D.4.3.1 – Guidelines to assess the quality of urban wastewater and coastal system

Document Control Sheet

Project number:	10044130
Project acronym	WATERCARE
Project Title	Water management solutions for reducing microbial environment impact in coastal areas
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Duration	36 months

Related activity:	4.3 – Feasibility studies to implement innovative solutions in the WATERCARE sites
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Work Package Title	WATERCARE Pilot realization
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Work Package Leader	ASET SPA

Status	Final
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INDEX

ANNEXES

- VOLUME 1 - Basics on the pollution monitoring and collected data analysis
- VOLUME 2 - Identification of a set of possible solutions to remove the pollution and/or to mitigate the pollution effect
- VOLUME 3 - The decisional process to identify the best solution and the relevant concept design
- VOLUME 4 - Site-specific reference

1. INTRODUCTION

ASET S.p.A. - as WP4 leader – is the responsible of the redaction of a Guide-Line for the execution of Feasibility Studies to implement innovative solutions in the WATERCARE sites.

Therefore, ASET elaborated a set of documents to be used by any PP in carrying out a proper feasibility study specific for the relevant project site.

The deliverable D.4.3.1 consists of:

- D.4.3.1 Guidelines to assess the quality of urban wastewater and coastal system;
- Volume 1: basics on the pollution monitoring and collected data analysis;
- Volume 2: identification of a set of possible solutions to remove the pollution and/or to mitigate the pollution effect;
- Volume 3: the decisional process to identify the best solution and the relevant Concept Design;
- Volume 4: site-specific reference;
- Typical drawings of the possible solutions to solve the pollution of the bathing area;

This document represents the introduction to the specifics Annexes / Volumes 1-2-3-4 consisting of the body of the deliverable.

2. FEASIBILITY STUDY

A feasibility study is defined as an evaluation or analysis of the potential impact of a proposed project (NFSMI, 2002). It aims to assist decision–makers and planners in determining the opportunities offered by the implementation of a project, based on research on the possible practices and measures and on an evaluation of their technical, environmental, social and financial impacts.

The realization of a detention tank to collect the water coming from existing CSO (Combined Sewer Overflow) in the Municipality of Fano – site of the WATERCARE pilot project – started from the execution of a proper feasibility study and the scope of this Guideline is to share the experience acquired as well as to explain how the whole design phase was carried out.

3. DATA COLLECTION AND ANALISYS

A feasibility study should address many different aspects such as geological, technical, economic, environmental, sociological, and quality and risks issues related to the proposed solutions. Data collection is a critical aspect of a feasibility study because from this specific activity depends the following selection of alternatives and impact evaluation.

Considering the theme of how untreated or partially treated wastewater can affect the bathing sea water and the quality of superficial water bodies, it is important to identify in general:

- Characteristics of the zone;
- Water quality and Integrated water balance of the catchment;
- Characteristics of the water supply networks, sewer networks and existing wastewater treatment plants;
- Seasonal variations of wastewater – past and future trends;
- Quality standards for effluent;

In the development of a feasibility study, it is therefore important to count with varied and reliable data values, indicators and information regarding different issues. To obtain this information it is necessary to engage the main stakeholders (public institutions, organisations and associations related to water, Water and Wastewater Agencies, Regional Environmental Agencies, Councils and Regional Governments, etc.

The most important data to be collected can include:

- Water supply and demand (local and seasonal);
- Land use and population (current state and projections);
- Industrial activities and produced wastewater;
- Sewerage network maps, presence and characteristics of combined sewer overflows and pumping stations;
- Points of discharge of treated and untreated water;
- Water and wastewater management agencies in the area;
- Regional water and wastewater facilities (in operation and planned);
- Environmental framework: climate characteristics, geography and topography, geological and hydrogeological information, surface water quality.

For any detail on this topic see ANNEXE - VOLUME 1.

4. TECHNICAL SUITABLE SOLUTIONS

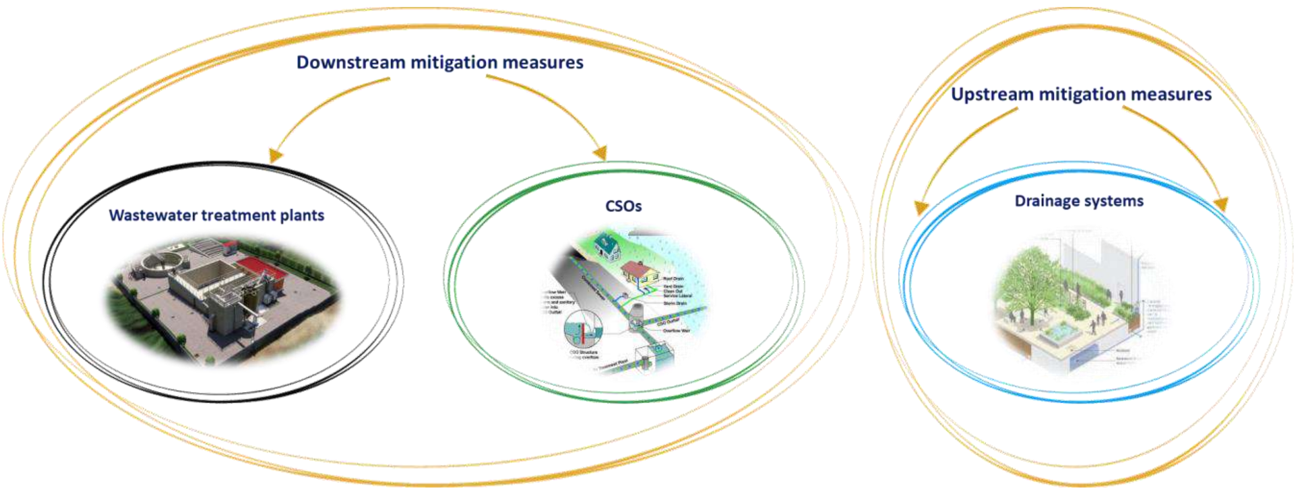
After rainfall events in densely populated areas, combined sewer overflows (CSOs) can have severe health-related effects upon surface water quality, as well as discharges from diffuse overland pollution and wastewater treatment plants (WWTPs) (Tondera, 2017). All of these sources emit pathogens and faecal indicator bacteria into the surface water, which the EU Bathing Water Directive addresses by giving threshold values for the indicators Escherichia coli and intestinal enterococci.

The analysis of possible solutions should include both **downstream mitigation measures**, which aim at treating the polluted water before it is discharged in the final recipient, and **upstream mitigation measures**, which focus on the drainage network.

Downstream solutions may include:

- the construction of new wastewater treatment plants or upgrading of existing ones to avoid the discharge of untreated water;
- the treatment of the water from combined sewer overflows and upgrading of existing structures to reduce the impact on recipient bodies.

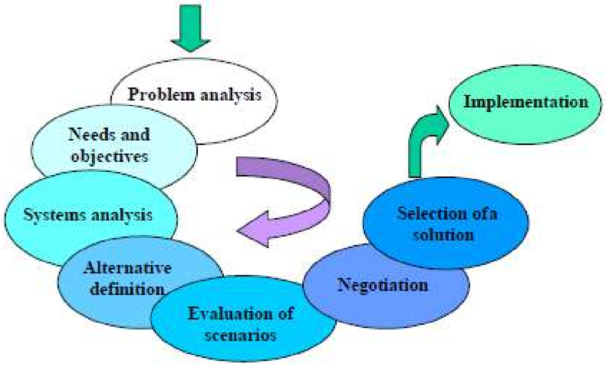
Upstream solutions aim at reducing the inflow of non-polluted rainwater in the wastewater networks, for example through the separation of stormwater and wastewater networks or the use of sustainable drainage solutions.



For any detail on this topic see ANNEXE - VOLUME 2.

5. THE DECISIONAL PROCESS

The following figure shows the different steps followed in a decision-making process (Thomas, 2003).



To evaluate the potential impact of a wastewater treatment solution, by addressing the calculation of social and environmental indicators, it may not be feasible or simple to quantify them all at a preliminary phase. A more visual and simpler method could comprise their representation in tables by associating their individual impact with a colour or with a score associated with a colour.

In this way, the overview of the impacts of all indicators could give an idea of the general assessment of each alternative and an impression of the overall impact of the project. However, the absence of weights in the indicators can lead to incorrect conclusions. Therefore, the main elements required to face a semi-quantitative assessment by a Multi Criteria Analysis (MCA) using key indicators are an expert knowledge to evaluate the impact reflected in the result, and the weights assigned to different categories (i.e. environmental, social and economic) that should be established by the project promoters and decision makers.

For small interventions, S.W.O.T analysis can be a more simplified approach.

In the **ANNEXE - VOLUME 3**, a simplified MCA is proposed for the targeted subjects: (i) new wastewater treatment for urban wastewater; (ii) upgrading of existing wastewater treatment for urban wastewater; (iii) small wastewater treatment; (iv) combined sewer overflow; (v) upgrading of existing drainage systems. The proposed simplified MCAs aim to help identifying most proper solutions in preliminary decision-making phases, guiding the development of detailed feasibility studies and basic design for site specific conditions.

6. SITE SPECIFIC REFERENCE

The aim of Watercare project is to share the experience and the knowledge acquired during the development of the Pilot Project realized in the Municipality of Fano with all the project partner and to make proper assessment in all the other project sites that are:

- mouth of Pescara River (project partner Regione Abruzzo);
- mouth of Rasa River (Istrian University of Applied Sciences / METRIS Research Centre Pola);
- mouth of Cetina River (Country of Split – Dalmatia Split);
- mouth of Neretva River (Dubrovnik and Neretva Region);

For any detail on this topic see ANNEXE - VOLUME 4.

D.4.3.1 – Guidelines to assess the quality of urban wastewater and coastal system

VOLUME 1 - Basics on the pollution monitoring and collected data analysis

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1 INTRODUCTION

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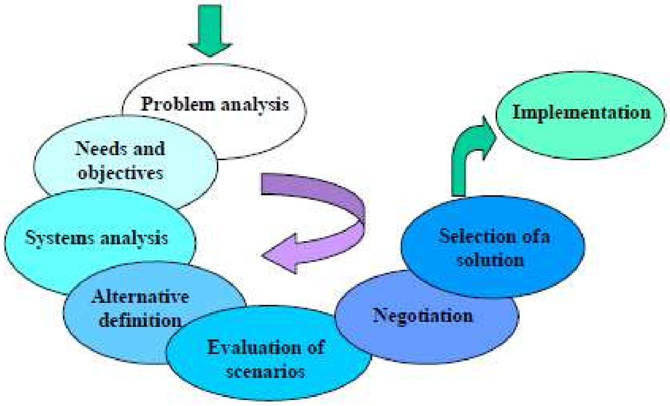

Figure 1. different steps followed in a decision-making process (Thomas, 2003)

This volume is intended for documentation and basic information, which needs to be compiled before proceeding with the preparation of feasibility study. Indeed, the drawing up of such a volume involves multifaceted knowledge, both economic and technical, which requires in the first place the creation of a complete and well-organized database destined for a whole picture that serves to work out the best solution.

