Call: HORIZON-CL6-2021-ZEROPOLLUTION-01
Project 101060922

Innovative methodology to prevent and mitigate diffuse pollution from urban water runoff

WATERUN

Deliverable D5.1

Definition of the risk based DSS architecture

Work Package 5

Risk management tool & guidance for decision making

Document type	:	OTHER
Version	:	V3
Date of issue	:	30/11/2023
Dissemination level	:	PUBLIC
Lead beneficiary	:	UNIVPM

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Executive Summary

Abstract	D5.1 provides a general description of the architecture of the Decision Support System (DSS) based on risk-assessment that will be developed during the WATERUN project. The DSS will allow an innovative approach for stormwater management, which will be based on a health and environmental risk assessment. The new tools will assist stakeholders in the decision-making process highlighting information related to risks derived by the presence of chemicals and pathogens in stormwater and will suggest appropriate reuse possibilities and management options. The DSS structure will be based on the integration of different software and mathematical tools that include: - SWMM software for urban runoff modelling, - a Python tool capable of processing the data generated by the SWMM outputs and performing a quantitative risk assessment (QMRA, QCRA), - an open-source GIS software to map the obtained information and to communicate with stakeholders.
Keywords	Risk assessment, urban runoff management, stormwater reuse, decision support system

Revision history

Version	Date	Status	Author	Description
0	18/11/2023	First draft	UNIVPM	Complete draft of the document
1	22/11/2023	Draft	Assigned Reviewer (UFZ)	Review of first draft
2	23/11/2023	Draft	UNIVPM	Minor change has been done and sent to QCG
3	30/11/2023	Final version	UNIVPM	Minor change has been done to include comments by QCG

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1 INTRODUCTION

1.1 Urban run-off management and reuse of harvested water

Climate change and the resulting problems of water scarcity represent an increasing threat to the entire world. Apart from limiting water resources for human consumption, water scarcity implies some environmental impacts such as increasing contaminants concentration and water pollution. Potential contamination sources include also diffuse inputs, such as urban run-off, which may occur during precipitation. In this scenario, the reuse of stormwater represents a potential option for meeting water demands in water stressed regions (diversification of water supplies), as well as preventing and mitigating diffuse pollution of receiving water bodies from Urban Water Runoff (UWR) through the reduction in discharge of untreated urban stormwater.

Stormwater harvesting involves collecting runoff from drains or creeks and represents a relatively new form of water reuse compared to rainwater tanks and the reuse of effluent from sewage treatment plants (Hatt et al., 2006; Xu et al., 2023). The rationale for harvesting stormwater for beneficial uses is to capture the excess stormwater before it contaminates the receiving water body and changes the stream hydrology, while providing a new source of water supply that may require less treatment than sewage for various non-potable uses (Fletcher et al., 2008; Grant et al., 2013; Hatt et al., 2006). However, reuse of stormwater is often impeded by social and institutional barriers resulting from a complicated mix of risk perceptions by multiple stakeholders (Dobbie and Brown, 2012). Particularly, one of the potential reasons for the limited exploitation of urban stormwater as a substitution water source is the lack of understanding of the pollutants' occurrences in the urban aquatic environment, and its associated environmental and public health risks (Jiang et al., 2015; Sidhu et al., 2012). Hence, a good understanding on the untreated quality of stormwater is essential as it allows for the development of a risk management framework to ensure water quality excursions are avoided as well as to make informed choices on the design of "fit-for-purpose" water treatment processes. To pursue this goal, the Horizon Europe WATERUN project (https://www.waterun.eu/) aims to set up an innovative methodology to contribute to the implementation of urban water runoff (UWR) management plans in cities according to a holistic perspective (from source identification to decision making). Particularly, an integrated urban run-off management plan within a city can:

- achieve the goals of water quality protection and flood mitigation to protect the natural and built environment,
- design for not just the worst-case scenario, but also for average and minimal events to minimize the impact of stormwater on neighboring lands,
- determine what solutions and infrastructure together with their interconnections are required to manage the stormwater runoff that results from different storm events,
- ensure that stormwater is treated as a resource that enhances our cities, rather than treat it as waste that needs to be removed through underground storm sewers.

In this framework, research activities in WP5 are focused on the development of a decision-making platform based on a mapping tool to share information about water quality and risk analysis within urban areas to evaluate stormwater reuse possibilities, as well as to assess the impacts of the stormwater reuse/discharges on human health and on the environment. Whitin the WATERUN project, the developed risk-based tool for stormwater management will be tested in selected urban districts of the cities of Santiago De Compostela (Spain) and Aarhus (Denmark).

1.2 Purpose and scope of the Decision Support System in WATERUN

The Decision Support System (DSS) that will be developed by research activities in WP5 allows the UWR management and reuse based on environmental and health-risk assessment. In particular, the DSS will support stakeholder decisions providing:

- A decision-making platform for collecting analytical data of UWR quality (i.e., collected from field campaigns), including a mapping tool with quality information about surface water affected by UWR and indication of safe uses of water according to a quantitative calculation of human health risk and/or environmental risk;
- An early warning system (EWS) to forecast UWR quality for critical precipitation events and notify stakeholders about the need for restrictions on reuse of harvested stormwater;

- A support to stakeholders for the implementation of a Water Sensitive Urban Design (WSUD) of a city area by assessing the reduction of health-risks and/or environmental risks after the implementation of a green infrastructure (GI).

In this document a general description of the expected structure/architecture of the DSS is given including the concept for the development of the risk-analysis and the organization of the mapping tool. Here the software utilized for urban-run-off modeling (Storm Water Management Model - SWMM) and its utilization to produce data will be described; this software will be implemented to perform a quantitative risk assessment (Quantitative Microbial Risk Assessment - QMRA and Quantitative Chemical Risk Assessment - QCRA) by programming language (i.e., Python). Foreseen applications for the use of the risk-based tool as EWS and for WSUD will be also highlighted.

2 INTERNATIONAL LEGISLATION AND TECHNICAL GUIDELINES RELATED TO URBAN RUN-OFF MANAGEMENT UTILIZED FOR THE DESIGN OF THE RISK-BASED TOOL

In 2019, the Commission performed an evaluation of the Council Directive 91/271/EEC under the Regulatory Fitness and Performance Program (the ‘evaluation’) (CSWD, 2019). It became apparent from that exercise that certain provisions of the Directive needed to be updated. Additional important sources of remaining load of pollution from urban wastewater that could be avoided were identified and these included sewer overflows and polluted discharges of urban runoff. During rainfall, sewer overflows and urban runoff represent a sizeable remaining source of pollution discharged into the environment. Those emissions are expected to increase due to the combined effects of urbanization and progressive change of the rain regime linked with climate change. Therefore, in the Article 5 of the Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment is indicated that Member States should ensure that integrated urban wastewater management plans are established at local level for all agglomerations of 100 000 p.e. and above as those agglomerations are responsible for a significant share of the pollution emitted. Furthermore, integrated urban wastewater management plans should also be put in place for agglomeration of between 10 000 p.e. and 100 000 p.e. where sewer overflows or urban runoff poses a risk for the environment or public health. The main goal of this new plan is to combat pollution from rain waters (urban runoff and sewer overflow) through the reduction of quantity discharge and phasing out of untreated discharges through separate collection systems. In addition, according to the Article 18 of this proposal, Member States shall identify the risks caused by urban wastewater discharges to the environment and human health, including those discharges that may affect the quality of a water body used for the abstraction of water intended for human consumption, the quality of bathing water falling within the scope of Directive 2006/7/EC, the status of receiving groundwater and surface water bodies as defined by the Directive 2000/60/EC, and the quality of a water body where aquaculture activities are present. In the Annex V of the draft of this directive, the document indicates objectives for the reduction of pollution from sewer overflows and urban runoff rainfall, which can be also estimated by the use of hydrological, hydraulic and water quality models as well as measures to be taken to achieve those objectives. In addition, in this annex it is reported that water reuse shall be considered in the context of the development of the integrated urban wastewater management plans.

