutant dynamics.

These operational variations provide insight into system sensitivity and the influence of hydraulic management strategies.

Step 4: Risk reduction measures

At this stage, CS6 does not compare alternative infrastructures but rather evaluates the model robustness and its applicability. The proposed data-driven model is designed as a transferable tool, adaptable to other CW systems or urban pilot plants.

KEY FOCUS AND STORYLINE

Pollution map and scenarios

In Case study 6, five operational scenarios were analyzed, corresponding to different combinations of flow rates and hydraulic retention times (18–48h) over two seasons (summer vs. winter). These scenarios revealed that longer HRTs improve pollutant predictability and system stability, while short HRTs introduce uncertainty. Uncertainty was explicitly considered by comparing periods with different environmental conditions (temperature, rainfall) and pollutants (COD and ammonium being more predictable, nitrite less so). The ensemble of models developed reflects these uncertainties and highlights where additional monitoring is required.

Stakeholder involvement

In Case study 6, the scenarios were discussed with researchers and local water managers, with the aim of assessing the potential for scaling up constructed wetlands for runoff water/CSO treatment in Tunisia. While the modeling work was mainly research-driven, it provides a decision-support tool for the Ministry for the Equipment, housing and Territorial Planning and other stakeholders managing stormwater in the Sebkhia Sijoumi catchment.

Preliminary exchanges with stakeholders highlighted the need to include microbial indicators and longer-term monitoring in future scenarios, which will improve both the reliability of the model and its usefulness for management decisions.

Further details concerning this case study can be found in Deliverable D3.4 “Treatment technology assessment for the CSO technology treatment options”.

DECISION SUPPORT SYSTEM – DSS

In the context of StopUP, a decision support system was developed. With respect to the URUQ-MAP the development of such a tool is interesting as municipalities will look for solution to meet the regulations. During the interview, we discussed the use of such a tool. A decision support system can be used to compare comparable solutions. For instance, in StopUP, decentralized solutions do not directly compare to post-CSO solutions. A DSS is meant to be customized for stakeholders in a context where repeated decisions have to be made. The consultant will adjust the alternative presented to the preferences of the stakeholders and their strategy. Such a tool question how to make aware stakeholders and decision-makers of the existing solutions to their challenges.

The decision support system presented in the case of StopUP is presented in deliverable D4.4 “Decision support method for treatment technologies”. Further information about the process and the evaluation of the technologies can be found in the different deliverables of work package 3, including D3.7