2 BACKGROUND DATA

A feasibility study should address many different aspects such as geological, technical, economic, environmental, sociological, and quality and risks issues related to the proposed solutions. Data collection is a critical aspect of a feasibility study because selection of alternatives and impact evaluation depends on this specific activity.

Considering the theme of how untreated or partially treated wastewater can affect the bathing sea water and the quality of superficial water bodies, it is important to identify in general:

- Characteristics of the area
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- Points of discharge of treated and untreated water;

- Water and wastewater management agencies in the area;
- Regional water and wastewater facilities (in operation and planned);
- Environmental framework: climate characteristics, geography and topography, geological and hydrogeological information, surface water quality.

2.1 Topographic and geographic framework

The preparation of the feasibility study of waste treatment alternatives must involve the gathering of data about basic topographic characteristics of the area of interest.

As for mapping at general level, it is possible to resort to:

- Technical map at regional scale (scale of 1:20'000 – 1:10'000)
- Aerial surveying of the communal territory (scale of 1:2.000)
- Relevant detailed maps provided by the local authority and/or maps available online

In addition, it is obligatory to proceed with the acquisition of urban planning tools, information on present restrictions as well as environmental and landscape maps of the intervention area.

Lastly, information on current topographic features of the sites should be collected, for which purpose it would be helpful to obtain the DTM (Digital Terrain Model) from the local public administration, if available.

Sources available for the acquisition of DTM can be accessed via the following link:

https://data.europa.eu/data/datasets?keywords=dtm&keywords=digital-terrain-model&locale=it&page=1

With regard to the processing of cartographic and topographic data, the GIS approach is recommended to allow for clear portrayal of various themes.

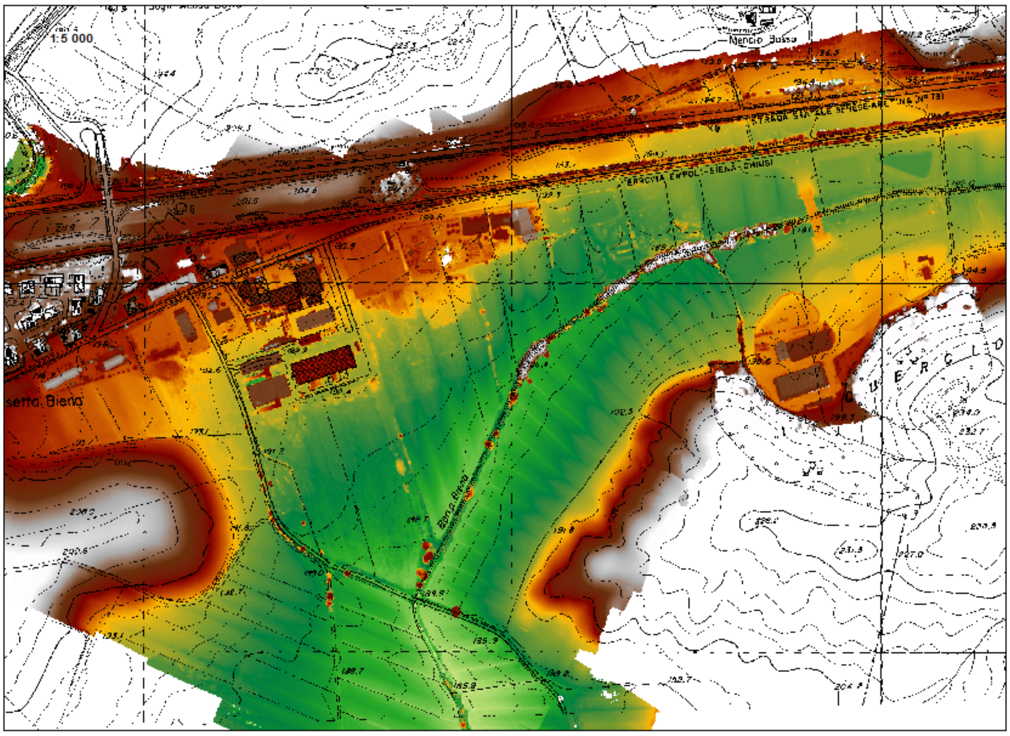


Figure 2. Elaborazione del DTM e della cartografia di base in ambiente GIS

2.2 Climate

Climate will definitely determine water resources and future water needs. It is for this reason that this aspect should be addressed in a feasibility study on water reuse.

The information to be surveyed might include:

- Annual evaporation, average temperature and average annual high and low temperatures.
- Main type of winds
- Risks associated to the climate.

The mean net and gross annual evaporation, annual average high and low temperatures should also be specified. Temperature seasonality, main drought periods, etc. might be included in this section with charts enclosed. Furthermore, future changes and trends (droughts, floods…)

might be pointed out.

2.3 Load assessment

The assessment of hydraulic load consists in the calculation of water consumption for the definition of wastewater flow rate, and in the hydrological analysis to define rainwater flow rate. With regards to the first aspect, the water consumption depends on both per-capita demand and the demographic density of the territory.

As for the calculation of rainwater flow rate, it is necessary to have the knowledge of rainfall frequency, morphological characteristics and land use in the drainage territory.

Considering fundamental role that the design flow rate plays in the size and cost-effectiveness of the treatment system, it is necessary to pay particular attention to the gathering and processing of data for the feasibility study.

2.3.1 Rainwater analysis

Given a sewer of mixed-type (wastewater flow rate + rainwater flow rate), the network study requires the knowledge of the flow rate in wet weather, and consequently the pattern of intense rainfall in the site of interest. Such pattern is expressed by the intensity-duration-frequency (IDF) curves, functions that statistically evaluate the height of rainfall at a certain geographical location as a function of rainfall duration (t) and return time (Tr). The factors are simply expressed in the following formula:

$$h = a_T \cdot d^n$$

The proposed methodologies to determine the parameters *a* and *n* are based on regionalization models available for the areas of intervention (especially for the areas where local rainfall time series are unavailable) or on local statistical analyses of annual maximum rainfall for various durations, if available. In this hypothesis, the analytical process goes through the extraction of available time-series for the annual maximum rainfall heights for required durations, usually those of 1, 3, 6, 12, 24 hours are chosen as the critical time range for the basins.

The data relating to rainfall can be found via specific websites of the Environment Agency or by direct request to specific entities that manage the local meteorological network.

The annual maximum series for required duration thus obtained can be considered as a sample of size N (with N equal to the number of observation years) of a random variable and thus, by means of the inferential statistics techniques, it is possible to do research on the more appropriate probability function for data interpretation. In common hydrological practice, the most widely used probability distributions are Gumbel distribution, log-normal distribution and GEV distribution (Generalized Extreme Value). Once the function that best suits the sample is identified, it is possible to estimate the parameters characterizing the IDF function.

Particular importance is attached to the selection of return time. In the study phase, a thorough analysis of the so-called insufficiency risk must be conducted, i.e. the risk associated with the occurrence of extreme events which are even more intense than those adopted in the design, leading to flow rates greater than predicted.

Recommended values of return time Tr are 5 or 10 years.

2.3.2 Flow rate calculation

To determine outflow rate there are various methods involving rainfall data which is obtainable from the aforementioned IDF curves, as well as morphological features of the drainage area.

This information will provide data on the actual rainwater inflow in the sewer because, as it is known, part of the rainwater amount is lost as a result of a series of hydrological phenomena. Therefore, the proper assessment of land use in those areas flowing into the network will be essential. Such information enables the correct estimation of influx coefficient in sewer.

In order to determine the flow rate, it is possible to apply various methodologies which are proposed in the specialized literature such as the *rational method, cinematic method, etc.* The detailed hydrological assessment can also be carried out through the application of inflow-outflow transformation models (*SWMM, HEC-HMS, InfoWorks WS*).

In the phase of drawing up the study, the methodology deemed most appropriate will be adopted.

2.4 Land use

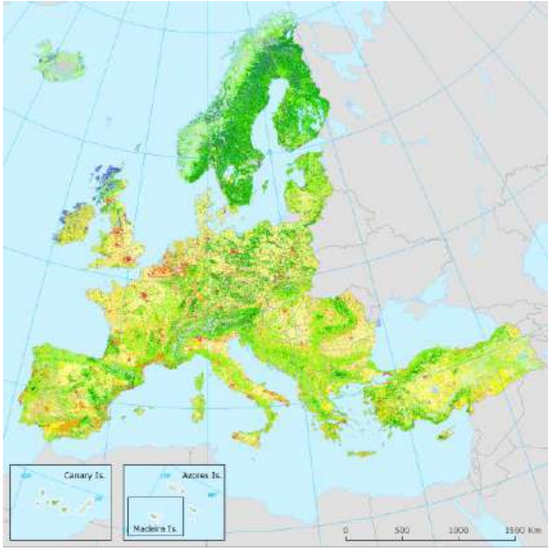
The proper evaluation of pollutant loads is strictly related to the estimation of flow rate at the network inlet in both dry weather and wet weather. As previously mentioned, the estimation of flow rate definitely starts from the assessment of land cover and the infiltration coefficient of the drainage areas connected to the drainage network.

The land cover is referred to as the biophysical cover of the land surface. According to the Directive 2007/2/CE, the physical and biological cover of the land surface comprises artificial surfaces, agricultural zones, woods and forests, semi-natural areas, humid zones, water bodies.

For several years the European Environment Agency has ensured the delivery, verification and improvement of a series of services for the program "*Copernicus*" destined for the monitoring of territory, including the "Corine Land Cover". The Europe's initiative Corine Land Cover (CLC) was launched in 1985 to survey and monitor the cover features and land use, with the aim to dynamically verify the state of the environment. The CLC data is the only source that guarantees an European and national framework which is complete and homogenous, with a time-series containing information of almost 30 years (1990, 2000, 2006, 2012, 2018). In the final version, the CLC presents a Map of Land Cover with high spatial resolution which constitutes the national-level reference for the implementation of analysis of the state of territory and landscape, as well as for the research of natural and anthropogenic process.