The Risk-based DSS tool that will be developed during WATERUN project will address the new challenges raised by the proposal of the new directive concerning urban wastewater treatment. Particularly, the risk-based tool will utilize simulated urban run-off events to perform Quantitative Microbial Risk Assessment (QMRA) and Quantitative Chemical Risk Assessment (QCRA) for different reuse scenarios of harvested stormwater. In addition, simulated water quality data and risk assessment will provide information about impacts of urban run-off management on human health and/or on the environment. Hence, the tool will support stakeholders in the decision-making process in agreement with the requirement of the upcoming regulation.

The modelling approach that will be used to provide data for the DSS can be also beneficial for the requirements of the European Bathing Water Directive (BWD) (EU Directive 2006/7/EC), which demands to elaborate the so-called bathing water profiles for all bathing waters that receive short-term pollution such as sewer overflows. Particularly, the bathing water profile needs to contain information on conditions likely to lead to short-term pollution, the likelihood of such pollution, its likely duration, the causes of the pollution, and measures taken with a view to preventing bathers' exposure to pollution and to tackle its causes. All those information can be obtained by simulation of stormwater events and can be reported in the GIS mapping tool of the DSS to assess possible environmental and human health impacts.

For the practical calculation of the risk for human health and the environment the following technical documents have been consulted: i) Quantitative microbial risk assessment: application for water safety management (WHO, 2016); ii) Australian guidelines for water recycling: managing health and environmental risks (Phase 1 and Phase 2) (NRMMC-EPHC-AHMC, 2006; NRMMC-EPHC-AHMC, 2009); iii) Technical Guidance Document on Risk Assessment of the European Chemical Bureau (EU 2003). Particularly, the WHO guidelines present a harmonized framework for the application of QMRA to evaluate risks associated with fecal pathogens for the drinking-water, wastewater and recreational water pathways. These documents provide formulas and data for a practical QMRA calculation.

The Phase 1 of the Australian guidelines provides a generic ‘framework for management of recycled water quality and use’ that applies to all combinations of recycled water and end uses. In this document, useful information to estimate human exposure to pathogens during different reuse scenarios is reported. On the other hand, the second volume of the Australian guidelines (Phase 2) extends the guidance given in Phase 1 to cover the harvesting and reuse of stormwater. Finally, the Technical Guidance Document (TGD) of the EU Commission supports legislation on assessment of the risks of chemical substances to human health and the environment. It is based on the Technical Guidance Document in support of the Commission Directive 93/67/EEC on risk assessment for new notified substances and the Commission Regulation (EC) No. 1488/94 on risk assessment for existing substances, published in 1996. This document provides formula and instructions to perform QCRA.

3 FRAMEWORK FOR STORMWATER REUSE APPLICATION

3.1 Harvesting and reuse of stormwater

The reuse of non-conventional water sources, such as stormwater, is crucial for the implementation of circular water economy, also promoting the local economy. Furthermore, safe reuse of stormwater has several benefits such as the reduction of the impact of urban development on water quality and stream flow, and allows to close water loops, reusing the resource to address the problems of water scarcity.

Urban stormwater may pick up chemical contaminants and pathogens during its passage over roads and other surfaces. Consequently, the analysis of health and environmental risks is crucial for the evaluation of all possible reuse practices which can be considered safe within an urban area. These may include:

- irrigation of public open spaces (parks and gardens, playing fields, etc)
- toilet flushing
- washing machine use
- car washing
- roadmaking or dust control
- street cleaning
- firefighting
- water features and ponds
- food crop irrigation (home grown)
- agricultural uses (crops other than food)
- dual reticulation
- industrial uses

Stormwater quality varies considerably between storm events, and between catchments. The levels of chemicals and pathogens in stormwater are strongly related to the catchment’s land use, particularly the proportion of the catchment that is impervious and the type of catchment use (commercial, residential, industrial). Other factors also influence pollutant concentrations such as pills or illegal dumping of chemicals and, consequently, apparently similar land uses might have different pollutant loads.

Hence, a complete analysis of the catchment is fundamental in order to identify the main challenges for stormwater management and address possibilities for reuse. A project screening tool checklist can be utilized for the scope and to collect all relevant information to support the risk analysis for stormwater re-use. It can be also useful to identify target contaminants that may be relevant due to their impact on human health or on the environment. This information is relevant to define input parameters for models, and to define the context and boundaries of the modeling. This typology of inspection forms are short, standardized observation checklists that can be adapted and used to assess risk factors in any kind of reuse system (WHO, 2022; NRMMC-EPHC-AHMC, 2009). In Table 1 a check-list that can be used for the scope is reported; this is a slight modification of the template suggested by the Australian Guideline for stormwater reuse (NRMMC-EPHC-AHMC, 2009).

Table 1: Check-list for stormwater reuse and management

Topic		Description
1. Target stormwater use	1.1 Goal of the project	
2. Catchment	2.1 Geographic coordinates of the site	
	2.2 Main use of the area (specify if industrial area, commercial area, or residential area)	
	2.3 Presence of civil residences?	
	2.4 Presence of commercial activities?	
	2.5 Presence of agricultural land use?	
	2.6 Presence of industries? *(If Yes answer to the following question)*	
	2.6.1 Specific information of the industries in the area (type, etc.), including indication of possible contaminants that can be released in the environment	
	2.7 Presence of municipal park?	
	2.8 Presence of a significant proportion of the catchment comprising corroding roofs?	
	2.9 Presence of extensive construction activity, eroding stream banks or other significant sources of sediment?	
	2.10 Are there contaminated sites or areas? *(Specify if possible)*	
3. Project	3.1 Type of green/grey infrastructures available to manage urban run-off	
	3.2 Basin area (ha) collecting water to the green/grey infrastructure	

	3.3 Presence of impervious area (percentage)?	
	3.4 Availability of Digital Elevation Model of the area or other topographic information?	
	3.5 Presence and localization (geographic coordinates) of pluviometric stations	
	3.6 Sewer network characteristics (e.g., separated, presence of pumping station, corrivation time to the green infrastructure etc.)	
	3.7 Presence of sewer overflows? Specify the number of sewer overflows	
	3.8 Geological characteristics of the area (soil characteristics, groundwater presence and depth from the soil, etc)	
	3.9 Is the stormwater drain where the stormwater is collected free from tidal influence, and is the catchment free from significant areas of high soil salinity (eg > 2dS/m) or known salty lakes?	
	3.10 Presence of receiving water bodies? Specify the characteristics of the receiving water bodies (river, lake, eutrophication issues, environmental quality status, etc.)	
	3.11 Presence of natural/protected areas close to the stormwater reuse/management scheme?	
	3.12 Is stormwater harvested for reuse purposes or only for flood risk reduction?	
	3.13 Green/grey infrastructures to manage stormwater are used for some specific environmental issue?	
	3.14 Is there the availability of a stormwater reuse scheme, including pipes for water distribution? Report a description and available information	
	3.15 Pathogens monitored	
	3.16 Contaminants monitored	
	3.17 Are flow rate measures available/planned?	
	3.18 Are hydraulic models available?	
	3.19 Activity for possible reuse:	
	3.19.1 Industrial process water (specify)	
	3.19.2 Urban reuse (specify)	

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	3.19.3 Road washing (specify)	
	3.19.4 Municipal irrigation (specify)	
	3.19.5 Agricultural irrigation (specify)	
	3.19.6 Other reuse possibilities?	
4. Data analysis	4.1 Average rainfall from historical data (mm/y)	
	4.2 Volume of rainwater collected in existing infrastructures (m^3)	

Most of the answers to the check-list questions can be obtained from the local authority, the water utility managing the sewer system, and the territory government departments responsible for environment and natural resource management.

In the case of the WATERUN project, many data were acquired with the support of the consortium partners.

3.2 Case Study of Santiago De Compostela (Spain) – catchment information

Santiago De Compostela is located in the Northwest of Spain and has a population of 98 179 inhabitants (year 2022). The climate of Santiago De Compostela is temperate oceanic, being strongly influenced by the Atlantic Ocean, with mild, rainy winters and mild or pleasantly warm summers. The average daily temperature ranges from 5 to 25 ºC between winter and summer seasons. The mean monthly rainfall ranges between 23 and 141 mm.

Santiago De Compostela is one of the selected case studies of the WATERUN project. Two catchments within an industrial area were selected to test WATERUN products. Both catchments collect urban runoff water to Sustainable Urban Design (SUDs) elements, which are located in (Figure 1):

- Ptolomeo street
- Sionlla park.

Figure 1: Localization of Santiago de Compostela CS

At Ptolomeo street, the available SUD is a Surface Sand Filter, which drains stormwater in a separated sewer network. On the contrary, at Sionlla park a SUD with a bioretention area is present, where stormwater can be harvested and potentially utilized for reuse (Figure 2). This second catchment and green infrastructure will be modeled by SWMM to assess risk analysis related to stormwater reuse and management.

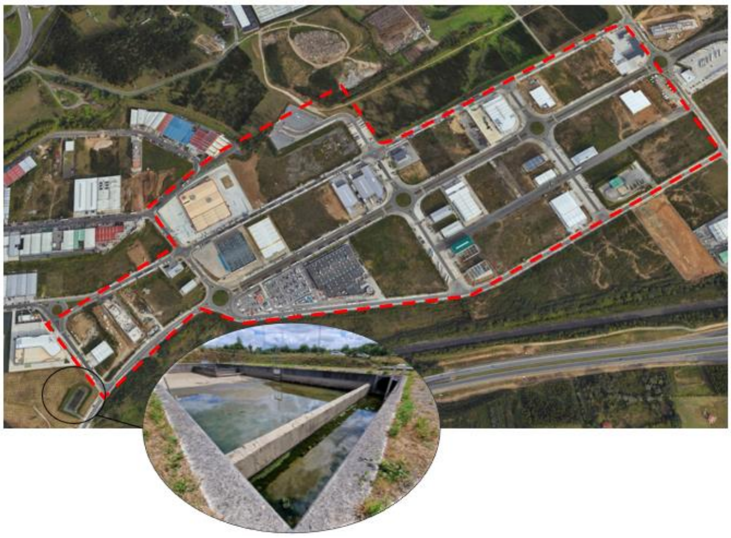

Figure 2: Santiago de Compostela CS - Sionlla park

Within the WATERUN project, the design of the SUD at Sionlla park is going to be improved to better manage the received stormwater. It will include different biofilters and retention basins.

Important information about this catchment, including characteristics of the sewer network, elevation data (DEM) and historical rainfall data of the area have been provided by the consortium partners for the elaboration of the corresponding SWMM model. Data about occurrence of chemical contaminants and pathogens will be provided when available from monitoring campaigns.

3.3 Case Study of Aarhus (Denmark) – catchment information

Aarhus is the second largest city in Denmark, located on the east coast of the Jutland peninsula with a population of 346 968 inhabitants (year 2023). Aarhus has an oceanic climate. There is rainfall during all months of the year. The average annual temperature for Aarhus is 11° degrees and there is about 226 mm of rain in a year. It is dry for 168 days a year with an average humidity of 81%.

Different SUDs elements will be investigated in Aarhus to test WATERUN solutions for UWR management. Particularly, seven SUDs were identified (5 wet detention ponds and 2 infiltration systems) in different sub- catchments of the city (Figure 3):

- Aarslev (wet detention pond in an industrial area)
- Tulipgrunden 1 (wet detention pond in a new residential area)
- Tulipgrunden 2 (infiltration ditch in a new residential area)
- Mårslet (wet detention pond in residential area)
- Risvangen (Infiltration bed in residential area)
- Nye (wet detention pond in a new residential area)
- Lystrup (wet detention pond in an urban area with industrial presence)

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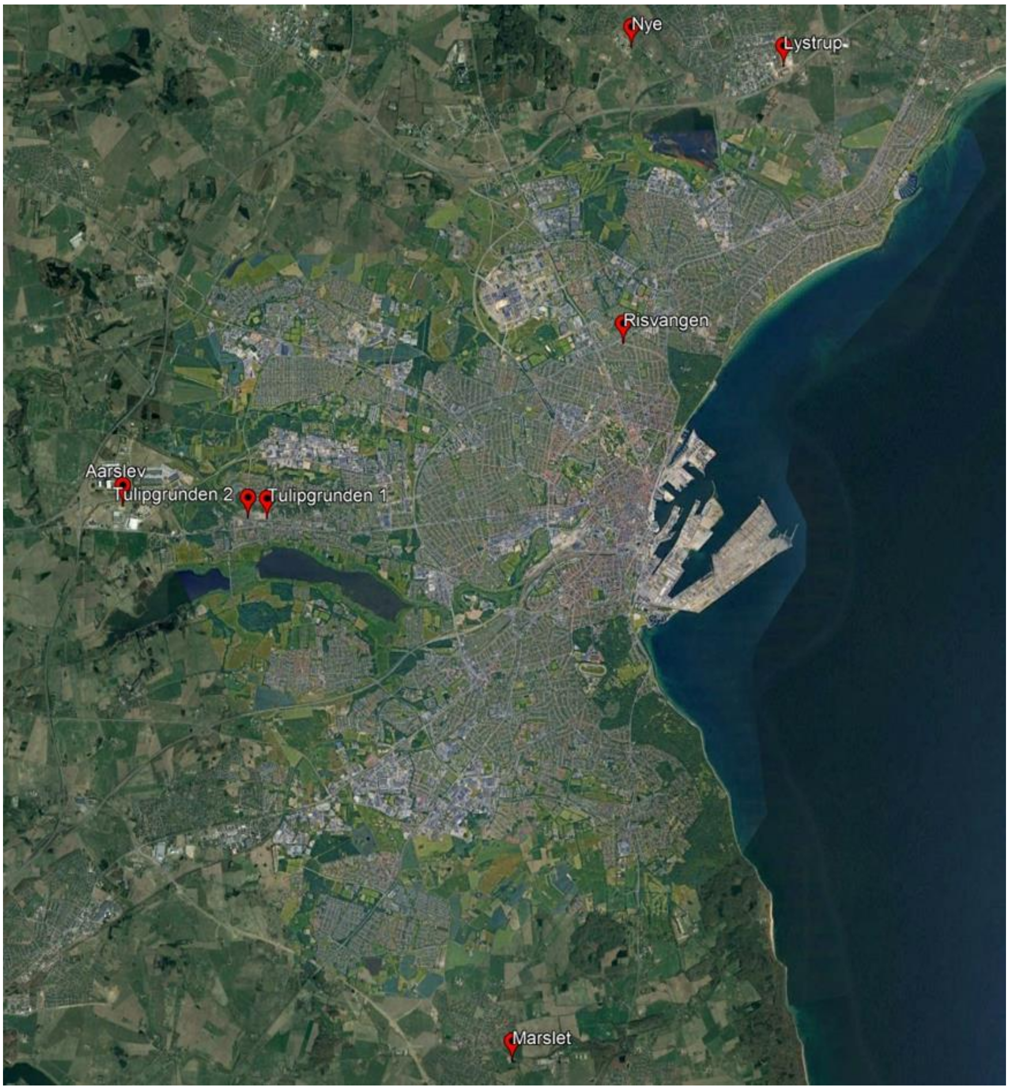


Figure 3: Localization of studied SUDs for urban runoff management in Aarhus

Tulipgrunden is a city district located in the western part of Aarhus. In the eastern part of the sub-catchment (Tulipgrunden 1), stormwater is transported by gravitation in underground pipes and collected in a wet detention pond (Figure 4). In the western part of the sub-catchment (Tulipgrunden 2), stormwater is transported on terrain in ditches, and collected in internally connected basin.