The database Copernicus European Project – Land Monitoring Service Corine Land Cover is available at Geomapviewer https://land.copernicus.eu/pan-european/corine-land-cover e usable as OGC service.

The GIS platform is recommended for processing data on land use.



Color	Percent	Hectares	Class
	0.008	859	Continuous urban fabric
	3.709	411600	Discontinuous urban fabric
	0.724	80370	Industrial or commercial units
	0.040	4419	Road and rail networks and associated land
	0.006	688	Port areas
	0.044	4832	Airports
	0.312	34640	Mineral extraction sites
	0.026	2841	Dump sites
	0.008	838	Construction sites
	0.042	4678	Green urban areas
	0.105	11600	Sport and leisure facilities
	35.048	3889000	Non-irrigated arable land
	0.129	14320	Rice fields
	1.311	145400	Vineyards
	0.587	65100	Fruit trees and berry plantations
	3.690	409400	Pastures
	1.819	201800	Complex cultivation patterns
	9.114	1011000	Land principally occupied by agriculture with significant areas of natural vegetation
	20.781	2306000	Broad-leaved forest
	4.819	534700	Coniferous forest
	5.750	638000	Mixed forest
	3.521	390700	Natural grasslands
	0.285	31640	Moors and heathland
	6.646	737500	Transitional woodland-shrub
	0.017	1901	Beaches - dunes - sands
	0.112	12430	Bare rocks
	0.364	40430	Sparsely vegetated areas
	0.003	370	Burnt areas
	0.081	8947	Inland marshes
	0.011	1263	Peat bogs
	0.000	32	Salt marshes
	0.007	800	Salines
	0.283	31390	Water courses
	0.585	64940	Water bodies
	0.003	365	Coastal lagoons
	0.011	1179	Sea and ocean

Figure 3. Banca dati CORINE LAND COVER

2.5 Water quality

The different categories of water quality in the study (main streams, lagoons, sea) should be described and the different water sources classified. Existing data on water quality should be collected for a sufficient number of year, making possible a statistical analysis to evaluate current and future trends. Water quality guidelines and parameter ranges within the studied zone should also be enclosed as reference.

In the present project, the water quality is mainly focused on reducing microbial environment impact in coastal areas; however it could be interesting to evaluate the water quality of the streams connected to the coastal area, as well as the water quality of transitional waters.

Every year the Commission and the European Environment Agency publish a summary report on the quality of bathing water and national country reports based on the information provided by Member States.

The Bathing Water Directive (BWD) (2006/7/EC) was introduced by EC in 1976 and revised in 2006. The European Commission is now reviewing the Bathing Water Directive, by publishing its roadmap on 04/03/2021.

Other directive of interest for the studies are the following:

- Urban Waste Water Treatment Directive, 91/271/EEC (EU 1991a).
- Nitrates Directive, 91/676/EEC (EU 1991b).
- Industrial Emissions Directive, 2010/75/EU (EU 2010).

Moreover at the national and regional level there could be specific norms, generally derived by the European directive, which should be investigated.

Within each site of the Watercare project, a monitoring of coastal sea water is provided for each site.

2.6 General information and gathering of data on sewerage network and wastewater treatment

In addition to the topographic knowledge of the territory and hydraulic function (design flow rate and rainfall), the analysis of the network and the selection of a treatment type require the knowledge and acquisition of some elements which are essential to the preparation of the feasibility study. The necessary information are as follows:

- Mapping and reconstruction of the existing sewer network with existing discharge points and treatment systems being identified
- Risk assessment
- Acquisition of information related to demographic consumption

- Acquisition of data related to residential water consumption
- In-depth investigation of industrial activities characterization
- Acquisition of development plans to identify areas designated for new manufacturing facilities

The activities needed for each item listed above will be described in the next paragraphs.

2.6.1 Mapping and reconstruction of existing network

The activities comprise the ascertainment of the state of the existing sewerage works in order to produce a whole picture of the network being studied in both quantitative, functional diagrams and qualitative terms. This is a fundamental activity which creates a starting point for the preparation of the study.

The reconstruction of the existing network can be implemented on the basis of information retrievable from management entities.

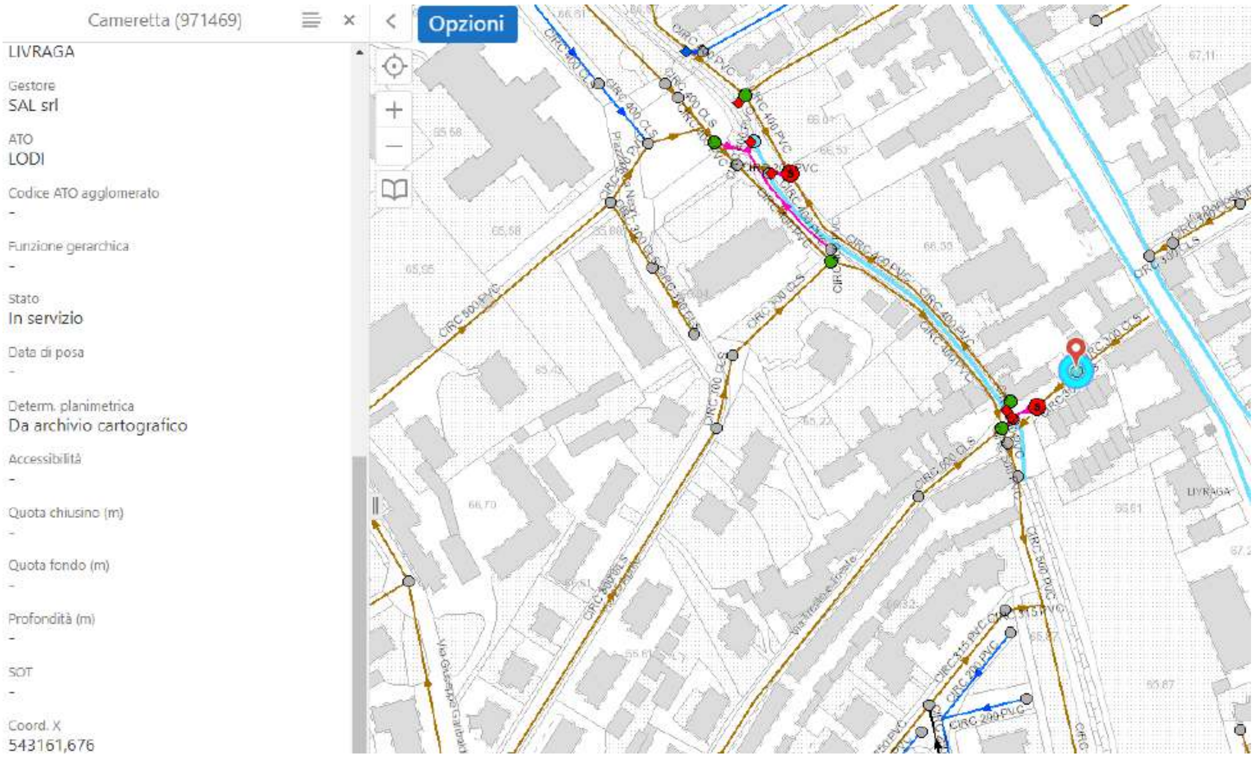


Figure 4. Example of database in GIS format of an existing sewerage network

The database analyses can be supported by field activities which are usually fundamental to obtain a more detailed knowledge of the scale of the existing network. By means of field activities and survey, it is possible to identify the sectors of the network that need to be further explored and where direct inspection can be implemented.

2.6.2 Treatment plants

In addition to the reconstruction of the existing network, it is necessary to review and survey the existing water treatment plants. For site, it is a good practice to build a database in GIS platform containing all the information useful for its characterization:

- Location of the system and discharge point;
- Catchment extension and characteristics (residential, industrial, network connection

percentage..);

- Current treatment type (including possible pre-treatment);
- Capacity (inhabitants equivalent);
- Influx flow rate and presence of possible bypass or overflow;
- Presence of monitoring points for discharge quality.

With regard to this aspect, it is fundamental to collect and retain the measured data.

2.6.3 Discharge points of drainage network

Equally important for the drawing up of the study is the surveying of discharge points and of CSOs of the network. It is essential to have detailed knowledge of such elements from both geometric and quantitative point of view (in terms of discharge rate) and from qualitative point of view. In order to delve into this aspect, it is advisable to launch a monitoring campaign (if not already in progress).

It is also recommended to carry out topographic survey campaigns to acquire a detailed knowledge of all significant structures.

2.6.4 Acquisition of information regarding demographic consumption

As for the assessment of pollutant loads, it is necessary to gather data on permanent and non-permanent residents in the territory of interest. The collected data have to be processed and integrated with the communal development plans and with the data on population density in order to be able to make an estimate of the future population trend. The integration of such information will be utilized instead of a simple application of classical mathematic models adapted for this purpose (e.g., logistic curve). This methodology stems from the consideration that, in zones already highly affected by human activities, the population rarely grows based on the evidence of the past increase, but rather on a development planning which needs to be taken into account.

It is recommended that even the agglomerations probably not connected to the public sewer systems at present should be included in the demographic analysis as the future contribution of such agglomerations may create problems for the design infrastructure if not taken into account.

2.6.5 Acquisition of data related to residential water consumption

The data related to drinking water consumption constitutes another decisive element in assessing the discharged water originated from residential use because almost the entire amount of water conducted by the distribution network pours into the sewerage system as the last destination.

In the preliminary phase of the study preparation, it is recommended that an in-depth investigation with the management of the distribution network should be carried out with the aim to acquire data related to the distributed volume. Together with information on the population served by the system, such data enables the assessment of per-capita water supply.

The in-depth investigation of the daily water supply and the predicted evolution of the population allow for the establishment of the design wastewater flow rate and consequently the pollutant loads to be treated.

2.6.6 Characterization of industrial activities

The industrial activities within the site of interest must be identified to estimate the expected flow rate based on average values or if available data from specific investigations. The type of industrial activity is important for the assessment of water quality and type of pollutant loads and to proceed with an initial “*screening*” of possible solutions.

Particular attention should be paid to the identification of activities with potential strong impact on the territory, in which case sample surveys of enterprises could be carried out to characterize their use of water resources and the subsequent discharge into the sewer system.

2.7 Assessment of dataset quality

All the collected and utilized data has to be evaluated in terms of both quality and completeness and registered in a database. The qualitative criteria typically used for the evaluation of data quality include:

- Accuracy: What are the levels of accuracy and precision of the available data?
- Completeness: Is some data missing? Has the missing data been integrated?
- Update: Is the data updated?
- Consistency: Are there contradictions within the collected data?
- Compatibility: Is the data produced on the same reference basis?
- Reliability: Is the data intuitively correct if compared with the information of typical local range?