Figure 4: Aarhus CS - Tulipgrunden 1

Stormwater harvested in the sub-catchment Tulipgrunden 1 can be evaluated for reuse application. In any case, environmental risk assessment related to the impact of stormwater discharges in the receiving environments (water bodies and soil) can be also performed in other sub-catchments.

SUDs in Aarhus have been equipped with devices and sensors for measuring receiving flowrate and for collecting water for laboratory analysis that will provide a chemical and physical characterization of the flowing stormwater.

Historical rainfall data, characteristics of the sewer network and elevation data (DME) were provided by consortium partners to develop SWMM models for different sub-catchments in Aarhus.

4 RISK ASSESSMENT FOR STORMWATER REUSE AND MANAGEMENT

For stormwater harvesting to achieve its full potential in mitigating water scarcity problems and restoring stream health, it is necessary to evaluate the human and environmental health risks and benefits associated with it. Stormwater harbors large amounts of pollutants and has traditionally been viewed as a leading cause of water-quality degradation of receiving waters. Harvesting stormwater for household use raises questions of human exposure to pollutants, especially human pathogens, which have the potential to cause large-scale disease outbreaks. These issues are compounded by uncertainties relating to the performance of stormwater treatment technologies in pathogen or chemical pollutants removal. In this framework, a risk management approach incorporates the concept of identifying and producing recycled water of a quality that is ‘fit-for-purpose’. A mandatory step in a risk management approach to recycle stormwater is the identification of potential hazards (pathogens and pollutants) associated to the planned reuse. Hence, a risk assessment should be conducted by utilizing quantitative or qualitative methods to evaluate the potential impact on human health and on the environment due to the presence of the identified hazards (pathogens and chemical pollutants).

Qualitative and semi-quantitative risk assessments can be developed through several approaches, such as event trees, matrices or indicators. A usual methodology is the one based on a combined evaluation of likelihood and magnitude/severity of the impact of a hazard on the exposed receptor (WHO, 2006).

Quantitative risk assessments can provide a numerical estimation of the risk, for example, the impact of specific microbial infection in one year under a specific scenario. This characterization of the risks to human health is usually based on dose-response relationships to identify if a hazard might have an effect on the health. A health risk assessment for a microbial hazard can be done using a Quantitative Microbial Risk Assessment (QMRA), which is based on the evaluation of dose-response relationships between the concentration of a hazard and the effect it may cause on the receptors. The outputs of this method represent the values of the probability of adverse health effects and are expressed by the probability of infection or by the Disability-Adjusted Life Years (DALY) indicator. Methodologies and criteria for QMRA and DALY can be consulted from the WHO Guidelines (WHO, 2006) and the WHO Guidelines on QMRA (WHO, 2016).

On the other side, a quantitative approach for assessment of the environmental risk or Quantitative Chemical Risk Assessment (QCRA) is usually based on the ratio of the Predicted Environmental Concentration (PEC), calculated with mathematical models on fate and transports of a specific pollutant to environmental compartments, and the Predicted No-Effect Concentrations (PNEC) or its maximum allowable concentration set out by applicable legislations (e.g., EQS applicable to water bodies according to their quality status) (EU, 2003). This approach requires a significant volume of monitoring data from the water reuse projects and a detailed characterization of the surrounding environment which limits its applicability only to projects were sufficient data are available and assumptions are supported by scientific evidence.

In the WATERUN project, data needed for quantitative risk assessment will be produced by SWMM (Storm Water Management Model – US EPA) simulation of run-off events. SWMM models will be calibrated using empirical data collected during experimental campaigns conducted by the WATERUN consortium at the case studies of Santiago De Compostela and Aarhus.

4.1 Quantitative Microbial Risk Assessment – QMRA

QMRA allows to quantitatively evaluate microbial risks for stormwater reuse, and it involves four steps: i) Hazard identification; ii) Hazard characterization; iii) Exposure assessment; iv) Risk characterization.

Hazard identification relies on the identification of the possible hazardous pathogens that may cause illness in humans due to wastewater reuse practices. Potential pathogens to consider for the analysis are suggested by WHO (2016) and include bacteria (e.g., campylobacter), spores or protozoa (e.g., Cryptosporidium) and virus (e.g., rotavirus), which are capable to cause adverse human health effects.

After a certain agent is identified as a hazard, the step of **hazard characterization** collects information on its characteristics, such as distribution, and main sources of emission. In the WATERUN project, SWMM simulations will be used to evaluate pathogen concentrations in run-off water and in the harvested stormwater.

The **exposure assessment** is needed to define all the activities through which people enter in contact with pathogens during stormwater reuse. For this scope, the Australian Guidelines for water recycling (2009) provide useful information about exposure volumes and frequencies of exposures per person for different reuse scenarios (e.g., park and garden irrigation, agricultural irrigation, toilet flushing) (NRMMC–EPHC–AHMC, 2006). Hence, the dose-response model suggested by WHO (2009) can be used to calculate the probability of infection (Pinf) for a target pathogen and exposed group.

The **Risk characterization** is the last step in risk assessment, which aims at integrating information from hazard identification, dose response and exposure assessment, to determine the magnitude of risk. Particularly, the probability of infection in one year and the parameter "Disability-adjusted life years (DALYs)" are the metrics for expressing the burden of disease within a population as suggested by (WHO, 2016) which can be used for the final characterization of the risk. A health-target of 10^{-6} DALYs was set by WHO as tolerable health risk (WHO, 2016).

In the WATERUN project, a Python tool is going to be elaborated to perform the latter two steps of the microbial risk analysis: exposure assessment and risk characterization. Particularly, statistical methods, including Monte Carlo techniques and fitting of theoretical distributions will be developed to elaborate data produced by SWMM modelling. The Python tool will be integrated to SWMM software by the development of an appropriate Guide User Interface (GUI) as described in the next paragraphs.

4.2 Quantitative Chemical Risk Assessment – QCRA

The methodology for quantitative chemical risk assessment (QCRA) is described by the European Union Technical Guidance Document on Risk assessment (EU 2003). Like QMRA, the QCRA is structured in: i) Hazard identification, ii) Hazard characterization, iii) Exposure assessment, iv) Risk characterization.

Potential **hazards** for QCRA are all chemical pollutants that may represent a risk for the health of ecosystems and/or humans. Target chemicals to use for the analysis can be identified by an accurate inspection of the catchment characteristics also using the check-list tool described in the previous paragraphs.

Hazards that were selected in WATERUN as target contaminants in urban runoff water include heavy metals (e.g., copper, lead, zinc, cadmium, nickel, chromium, etc.) and polycyclic aromatic hydrocarbons (PAHs) (e.g., anthracene, phenanthrene, naphthalene, benzopyrene). These compounds will be monitored at the WATERUN cases studies, and if detected they will be used as hazards for risk analysis. Even in this case, concentration of heavy metals and PAHs in urban runoff will be modeled by SWMM during simulation of different precipitation events, which will be based on historical data of rainfall events (**hazard characterization**). PNEC

(Predicted No-Effect Concentrations) values for the different environmental endpoints of concern can be obtained from the literature analysis. Particularly, the two ecosystems of concern for this work are the soil and the aquatic ecosystem, which may be affected during reuse practices or after the discharge of stormwater. Hence, for the assessment of risks concerning soil microorganisms and soil invertebrates, $PNEC_{soil}$ need to be collected for the selected contaminants. On the other hand, for environmental impact on the aquatic ecosystem, algae and crustacea are typical receptors of concern. To assess risk on these aquatic organisms, $PNEC_{water}$ values are needed. All those values are provided by the European Union Technical Guidance Document on Risk assessment (EU, 2003). Furthermore, this European Technical guidance provides formula and mathematical approaches for the calculation of Predicted Environmental Concentration (PEC) in a receiving water body or in the soil starting from expected concentration of pollutants in the reclaimed water. For this scope, a Python tool will be developed to calculate PEC concentrations of target contaminants starting from data obtained by SWMM simulation for the two ecosystems of concern (PEC_{water} and PEC_{soil}) (**exposure assessment**). Risk characterization for the selected environmental endpoints is conducted by calculating the risk quotient (RQ) for the respective endpoints, which is the ratio between the calculated PEC value and the PNEC value provided by reference literature (EU, 2003). A RQ higher than 1 indicates a non-tolerable risk.

5 SOFTWARE TOOLS TO SUPPORT STORMWATER MANAGEMENT ACCORDING TO A RISK-BASED APPROACH

The risk-based decision support system (DSS), which will be developed during WP5 research activities in the WATERUN project, will be based on the integration of different software and mathematical tools that include:

- Storm Water Management Model (SWMM) US EPA, which allows the modelling of urban runoff in a selected urban catchment.
- A Python code able to collect and elaborate output data produced by the SWMM model with the aim to perform quantitative risk assessment (QMRA, QCRA).

- An open-source GIS software, which can be fed with outputs produced by the Python tool, will allow a simplified communication of elaborated results to interested stakeholders.

The SWMM model will need to be calibrated and validated by using empirical data collected at the WATERUN cases studies during the planned monitoring campaigns. In Figure 5 the designed architecture of the risk based DSS is represented, which is based on the integration of the software above mentioned. Hence, starting from empirical data collected during monitoring campaigns, the DSS will display in a GIS-mapping tool information related to health and environmental risks associated with the reuse/management of urban stormwater. This information can be used by interested stakeholder to make decision about the most convenient use and management of urban stormwater as well as to plan future interventions to reduce the risk associated with stormwater reuse and discharge.

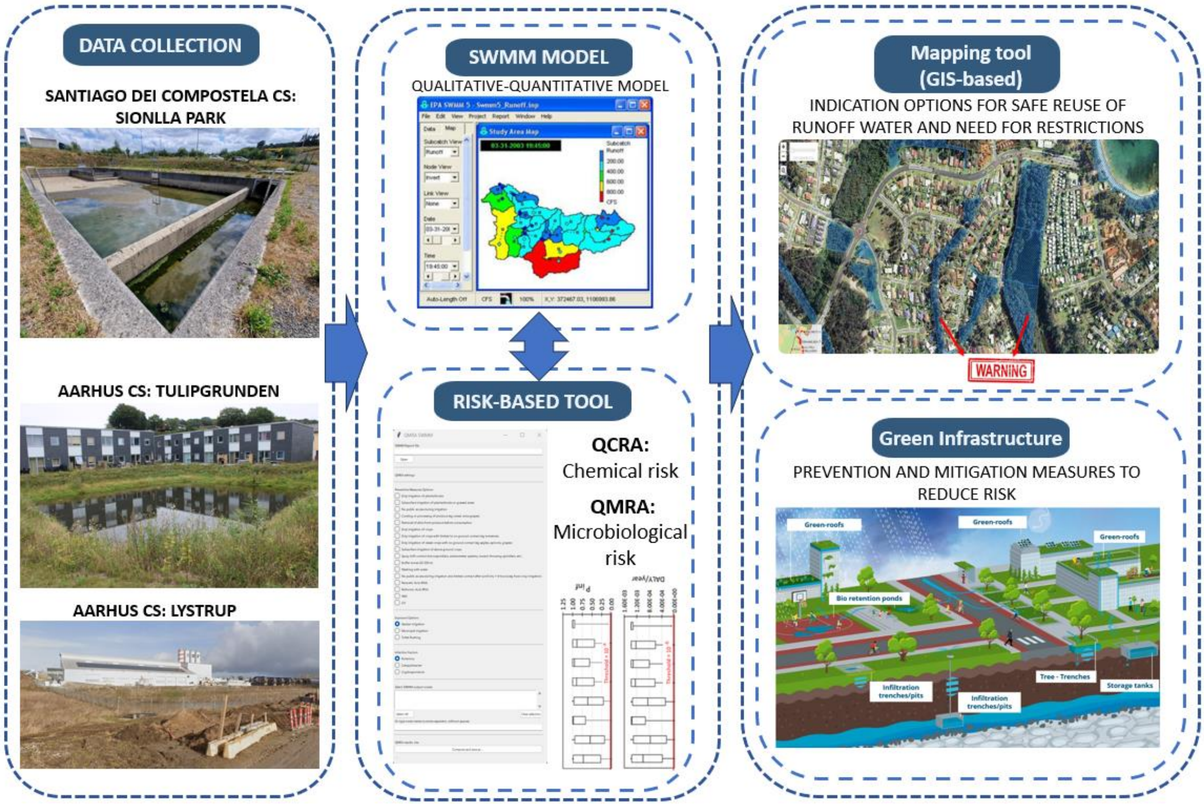


Figure 5: DSS architecture

5.1 SWMM modelling of stormwater runoff

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from urban areas. SWMM is a Windows-based desktop program. It is an open-source public software and is free for use worldwide. It can be used to evaluate grey infrastructure stormwater control strategies, such as pipes and storm drains, and is a useful tool for creating cost-effective green/grey hybrid stormwater control solutions (Figure 6).

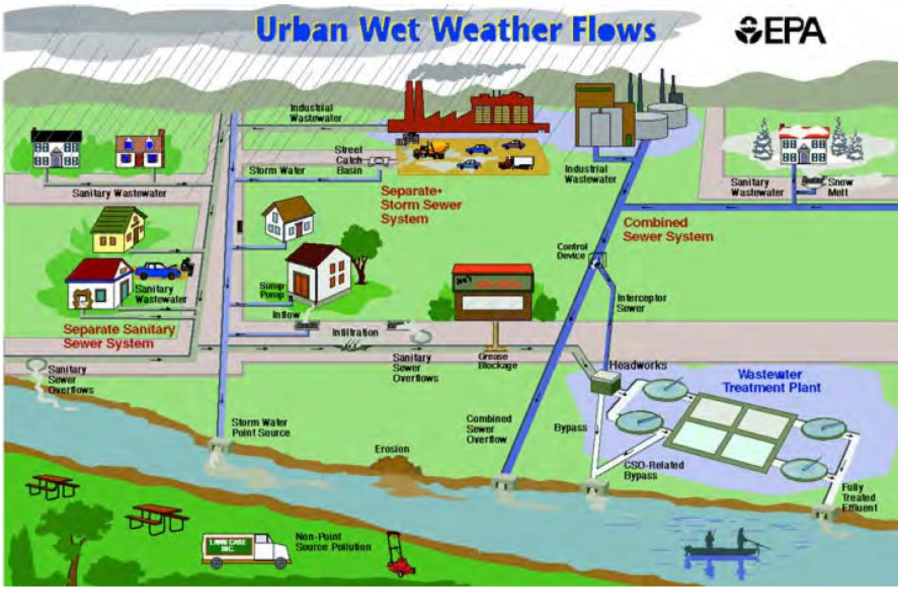


Figure 6: Elements of a typical drainage system in the SWMM model

SWMM contains a flexible set of hydraulic modelling capabilities used to route runoff and external inflows through the drainage system network of pipes, channels, storage/treatment units and diversion structures. In addition, SWMM can estimate the production of pollutant loads associated with stormwater runoff. The advance that will be produced in the WATERUN project is to set up a methodology for data management and elaboration by SWMM software that can be used for risk analysis.