2.8 Legal framework and constraints

The preparation of the feasibility study should take in account European Community legislation regarding the treatment of urban wastewater (Directive 91/271/CEE), national and regional regulations and identify possible constraints of the site. In particular, limitations on the use of the project areas should be evaluated within the framework of urban-territorial policy and planning instruments in effect at communal, provincial and regional level. Furthermore, it is essential to consider the possible existence of environmentally protected areas, with specific reference to the existence of Places of Community's Interest or Zones of Special Protection.

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VOLUME 2 - Identification of a set of possible solutions to remove the pollution and/or to mitigate the pollution effect

Interreg Italy - Croatia WATERCARE

EUROPEAN UNION

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This volume will be dedicated to the description of different solutions to mitigate the impact of urban wastewater discharge on the coastal areas.

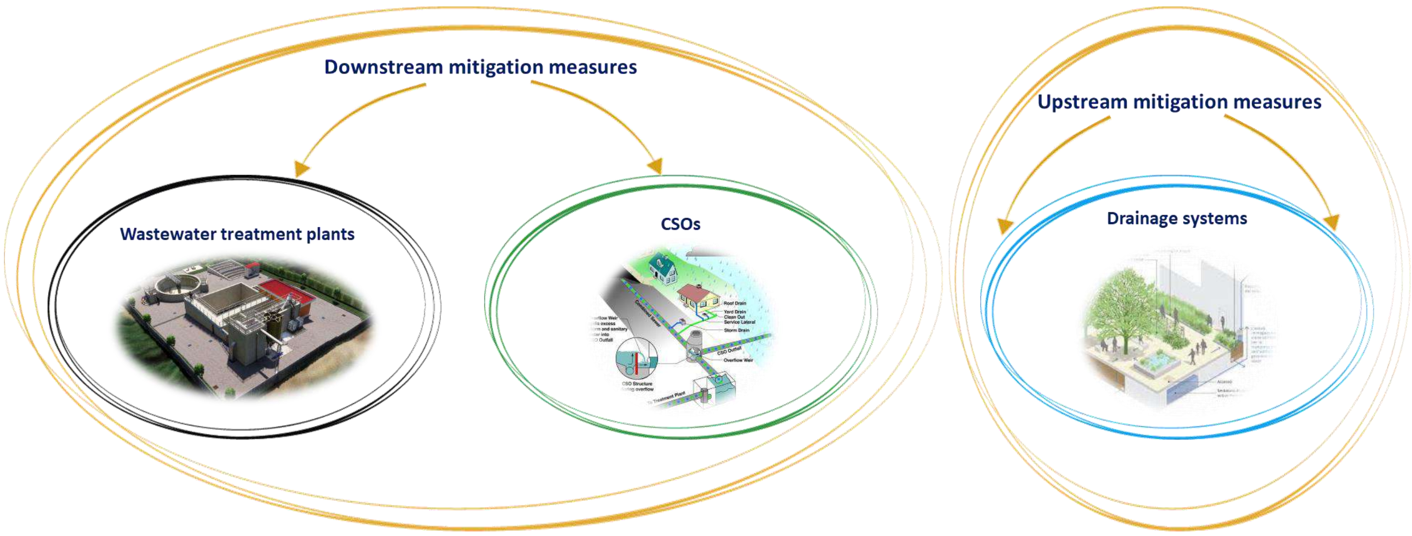
After rainfall events in densely populated areas, combined sewer overflows (CSOs) can have severe health-related effects upon surface water quality, as well as discharges from diffuse overland pollution and wastewater treatment plants (WWTPs) (Tondera, 2017). All of these sources emit pathogens and faecal indicator bacteria into the surface water, which the EU Bathing Water Directive addresses by giving threshold values for the indicators Escherichia coli and intestinal enterococci.

The analysis of possible solutions should include both **downstream mitigation measures**, which aim at treating the polluted water before it is discharged in the final recipient, and **upstream mitigation measures**, which focus on the drainage network.

Downstream solutions may include:

* the construction of new wastewater treatment plants or upgrading of existing ones to avoid the discharge of untreated water;
* the treatment of the water from combined sewer overflows and upgrading of existing structures to reduce the impact on recipient bodies.

Upstream solutions aim at reducing the inflow of non polluted rainwater in the wastewater networks, for example through the separation of stormwater and wastewater networks or the use of sustainable drainage solutions.



The following paragraphs identify a set of possible solutions for each of the main categories listed above, providing a general description, field of application, some indication on dimensioning parameters and methods, and the main features of each.

2 NEW WASTEWATER TREATMENT FOR URBAN WASTEWATER

Depending on the composition of the wastewater to be treated, the technology and the involved processes can be different. In the following list, different treatment schemes are summarized. Usually, intensive treatments are more expensive, more technological and require less space compared to extensive ones. Considering that the study areas are along the coastal line, the option of submarine pipeline is also considered, despite it cannot really be considered a kind of wastewater treatment.

1. Activated sludge plant
2. SBR
3. MBR
4. MBBR
5. Constructed Wetlands
6. WSP
7. Trickling filters
8. Rotating Biological contactors
9. Submarine pipeline

Based on background information, the design data and targets of each proposed new treatment plants has to be determined, in order to select the most appropriate treatment scheme:

- Study of water demands and needs by different uses (current and future).
- Flow analysis (fluctuations, seasonality)
- Expected wastewater quality in terms of organics, solids, nutrients, pathogens.
- Water quality to be fulfilled by each system

2.1 Technology options and main features

2.1.1 Activated sludge plant

Activated sludge plants have a high treatment efficiency and they are characterized by good reliability and flexibility, which makes them ideal for the treatment of domestic or industrial wastewater where space availability is limited. They are basically composed of:

- Primary settling tank (optional and generally used in the larger installation)
- Aeration tank
- Settling tank (secondary sedimentation tank)

Wastewater enters the aeration tank, where the oxygen concentration is kept at 2 mg/L minimum, the biomass is formed by using the substrate present in the influent sewage, and has a concentration of 3-5 g_{SS}/L. The hydraulic residence time is about 15 – 20 hours, after which the effluent is sent to the settling tank, where the biomass, made of large flocs, settles on the bottom, forming the sludge. A part of the sludge is recirculated to the aeration tank (*return sludge*) to maintain a high concentration of biomass in the reactor, while the rest is withdrawn from the system and sent to the sludge treatment system (*excess sludge*). (Von Sperling, M. (2007)).

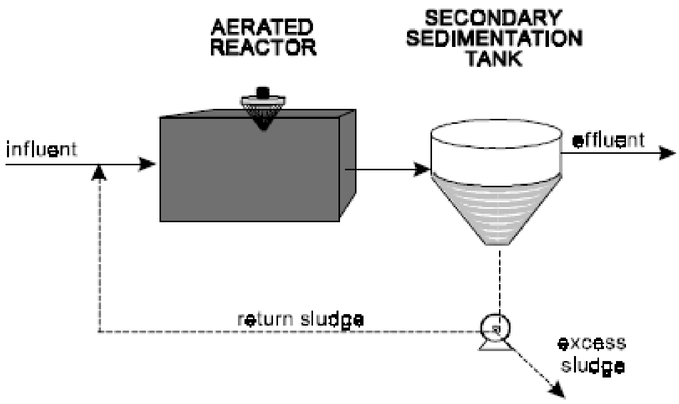


Figure 1. Main units of the biological stage of the activated sludge system (Source: Von Sperling, M. (2007))

A higher removal of nitrogen can be obtained by periodically interrupting the aeration in the reactor, by maintaining a lower oxygen concentration (< 1 mg/L), or by implementing specific denitrification compartments, before the aeration tank (*pre-denitrification*), or after the settling tank (*post-denitrification*).

The **Hydraulic Retention Time** (HRT), is in the order of hours, allowing for a reduced volume, while the recirculated sludge remains in the system for longer. The **sludge age** is about 10-15 days, and is defined as the ratio between the mass of biological sludge present in the reactor and the mass of biological sludge removed from the activated sludge system per day. Another practical parameter used for the activated sludge process is the food/microorganism ratio (**F/M ratio**), which is defined as the load of food or substrate (BOD_5) supplied per day per unit biomass in the reactor (represented by MLVSS – mixed liquor volatile suspended solids), and expressed as kgBOD/kgMLVSS·d (Von Sperling, M. (2007)).

The **oxygen demand**, that determines the energy consumption, is calculated with the oxygen consumption for active respiration (BOD_5 consumption), for endogenous respiration and for nitrification.

2.1.2 SBR (Sequencing Batch Reactor)

Sequencing Batch Reactors are activated sludge reactors where all of the operations happen in a single unit, and the different phases occur in temporal sequence rather than in spatial sequence. The **duration of each cycle** is the main dimensional parameter, and a treatment system can be implemented with a single SBR unit or with more SBR units working in parallel.

The phases in the treatment cycle are the following (Von Sperling, M. (2007)):

- Filling – input of wastewater into the reactor
- Reaction – aeration and mixing of the liquid in the reactor
- Settling – settling of the suspended solids
- Withdrawal – removal of the clarified effluent from the reactor

- Idle – adjustment of the cycles and removal of the excess sludge

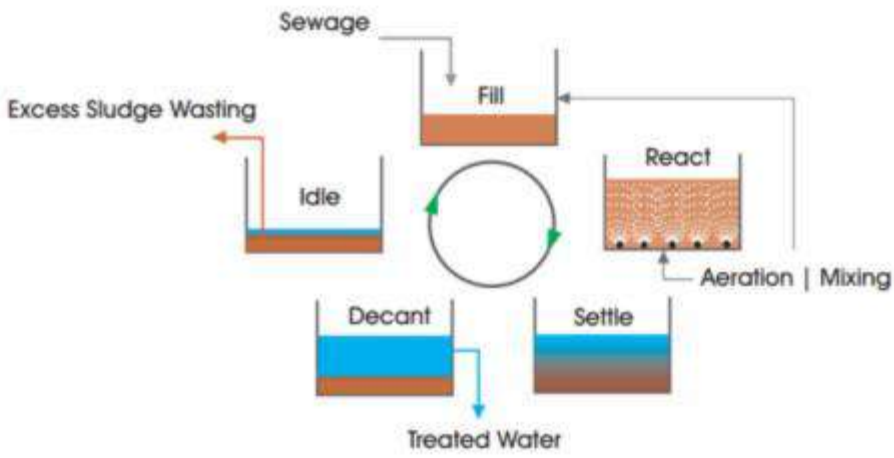


Figure 2. Cycle phases of a SBR (source: flocqua.com)

The SBR is characterised by a high operational flexibility, and the efficiency of the SBR is similar to that of the activated sludge plant.