To verify the accuracy of the model, a qualitative and quantitative calibration of the model must be carried out for dry and wet periods, using real data. Hence, monitoring campaigns at the case studies need to be planned for this scope.

5.2 Python tool for risk quantification

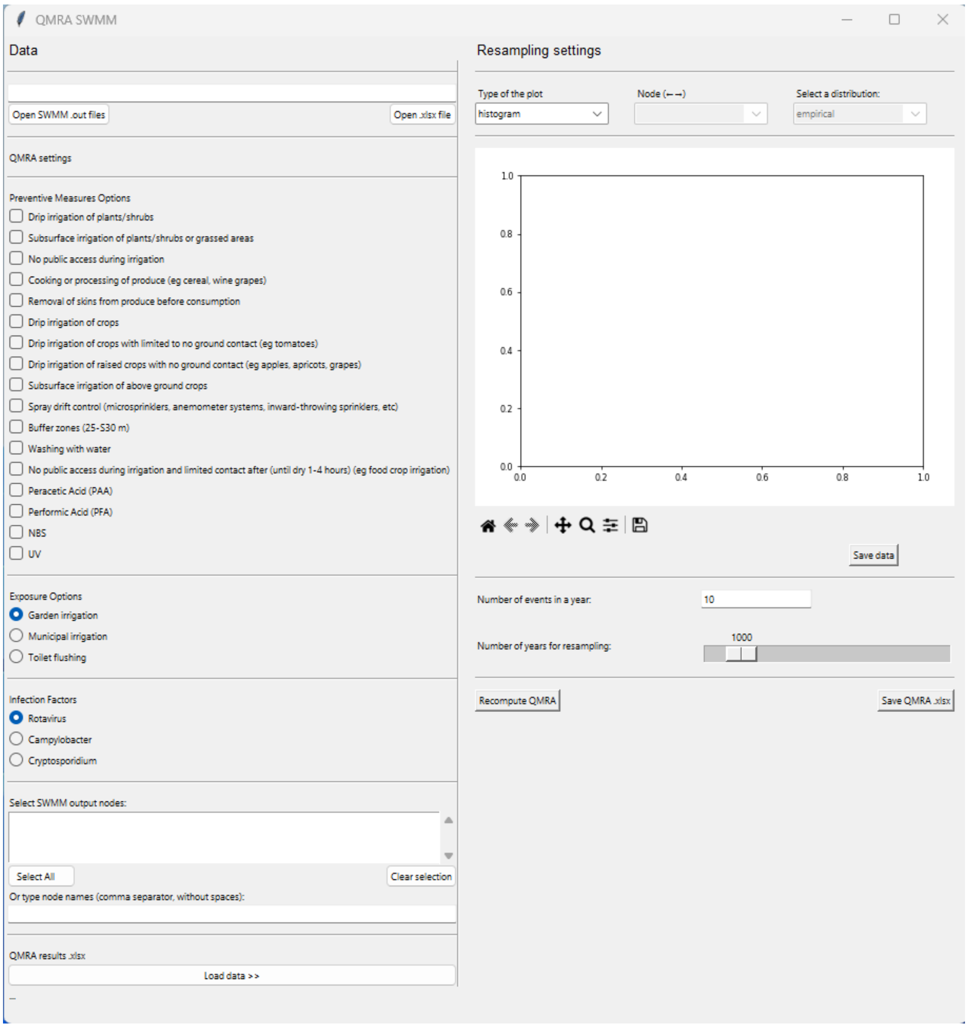
The integration of the SWMM model with the risk analysis is carried out using Python as a programming language to calculate quantitative microbiological and chemical risk (i.e., QMRA, QCRA). Python is a high-level, general-purpose, and very popular programming language. The biggest strength of Python is a huge collection of standard library which can be used for different purposes, including: Machine Learning, GUI Applications, Web frameworks like Django, Image processing, Web scraping, Test frameworks, Multimedia, Scientific computing, Text processing and many more.

The Python tool that is being developed in the WATERUN project will be able to elaborate data simulated by SWMM in selected outfall nodes of a sewer network. The programmed code will use statistical tools such distribution functions and Monte Carlo techniques to calculate QMRA and QCRA using data simulated by the SWMM model. A GUI will assist the user to define the boundaries and conditions of the risk analysis for selected reuse application or management of urban run-off water.

A first prototype of GUI to define conditions for risk assessment in stormwater reuse/management is shown in Figure 7. This GUI will be further improved to include more calculation possibilities and scenarios for risk assessment. Thanks to this GUI, the boundary conditions of the risk assessment can be chosen directly by the user. These conditions include, but are not limited to:

- Exposure options/reuse scenario (garden irrigation, toilet flushing, etc.);
- Infection factors (pathogen and contaminant);
- Outfall node at which to assess risk;
- Preventive measures options.

The final outputs of the risk analysis will be produced as text/excel file, but also in a graphical form. For example, in Figure 8 results of the microbiological risk assessment in terms of probability of infection per year and DALY/year are compared with acceptable thresholds as defined by US EPA and WHO, respectively.



QMRA settings

Preventive Measures Options

☐ Drip irrigation of plants/shrubs
☐ Subsurface irrigation of plants/shrubs or grassed areas
☐ No public access during irrigation
☐ Cooking or processing of produce (eg cereal, wine grapes)
☐ Removal of skins from produce before consumption
☐ Drip irrigation of crops
☐ Drip irrigation of crops with limited to no ground contact (eg tomatoes)
☐ Drip irrigation of raised crops with no ground contact (eg apples, apricots, grapes)
☐ Subsurface irrigation of above ground crops
☐ Spray drift control (microsprinklers, anemometer systems, inward-throwing sprinklers, etc)
☐ Buffer zones (25-S30 m)
☐ Washing with water
☐ No public access during irrigation and limited contact after (until dry 1-4 hours) (eg food crop irrigation)
☐ Peracetic Acid (PAA)
☐ Performic Acid (PFA)
☐ NBS
☐ UV

Exposure Options

● Garden irrigation
○ Municipal irrigation
○ Toilet flushing

Infection Factors

● Rotavirus
○ Campylobacter
○ Cryptosporidium

Select SWMM output nodes:

Or type node names (comma separator, without spaces):

QMRA results .xlsx

Type of the plot: histogram
Node (--):
Select a distribution: empirical

Number of events in a year: 10

Number of years for resampling: 1000

Figure 7: Python GUI to define the boundary conditions for risk assessment

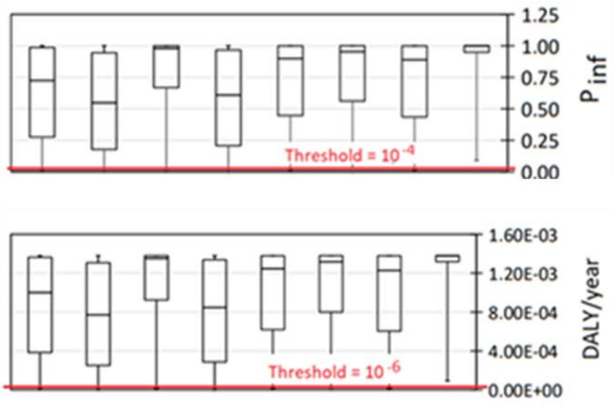


Figure 8: Example of box plot for QMRA calculation

The Python tool will be integrated with a GIS software to facilitate the communication of the obtained results by a mapping tool.

5.3 QGIS to map information

QGIS is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, printing, and analysis of geospatial data. QGIS functions as geographic information system (GIS) software, allowing users to analyze and edit spatial information, in addition to composing and exporting graphical maps. QGIS supports raster, vector and mesh layers. Vector data is stored as either point, line, or polygon features. Multiple formats of raster images are supported and the software can georeference images. QGIS supports shapefiles, personal geodatabases, dxf, MapInfo, PostGIS, and other industry-standard formats. Web services, including the Web Map Service and the Web Feature Service, are also supported to allow use of data from external sources.

In addition, QGIS provides an integrated Python console for scripting, and the functionality of QGIS can be extended using plugins written in Python.

In the WATERUN project, outputs of the risk assessment calculated in Python language will be linked and visualized in a mapping tool using QGIS. The mapping tool will be an intuitive visualization map where infrastructures for managing UWR can be easily visualized and linked to data and to communication texts. These features will be designed to assist stakeholder in decision making. For example, information about possible reuse of the stormwater or safe discharge of the harvested water can be displayed in the map (Figure 9). All these suggestions/information will be supported by scientific data and by the outputs of a risk analysis.

Figure 9: Mapping tool

6 WATER SENSITIVE URBAN DESIGN BASED ON RISK APPROACH

The risk-based tool developed during WP5 research activities will be integrated with specific features that will allow a Water Sensitive Urban Design (WSUD) based on risk assessment. Particularly, the risk-based tool will allow to evaluate the reduction of the health and environmental risk after the implementation of different green infrastructures or UWR treatment processes. The new tool will be able to perform QCRA and QRMA utilizing simulated data after the application of selected stormwater treatment technologies. Hence, a library containing expected ranges of log removal for pathogens and chemical contaminants after stormwater treatments will be included in the Python code. Expected removal for pathogens or chemical substances removal will be acquired by literature review and by data collected from the monitoring campaigns at Santiago De Compostela and Aarhus cases study.

According to a preliminary literature analysis, chemical and physical treatments of UWR perform better than natural treatments for bacteria removal (Crocetti et al., 2021; NRMMC–EPHC–AHMC, 2009; Ragazzo et al., 2013; Rocher & Azimi, 2021). Particularly, the combination of GI with disinfection processes (i.e., performic acid disinfection or UV disinfection) may allow important bacteria log removals with significant reduction of the microbiological risk. In Table 3, expected log removal for bacteria after treatment of stormwater with Nature Based Solution, UV disinfection and performic acid (PFA) disinfection are reported.

Table 2: Expected bacteria log-removals

Bacteria removal			
Treatment	**Typical dosages**	**Log removals**	**Reference**
Nature Based Solution/Green Infrastructure	-	0.5 – 1	NRMMC–EPHC–AHMC, 2009
UV disinfection	100 – 200 mJ/cm^2	2 - 4	Crocetti et al., 2021; NRMMC–EPHC–AHMC, 2009; Ragazzo et al., 2013; Rocher and Azimi, 2021
PFA disinfection	2.5 – 5 mg/L	2.5 - 3	Crocetti et al., 2021; NRMMC–EPHC–AHMC, 2009; Ragazzo et al., 2013; Rocher and Azimi, 2021

This further feature of the risk-based tool can be utilized to assist stakeholders in the selection of the most suitable GI or combination of stormwater treatment technologies to reduce health and environmental risk during stormwater reuse and management.

7 EARLY WARNING SYSTEM FOR STORMWATER MANAGEMENT

An Early warning system (EWS) can be defined as a set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

In the framework of the DSS based on risk assessment, its “EWS” capacity consists in the feature to forecast the UWR quality in water basins designed for reuse or connected to recreational activities and inform stakeholders about the need of restrictions on the use of water.

The EWS should be based on precipitation forecast and expected load of diffuse pollution in a target area. This provisional information can be used by the SWMM model to simulate the expected stormwater event and the production of pollutant loads associated with stormwater runoff. Hence, concentration of contaminants/pathogens predicted by the SWMM model can be compared with thresholds determined by a previous risk analysis or fixed by the legislative framework to provide indication on restrictions on the use/reuse of water. Thresholds can be defined for pollutants concentrations in stormwater to generate warnings in the mapping tool. For example, the current European bathing water directive (BWD) (EU 76/160/EEC, 2006) requires the implementation of reliable early warning systems for bathing waters because adverse health effects are related to the exposure of bathers to pathogens during bathing activities. In this case, thresholds for pathogens concentrations defined by the BWD for the classification of water quality (Table 5) can be used by the EWS to produce a warning if E. Coli concentration in the sewer overflows are higher than those threshold values.

Table 3: Standard limits for E. Coli concentration established by the EU Directive 2006/7/EC for bathing sites in coastal waters and transitional waters

EU Directive 2006/7/EC			
Parameter	**Excellent quality**	**Good quality**	**Sufficient**
Escherichia coli (cfu/100 ml)	250[a]	500[a]	500[b]
a = Based upon a 95-percentile evaluation; b = Based upon a 90-percentile evaluation			

Simulations of the SWMM model to define thresholds for the EWS feature of the DSS will be strictly based on collected data for chemical contaminants and pathogens during the planned monitoring campaigns at the cases study of Santiago De Compostela and Aarhus.

8 APPLICATION OF A PRELIMINARY VERSION OF THE RISK-BASED TOOL TO CUPRA MARITTIMA CASE STUDY

A first prototype of risk assessment tool was tested in an Italian Case Study, the municipality of Cupra Marittima that is located in the South of Marche Region (central Italy), in order to evaluate the quality of occurring sewer overflows during different precipitation events and to calculate QMRA. Particularly, outputs of the simulations and QMRA analysis provided indications about reuse possibilities of treated and untreated sewer discharges and impacts of sewer overflows in the receiving bathing water (i.e., Adriatic Sea).

The drainage basin of Cupra Marittima (Figure 10) covers an area of 2.15 km^2 with a sewerage network consisting of 37% combined network. The WWTP is located near the coast and collects flows from the West and South part of the basin.

Figure 10: basin of Cupra Marittima CS

Along the sewage network there are 13 Combined Sewer Overflows - CSOs (4-line spillways and 9 spillways associated with pumping stations) that discharge excess flow during wet period into several surface streams that convey the collected water into the Adriatic Sea.

After a detailed analysis of the sewer network, a qualitative-quantitative model was built using SWMM to estimate quantity and quality of water flowing in the sewer network system of Cupra Marittima. The model was calibrated and validated using field data collected during dry and wet weather. SWMM model was utilized to predict E. Coli and Campylobacter concentrations in the 13 sewer overflows present in the sewer network.

Simulated E. Coli concentrations in sewer overflows related to typical rainfall events in the area are shown in Figure 11 in the case of untreated sewer overflows and treated sewer overflows by Nature Based Solutions (NBS) and PFA disinfection. In Figure 11, E. Coli concentrations are compared with thresholds established by the EU Directive 2006/7/EC.