2.1.3 MBR (Membrane Biological Reactor)

Membrane biological reactors are reactors in which the biomass is separated from treated water by a **membrane** rather than by sedimentation. The membrane is usually a microfiltration or ultrafiltration membrane, and it is either submerged in the reactor itself (*submerged membrane*) or in a separated unit (*side-stream*).

The cleared effluent is extracted by a pump, and an air insufflation system removes the biomass deposit from the membrane. The membrane is able to retain both floc-forming and filamentous bacteria, allowing to operate with lower sludge loads (0.04-0.08 kgBOD/(kgSS*d)) and higher sludge concentrations (10-18 kgSS/m^3), this results in a smaller volume needed for the tanks. The high sludge age of these processes allows greater mineralization of the organic substance, therefore greater stabilization, and disinfection is often not necessary.

2.1.4 MBBR (Moving Bed Bio Reactor)

Moving Bed Bio Reactors are reactors where the biomass is supported by **moving beds**, made of materials with large specific surface area for the attachment of the biomass (0.2-2 mm grains or materials with high porosity). The bed is kept moving by air insufflation or mechanically, the tanks are equipped with grids to prevent the elements of the reactor from being dragged and spilled. MBBRs are characterized by a high treatment capacity and the absence of clogging of the filter medium, however, the operational costs are quite high due to the energy consumption (Von Sperling, M. (2007)).

2.1.5 CW (Constructed Wetland)

Constructed wetlands are systems that exploit natural processes to treat wastewater, the two main types of CWs are **Free Water Systems** (FWS or SF) and **Subsurface Flow Systems** (SFS). In FWS a basin is filled with about 50 cm of water, in which floating or emergent rooted macrophytes grow. In SFS wastewater flows vertically (VF) or horizontally (HF) through a filling material (sand or gravel) and the roots of the plants growing in the basin.

The influent wastewater undergoes physical, chemical and biological degradation processes, and the effluent is collected at the end of the basin through collecting pipes. These systems require a higher **surface**, as adequate exposure to sunlight is essential for its proper functioning, and the bottom of the basin must have a slope for the water to flow. CWs are characterised by easy maintenance, but they require regular mowing of the emergent part of the vegetation and the removal of plant material from the bed.

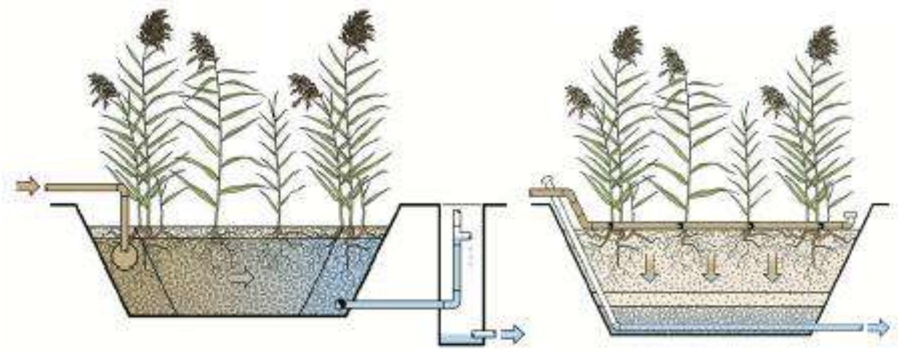


Figure 3. Horizontal flow (left) and vertical flow (right) subsurface systems (source: Dotro et al., 2017)

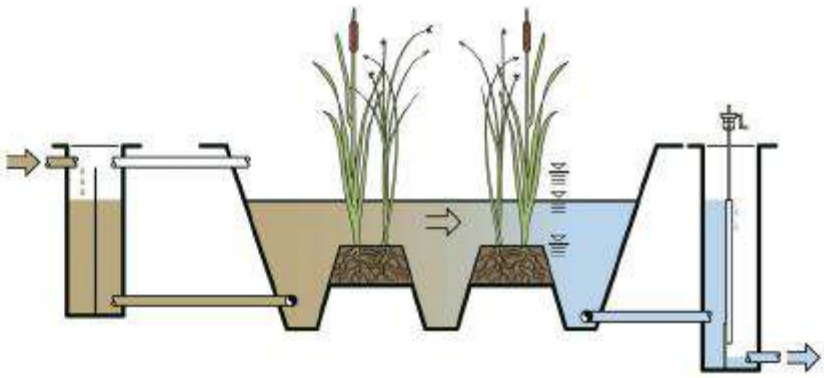


Figure 4. Free water system constructed wetland (source: Dotro et al., 2017)

The different systems (HF, VF and FWS) can be combined to constitute hybrid (or multi-stage) systems. Hybrid systems are usually employed in large-scale wastewater treatment, while single stage CW systems are implemented for single houses or small groups of houses (paragraph 4.2). The design of hybrid systems needs individual considerations based on the treatment goal, the final design of each stage may differ from the design of the same stand-alone system (Cross et al., 2021).

One of the most significant examples of multistage systems in Europe is the constructed wetland of Orhei, Moldova. The plant treats about 20,000 PE wastewater in about 5 ha, being one of the largest primary and secondary CW WWTPs worldwide, it has been designed to face different issues such as seasonal variations of wastewater and low temperatures in winter (reaching -27°C), the multi-stage system is divided into four lines, each of them composed of two stages in series: the first stage is a French system with a vertical flow reed bed for raw sewage, and the second stage is a classical vertical flow reed bed system; the average hydraulic load is 1,014± 275 m^3/d, with a peak value up to 1,926 m^3/d (Masi et al., 2017).

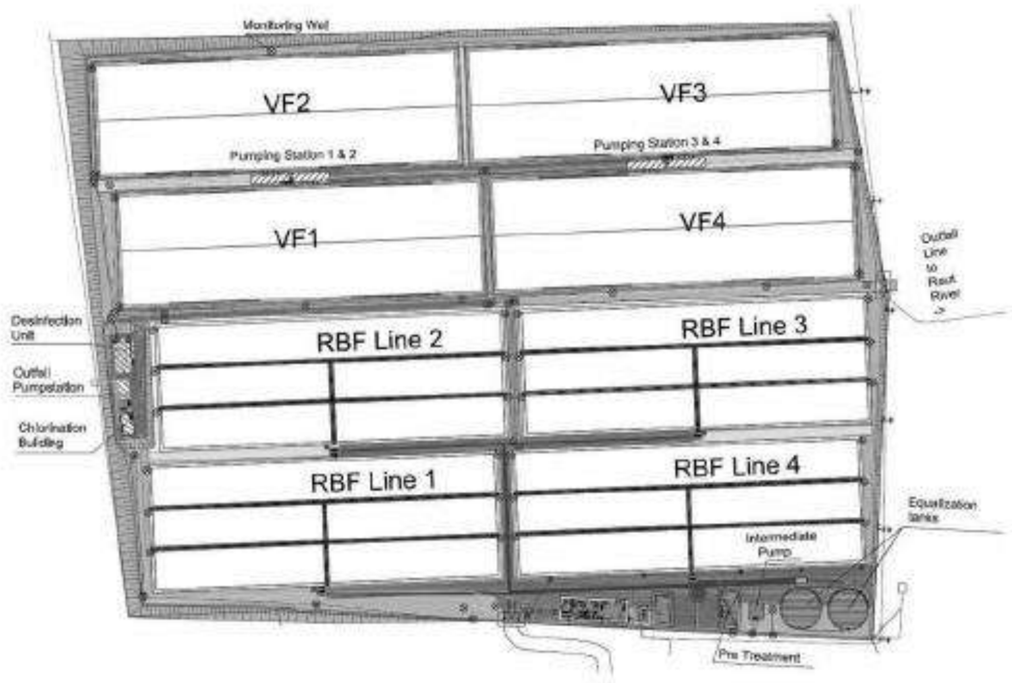


Figura 5. Plant layout of the CW wastewater treatment plant of the Orhei Municipality (source: Masi et al., 2017).

Figura 6. Photo of the multi stage constructed wetland system of Orhei

Figura 7. Aerial view of the multi stage constructed wetland system of Orhei (source: Google Earth)

2.1.6 WSP (Waste Stabilization Pond)

Waste stabilization ponds are basins where wastewater undergoes a treatment process thanks to **algae and bacteria** that live in symbiosis in the pond. The **surface** of the pond is an important parameter as algae need sufficient light for the photosynthesis. Depending on the depth of the pond the process can be:

- Anaerobic – 4-5 m, - 60% BOD
- Aerobic – 0.3-0.8 m, - 90% BOD
- Facultative – aerobic and anaerobic processes, 0.8-1.6 m, -90% BOD

WPSs can be equipped with an aeration system, to maintain aerobic conditions at any depth, making them more similar to activated sludge plants. They usually have a depth of about 3 m .

WSPs are characterised by high residence times (2-3 days), and low energy consumption, however, algae removal is quite difficult, which risks leading to algal crash and subsequent death.

2.1.7 Trickling filters

Trickling filters are made of circular tanks with a **porous bed** with a high surface area on which the biofilm grows (1-3 mm). Wastewater coming from a primary sedimentation tank enters from above through a rotating sprinkler, and it percolates through the packing medium with a diameter in the order of centimetres (stones, wooden chips, plastic material or others) until it reaches the bottom of the tank as a clarified effluent (Von Sperling, M. (2007)). The wastewater flowing on the biofilm allows bacterial growth and undergoes a process of oxidation and stabilization, as the biofilm grows, the rate of descent of the liquid increases, until the biomass detaches from the support due to wastewater-surface friction, therefore, a secondary sedimentation tank is necessary to separate the biofilm from the effluent. Aeration is natural, and the residence time depends on the vertical travel time.

The main dimensioning parameters are the volumetric **organic loading rate** (generally between 0.3-0.5 kgBOD/(m^3*d) for plastic materials) and the **surface loading rate** (generally between 2-3 m^3/(m^2*h)).

Trickling filters are simple to operate and have low operational costs, they don't need aeration or energy. Their efficiency is influenced by temperature and recirculation, they have a good abatement of organic matter, but N and P removal is low, unless a specific treatment is used .