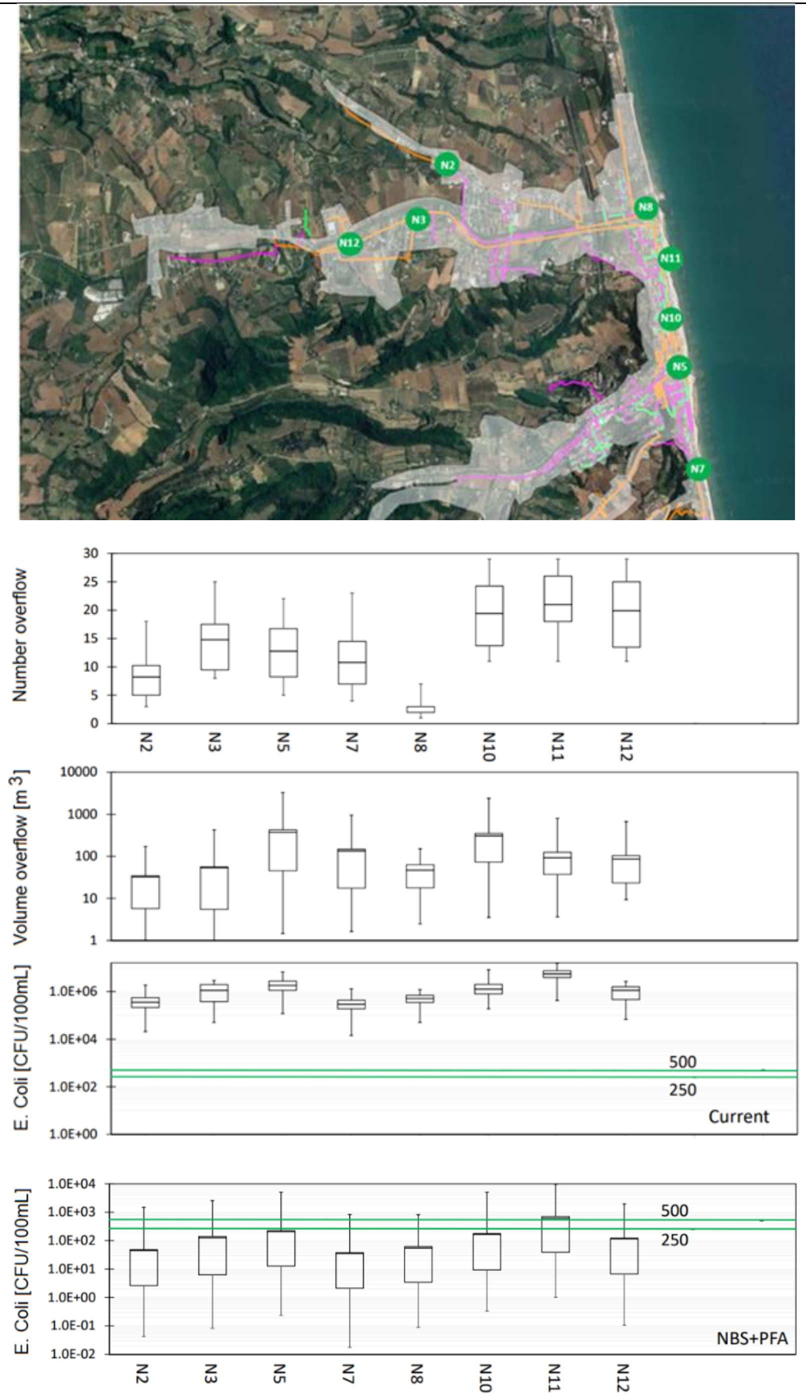


Figure 11: Localization of sewer overflows at Cupra Marittima and simulated E. Coli concentrations in untreated and treated stormwater. Green lines represent thresholds related to the EU Bathing Water Directive 2006/7/EC

The Python tool was utilized to elaborate SWMM outputs and to perform QMRA. The risk for Campylobacter infections when reusing stormwater for green areas irrigation was calculated

Funded by the European Union

in terms of DALY/year in the untreated sewer overflows streams and after treatment with Nature Based Solutions (NBS) and disinfection (performic acid – PFA, and UV irradiation). Particularly, campylobacter concentrations simulated with SWMM were estimated in sewer overflows with and without presence of treatment technologies by using a uniform distribution function to apply log-removal for bacteria provided in Table 3. These different set of data were utilized to calculate QMRA before and after treatment. Obtained results and comparison with WHO (2016) thresholds are reported In Figure 12.

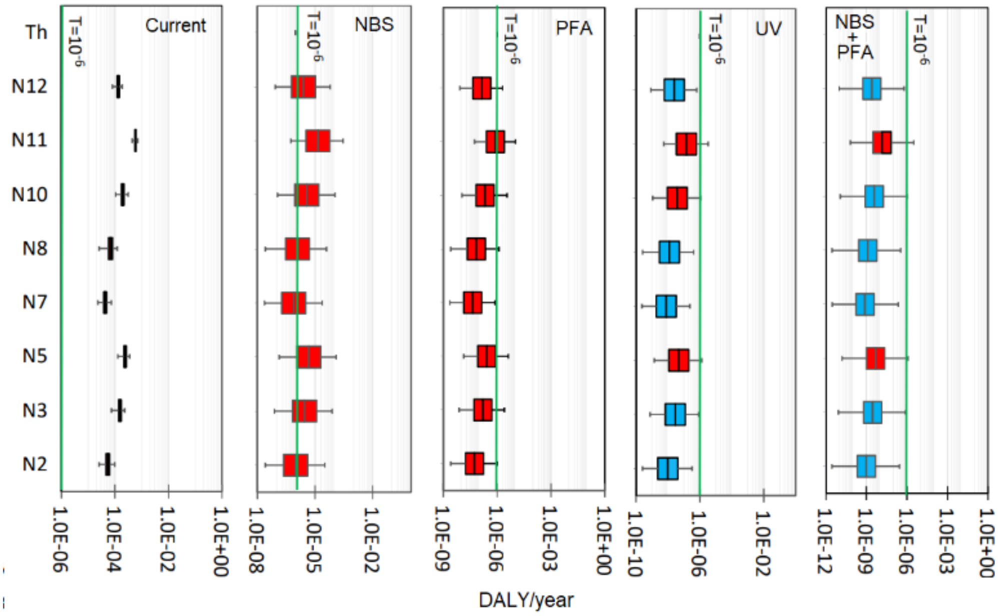


Figure 12: DALY/year for: a) current, b) NBS, c) PFA, d) UV, e) NBS+PFA

9 CONCLUSION

The definition of the general structure of the risk based DSS is an important task that will lead the future development of this WATERUN product. In this document all the criteria taken into account to design the structure of the DSS have been discussed.

First, an analysis of the European regulation framework was conducted to define features of the DSS that may be useful to address challenges raised by the recent and upcoming regulations. Hence, opportunities and benefits for the reuse of stormwater were discussed along with a presentation of the WATERUN cases studies, where the DSS will be tested.

The technical guidelines that provide information for the calculations of the quantitative risk assessment are presented as well as the description of the approaches that will be utilized to perform a quantitative microbiologic and chemical risk assessment (QMRA and QCRA).

The integration of software and tools (i.e., SWMM, Python tool, QGIS) that will be utilized to create the DSS was discussed as well as the possibilities to support the decision making process, to produce warning and suggestions for the use of water, and opportunities for water sensitive urban design within an urban area.

The scope of this document is to provide a general description of the risk based DSS and its main features. The document can be useful to increase the collaboration with partners and stakeholders during the co-creation process envisioned in WATERUN.

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