Depending on the organic and surface loading rate, trickling filters can be classified in:

- Low rate trickling filter
- Intermediate rate trickling filter
- High rate trickling filter

- Super high rate trickling filter
- Roughing trickling filter

Operational conditions	Low rate	Intermediate rate	High rate	Super high rate	Roughing
Packing medium	Stone	Stone	Stone	Plastic	Stone/plastic
Hydraulic loading rate ($m^3/m^2 \cdot d$)	1.0 to 4.0	3.5 to 10.0	10.0 to 40.0	12.0 to 70.0	45.0 to 185.0
Organic loading rate ($kgBOD/m^3 \cdot d$)	0.1 to 0.4	0.2 to 0.5	0.5 to 1.0	0.5 to 1.6	Up to 8
Effluent recycle	Minimum	Occasional	Always*	Always	Always
Flies	Many	Variable	Variable	Few	Few
Biofilm loss	Intermitt.	Variable	Continuous	Continuous	Continuous
Depth (m)	1.8 to 2.5	1.8 to 2.5	0.9 to 3.0	3.0 to 12.0	0.9 to 6.0
BOD removal (%)**	80 to 85	50 to 70	65 to 80	65 to 85	40 to 65
Nitrification	Intense	Partial	Partial	Limited	Absent

Table 1. Typical characteristics of the different types of trickling filters (source: Von Sperling, M. (2007))

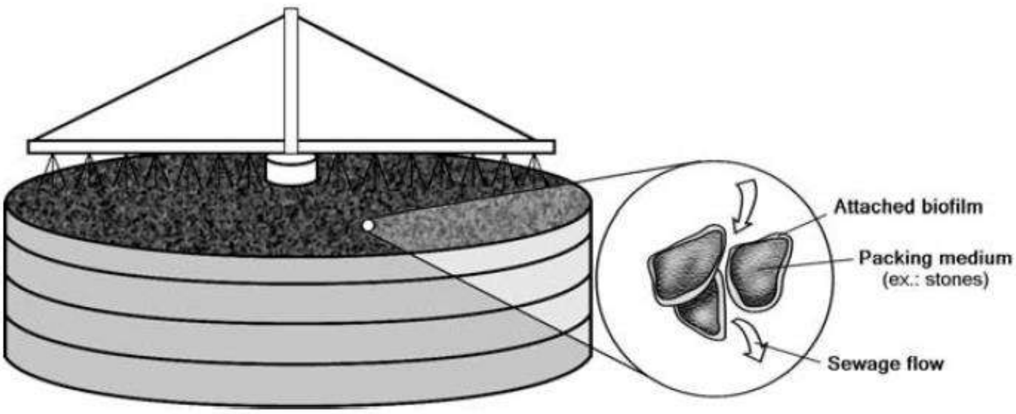


Figure 8. Schematic representation of a trickling filter (source: Von Sperling, M. (2007))

2.1.8 Rotating Biological contactor

Rotating biological contactors consist of thick wheels made of several circular disks (diameter 2-3 m) of plastic or metallic materials that rotate along a horizontal shaft. The disks are partially immersed in the wastewater (40-60%) and act as a support for biofilm growth, they rotate slowly (1-2 rpm) allowing the biomass to come into contact with the wastewater and promoting aeration. process. When the biofilm reaches an excessive thickness, part of it detaches, and is maintained in suspension in the liquid medium due to the movement of the discs. Rotating biological contactors necessitate of both primary and secondary sedimentation tasks, aeration is natural but they need energy. Rotating biological contactors can be immersed by 90%, in this case aeration is necessary (Von Sperling, M. (2007)).

The efficiency of rotating biological contactors in the removal of organic matter can be improved by implementing more stages in series, usually at least two are foreseen . Rotating biological contactors are usually designed on the base of s**urface organic loading rate** (gBOD/m^2*d) and **hydraulic loading rate** (m^3/(m^2*d)).

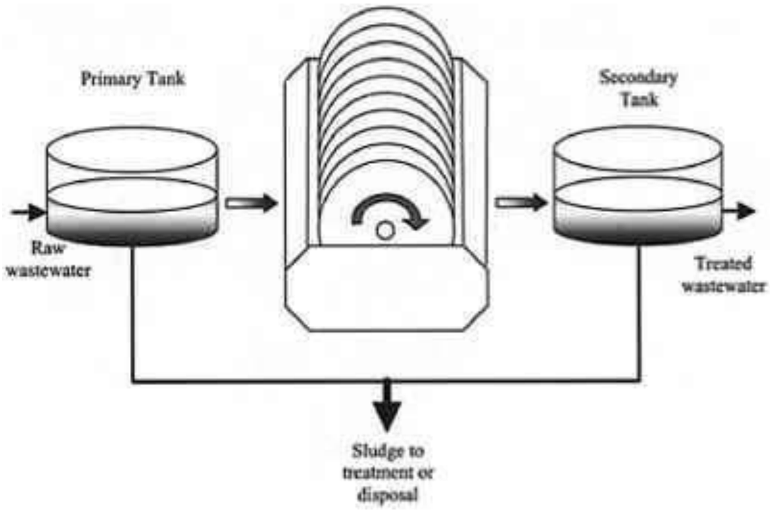


Figure 9. Schematic representation of a rotating biological contactors (source: www.climate-policy-watcher.org)

2.2 Wastewater and effluent quality

Depending on the country, region, or specific situation (type of agglomerates, type and state of the sewer, presence of infiltration water, etc) the wastewater quality can be different, as well as the required quality of the treated water, which can depend on the capacity of the plant, the characteristics of the water body receiving the discharge, the national norms.

Although the list of parameters to be controlled in wastewater treatment, concerning the sea water quality it is important to take into account:

- Coliforms (Total or Faecal)
- Escherichia Coli
- BOD_5 (Biochemical Oxygen Demand)
- COD_5 (Chemical Oxygen Demand)
- Total Suspended Solids
- Nitrogen (in its different forms)
- Phosphorus

If relevant industries are connected to the sewer, other specific contaminants (such metals or others) should be considered.

3 UPGRADING OF EXISTING WASTEWATER TREATMENT FOR URBAN WASTEWATER

Whereas the existing wastewater treatments do not fulfil the identified targets to improve river and sea water quality, it is important to evaluate if the system can be upgraded and can furnish a significant improvement to the environment. This requires to analyse the sizing, the treatment scheme, the operational aspects, the analytical performance, the state of conservation of civil works and mechanical equipment in order. In case it is not convenient an intervention of revamping, a new WWTP should be considered according to indications in chapter n°3.

From a process point of view, several options can be considered in the upgrading, depending which is the critical section of the plant. If the main goal is to reduce bacteriological pollution, a disinfection system can be added to the existing plant. When the critical section is the biological process, this can be improved adapting the volumes of aeration basins or settling tank, introducing nitro-denitro or renewing the aeration system; in some other cases, it could be convenient to consider a MBR in place of gravity settling. Several type of tertiary treatments could help also to improve performance without intervening drastically on the existing treatment plant: constructed wetlands and lagoons can improve BOD, COD and TSS performance, as well as denitrification and bacterial reduction.

When instead the existing treatment plant is limited to preliminary mechanical treatment, it has to be provided a new treatment plant, following the indications included in chapter 2, and evaluating depending the selected treatment if the existing preliminary treatments are adequate or they needs to be improved or substituted.

Here a non-exhaustive list of possible upgrading solutions, to be applied separately or in combination.

- **Disinfection**

UV, Chlorination, Peracetic Acid, Ozone, UF, etc…

- **Improvement of biological process**

Nitro-denitro, MBR, aeration system revamping, …..

- **Tertiary treatment**

Constructed wetlands, Waste stabilization lagoons, UF

- **Improvement of existing mechanical treatment**

See Chapter n°3

Based on background information, the design data and targets of each proposed up-grading of existing treatment plants have to be determined, in order to select the most appropriate treatment scheme:

- Verification of water demands and needs by different uses (current and future).
- flow analysis (fluctuations, seasonality)
- expected wastewater quality in terms of organics, solids, nutrients, pathogens.
- Water quality to be fulfilled

3.1 Main features of different treatment schemes

3.1.1 Disinfection

UV

UV disinfection is a photochemical process in which mercury vapour lamps transfer **electromagnetic energy** and microorganisms undergo DNA and RNA alterations. It is a process that leaves no residues or by-products, the dosage is given by the product of the **intensity** of the light for the time of exposure to light (about 20 seconds) (Masotti, L. (1996)).
Disinfection with UV rays is effective if the content of suspended solids is less than 30-35 mg/L and if the transmittance values at 254 nm are greater than 50% .

Chlorination

Chlorine can be used for disinfection in different forms:

- **chlorine gas** (Cl_2) is mostly used in large plants, as it is dangerous and difficult to handle
- **sodium hypochlorite** ($NaClO$) is safer and easier to manage, is persistent and active, but releases toxic by-products, it has modest costs, and is widely used in small plants.
- **Calcium hypochlorite** ($Ca(ClO)_2$) is also used in small plants as it is safe and simple to use, but more expensive than sodium hypochlorite.
- **Chlorine dioxide** (ClO_2) does not produce chloramines but is not very persistent, has very good disinfectant properties, but must be produced immediately before contact with water because it decomposes very quickly .

The treatment takes place in tanks equipped with septa to favour turbulent motion, where the disinfectant is introduced through dosing pumps, the efficiency of disinfection depends on the concentration of active chlorine, on the contact time (concentration * contact time = dose) and on the degree of mixing (Masotti, L. (1996)).

Peracetic Acid

Peracetic acid (CH_3COOOH) is persistent and is not affected by the presence of suspended solids, the investment costs are similar to those of chlorine but the operating costs are higher, furthermore the dosage of peracitic acid can lead to an increase in the concentration of TOC in wastewater .

Ozone

Ozone (O_3) as a disinfectant is less used, it is produced by passing dried air or pure oxygen through an electric discharge, it has no smell or taste, however it can release by-products. It is an allotropic form of oxygen, characterized by a very high oxidizing capacity, the gas is unstable and rapidly decomposes into O2, and for this reason it must be produced on site. The dosages are of the order of **10-20 mg/l of ozone**, with an energy consumption of 7÷10 kWh/kg of ozone produced, for the generator only (Masotti, L. (1996)).

UF

With the passage through the **ultrafiltration** membranes there is an almost complete interception of the bacteria, and partial of the viruses, which however reaches very high values. The retention capacity may undergo reductions (in the case of membranes that are not in perfect operating conditions), therefore it may be necessary to resort to a final disinfection.

3.1.2 Improvement of biological process

Nitro-denitro

Nitrification, i.e. the oxidation of inorganic nitrogen compounds in the reduced state, can occur simultaneously with the biological reactions in the oxidation tank (**simultaneous nitrification**), or separately in another stage, after the secondary sedimentation tank (**separated nitrification**). Separate nitrification involves a reduction in the volumes of the tanks but requires an additional secondary sedimentation stage.

The sizing of the nitrification tank is based on the net growth index of nitrifying bacteria (0.10-0.15 kg_{SSVN}/kg_{TKN}), the growth rate of nitrifying bacteria (0.33-1.02 d^{-1}) and the fraction of the biomass of nitrifying autotrophic bacteria on the total (3-5%) (Masotti, L. (1996)).

The factors that influence nitrification are:

- nature of the influent sewage
- temperature
- pH
- concentration of dissolved oxygen

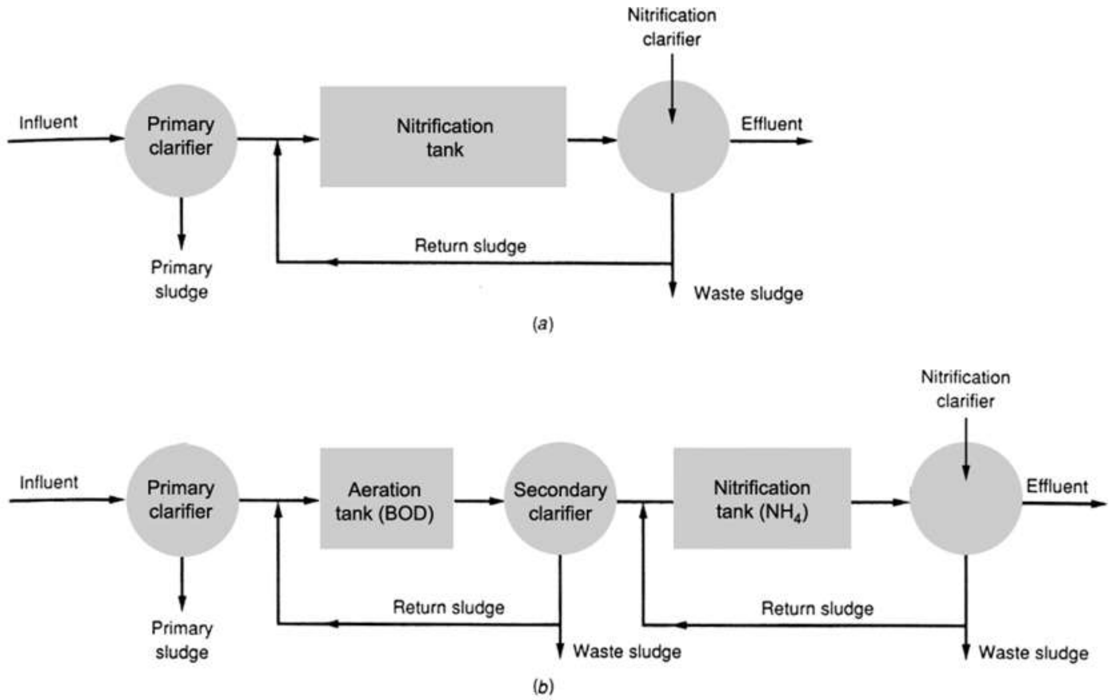


Figure 10. Simultaneous and separated biochemical nitrification processes (source: Wastewater Treatment Plant Operator Certification Training, PSATS, 2014)

Denitrification is the process of converting nitric nitrogen to gaseous nitrogen, for this process to take place there is a need for: anoxic conditions, the presence of nitrates, a carbon source. The denitrification tank can be positioned after the secondary sedimentation tank (**post-denitrification**), with the addition of a third sedimentation tank, or after the primary sedimentation tank, with recirculation from the oxidation tank (**pre-denitrification**).

The factors that influence nitrification are:

- nature of the carbonaceous substrate
- temperature
- pH
- concentration of dissolved oxygen

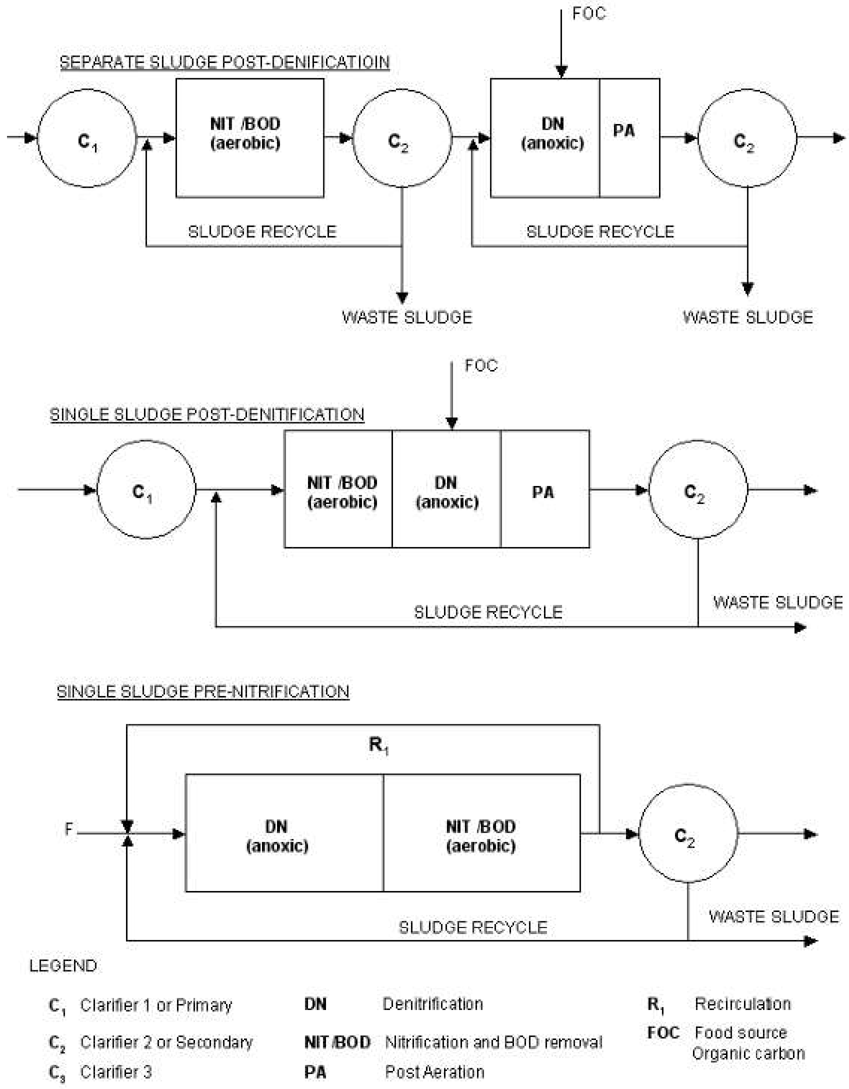


Figure 11. Post-denitrification and pre-denitrification processes (source: Wastewater Treatment Plant Operator Certification Training, PSATS, 2014)

MBR (Membrane Biological Reactor)

Membrane biological reactors are reactors in which the biomass is separated from treated water by a **membrane** rather than by sedimentation. The membrane is usually a microfiltration or ultrafiltration membrane, and it is either submerged in the reactor itself (*submerged* *membrane*) or in a separated unit (*side-stream*).

The cleared effluent is extracted by a pump, and an air insufflation system removes the biomass deposit from the membrane. The membrane is able to retain both floc-forming and filamentous bacteria, allowing to operate with lower sludge loads (0.04-0.08 kgBOD/(kgSS*d)) and higher sludge concentrations (10-18 kgSS/m^3), this results in a smaller volume needed for the tanks. The high sludge age of these processes allows greater mineralization of the organic substance, therefore greater stabilization, and disinfection is often not necessary.

3.1.3 Tertiary treatment

Constructed wetlands

Constructed wetlands are systems that exploit natural processes to treat wastewater, the two main types of CWs are **Free Water Systems** (FWS or SF) and **Subsurface Flow Systems** (SFS). In FWSs a basin is filled with about 50 cm of water, in which floating or emergent rooted macrophytes grow. In SFSs wastewater flows vertically or horizontally through a filling material (sand or gravel) and the roots of the plants growing in the basin, the different systems can be combined to constitute hybrid systems.

Both types, or a combination of them, can be used as tertiary treatment; however, in most of the case a SF system is preferred.

In SF, water flows above ground and plants are rooted in the sediment layer at the base of the basin or floating in the water. As the water slowly flows through the wetland, simultaneous physical, chemical and biological processes filter solids, degrade organics and remove nutrients from the wastewater. The channel or basin is lined with an impermeable barrier (plastic liner, or clay) covered with rocks, gravel and soil and planted with native vegetation (e.g., cattails, reeds and/or rushes). The wetland is flooded with wastewater to a depth of 10 to 50 cm above ground level. Wastewater can be fed into the wetland by gravity using weirs or plastic pipes, to allow it to enter at evenly spaced intervals. The FWS basin is planted advantageously with native plants and can be vegetated with emergent, submerged and floating plants; therefore, FWS can give a high contribution to biodiversity increase.

Free-water surface constructed wetlands can achieve a high removal of suspended solids and moderate removal of pathogens, nutrients and other pollutants, such as heavy metals. This technology is able to tolerate variable water levels and nutrient loads. Plants limit the dissolved oxygen in the water from their shade and their buffering of the wind; therefore, this type of wetland is appropriate for low-strength wastewater. Typically, it is used for polishing effluent that has been through secondary treatment to enhance denitrification (Masi 2008), to improve disinfection (Wu et al., 2016), or to reuse treated wastewater (Ghermandi et al., 2007). FWS are also often used for stormwater retention and treatment (Woods-Ballard et al., 2015). This technology is best suited for warm climates. Moreover, the use of FWS can give multiple benefits in terms of ecosystem services , in terms of biodiversity increase, flood mitigation and social benefits (Hsu et al., 2011; Ghermandi and Fichtman, 2015; Liquete et al., 2016, Masi et al., 2017).

Waste stabilization ponds (WSP)

WSP are basins where wastewater undergoes a treatment process thanks to **algae and bacteria** that live in symbiosis in the pond. The **surface** of the pond is an important parameter as algae need sufficient light for the photosynthesis.

They can be used individually or connected in series. WSPs are generally composed by three types of ponds: anaerobic, facultative, for BOD removal, and aerobic maturation ponds, for the removal of pathogens and final polishing.

In WSP in series, effluent enters in the anaerobic pond, where the removal of solids and BOD takes place by sedimentation and subsequent anaerobic digestion. In the case of tertiary treatment, anaerobic ponds are not used due to the low strength of the incoming water. Subsequently the effluent reaches the facultative pond, where the organic and nutrient removal take place.

Maturation pond is a superficial pond where sunlight penetrates in all the depth to favour the removal of pathogens.

Anaerobic ponds have a depth of 2 to 5 m, with a detention time of 1 to 15 days. Facultative ponds have a depth of 1 to 2.5 m and a detention time between 5 to 60 days. The depth of maturation ponds is usually between 0.5 to 1 m.

Ponds are generally constructed by earthmoving works; the bottom and the banks are lined with plastic liners, or in few case by concrete or clay, in order to protect groundwater from leaking of untreated water. A protective berm with excavated material is necessary to prevent the ponds from runoff and erosion.

The effluent produced by the WSP is generally poor in pathogens. WSPs are suitable for rural and peri-urban areas, where there are large spaces available, and must be located far from settlements. Odours diffusion can be an issue to consider, even if in tertiary treatment is generally limited by the low strength of the incoming water.

The main advantages are:

- Resistant to organic and hydraulic shock loads
- High reduction of solids, BOD and pathogens
- Low operating costs
- No electrical energy
- Easy construction

Lagoons can be also equipped with an aeration system, to maintain aerobic conditions at any depth, making them more similar to activated sludge plants. They usually have a depth of about 3 m.

Lagoons are characterised by high residence times (2-3 days), and low energy consumption, however, algae removal is quite difficult, which risks leading to algal crash and subsequent death.

UF (Ultrafiltration)

In the treatment with ultrafiltration, the filtering medium consists of **membranes** that have a high capacity to retain solid particles with a minimum resistance to the passage of the fluid that passes through it. In particular, ultrafiltration is a mechanical sieving process capable of retaining large molecules (proteins, bacteria, viruses, etc.).

The ultrafiltration process can be used as a secondary or tertiary treatment and the main parameters of the ultrafiltration process are:

- pore size – 0.1-10 µm
- operating pressure – 1-5 bar
- energy consumption – 3 kWh/m^3

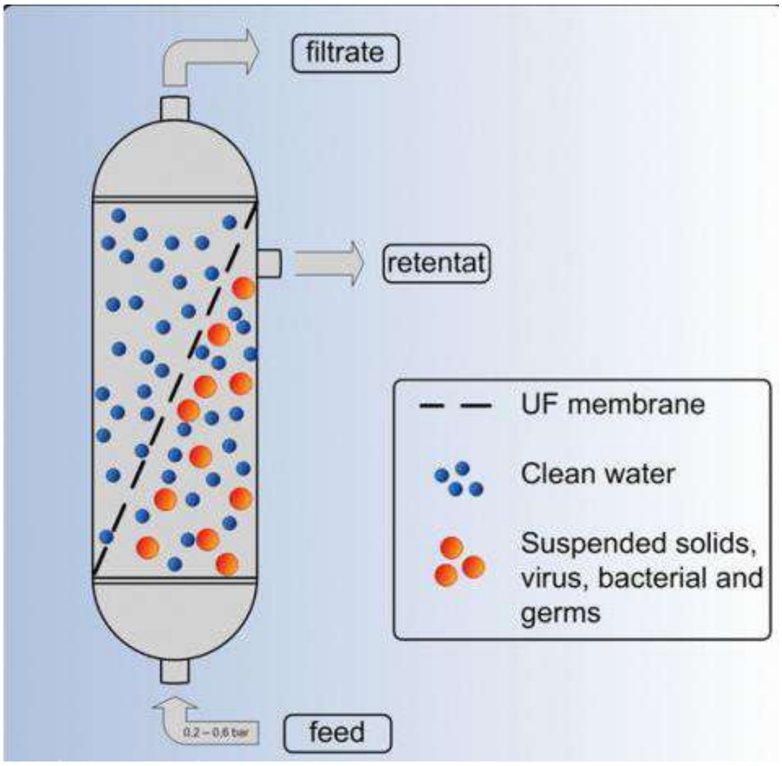


Figure 12. Schematic ultrafiltration process (source: www.leatherpanel.org)

3.1.4 Improvement of existing mechanical treatment

When the existing treatment plant is limited to preliminary mechanical treatment, it has to be provided a new treatment plant, following the indications included in chapter 2, and evaluating depending the selected treatment if the existing preliminary treatments are adequate or they need to be improved or substituted.

3.2 Wastewater and effluent quality

In the case of existing plants, it is easier to determine quantity and quality of the effluent if monitoring data are available; otherwise, a monitoring campaign can be organized collecting some samples from inlet and outlet and measuring the inflow, comparing the data with background information.

The required quality of the treated water is generally also already determined by authorization or local norms, even if not completely fulfilled. Also in this case concerning the sea water quality it is important to take into account:

- BOD_5 (Biochemical Oxygen Demand)
- COD_5 (Chemical Oxygen Demand)
- Total Suspended Solids
- Coliforms (Total or Faecal) or Escherichia Coli
- Nitrogen (in its different forms)
- Phosphorus

and, if relevant industries are connected to the sewer, other specific contaminants (such metals or others).

4 SMALL WASTEWATER TREATMENT PLANTS

Depending on the composition of the wastewater to be treated, the treatments and systems will be different. In the following table, different treatment schemes are resumed. Usually, intensive treatments are more expensive, more technological and require less space compared to extensive ones.

Here a tentative list of the most used technologies for small wastewater treatment plants:

1. Imhoff and soil dispersion
2. Constructed wetlands
3. Compact activated sludge plants
4. Aerobic Trickling filters

Based on background information, the design data and targets of each proposed new treatment plants has to be determined, in order to select the most appropriate treatment scheme:

- Study of water demands and needs by different uses (current and future).
- flow analysis (fluctuations, seasonality)
- expected wastewater quality in terms of organics, solids, nutrients, pathogens.
- Water quality to be fulfilled

4.1 Imhoff tank and soil dispersion

The **Imhoff tanks** consist of two stacked compartments, communicating through openings that allow the passage of solids. In the upper compartment the sedimentation takes place, while in the lower one there is the anaerobic digestion of the sludge the digestion gas is conveyed to the vents. The separation of the compartments allows to keep the residence times of the sewage low and therefore avoids the establishment of septic conditions. The tanks are underground and pre- treatments of sand removal and oil removal are required. The sizing is based on the residence time and the volume needed depending on the inhabitants served, the sludge is extracted between 1 and 4 times a year.

Imhoff tanks can be used as primary treatments before **soil dispersion**, in which the purifying action of the aerobic biomasses that develop on the filter media in the soil is exploited. It consists of a system of dispersion through trenches (width ≈ 0.5-1 m, depth ≈ 1 m) with perforated or slotted pipes that disperse the sewage within a layer (50-90 cm) of crushed stone at the bottom of the trench; the trench is covered by a top layer of natural soil, between the two layers is placed the non-woven fabric to avoid clogging. It is important that the distance between the bottom of the trench and the maximum level of the aquifer is greater than 1 m. This solution is generally used for applications with a maximum of 200 PE.

4.2 Constructed wetlands

For small scale applications, single stage constructed wetlands (CWs) can be implemented, usually **Subsurface Flow Systems** (SFS) are used, while Free Water Systems (FWS or SF) are not used for small wastewater treatment plants, or are used only as final tertiary treatment.

SFSs can be Vertical Flow (VF) CWs or Horizontal Flow (HF) CWs, depending on the direction of the flow of wastewater, which passes through the filling material (sand or gravel) where the vegetation grows.

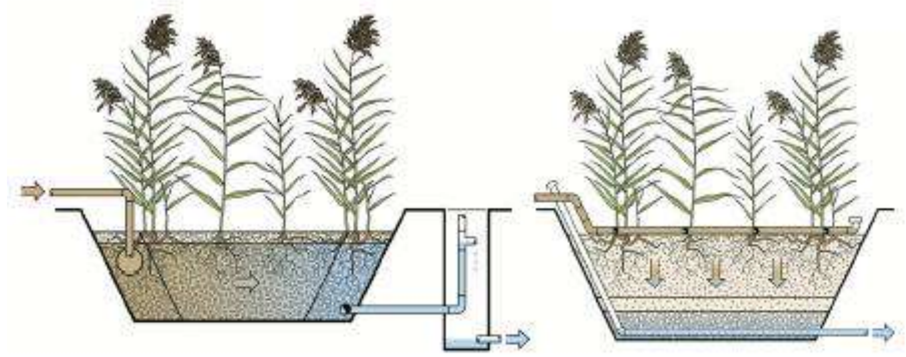


Figure 13. Horizontal flow (left) and vertical flow (right) subsurface systems (source: Dotro et al., 2017)

Constructed wetlands main advantages are their easy maintenance, the low operational costs and their adaptability to flow variations, moreover, they do not require energy or skilled workers. However, these systems require a higher **surface**, as adequate exposure to sunlight is essential for its proper functioning, and the bottom of the basin must have a slope for the water to flow. CWs are characterised by easy maintenance, but they require regular mowing of the emergent part of the vegetation and the removal of plant material from the bed. CWs can be used as treatment systems for applications up to 2000 PE.

Figura 14. HF constructed wetland for the treatment of a single house wastewater, 8 PE (source: www.iridra.com)

4.3 Compact technological plants

4.3.1 Activated sludge plant

For small-scale wastewater treatment it is possible to use compact activated sludge plants, the operation of activated sludge systems is explained in paragraph 2.1.1. Compact activated sludge tanks are made of armed concrete, or high density polyethylene for smaller applications, and can be implemented either underground or above ground. They can have a cylindrical or cuboidal shape they are available in different sizes and are easy to install (applicability: up to 1000 PE). These solution occupies less space compared to others, but it requires a source of energy and higher investment on operational costs

Typical dimensions:

- width = 1.5 – 2.5 m
- height = 2 – 4 m
- length = 5 – 24 m

Figura 15.Compact activated sludge plant (source: www.rototec.it)

4.3.2 MBR (Membrane Biological Reactor)

Another possible solution for small-scale wastewater treatment is compact MBR systems, the operation of MBRs is explained in paragraph 2.1.3. Compact MBR systems are generally constituted by containers or prefabricated tanks in reinforced concrete, and have a potential between 100 and 3000 AE. Compact MBR systems are highly automated and involve a considerable reduction in the overall volume, however, investment and operational costs are higher compared to other solutions, and they require energy to function.

Typical dimensions:

- width = 2 – 4 m
- height = 2 – 4 m
- length = 14 – 24 m

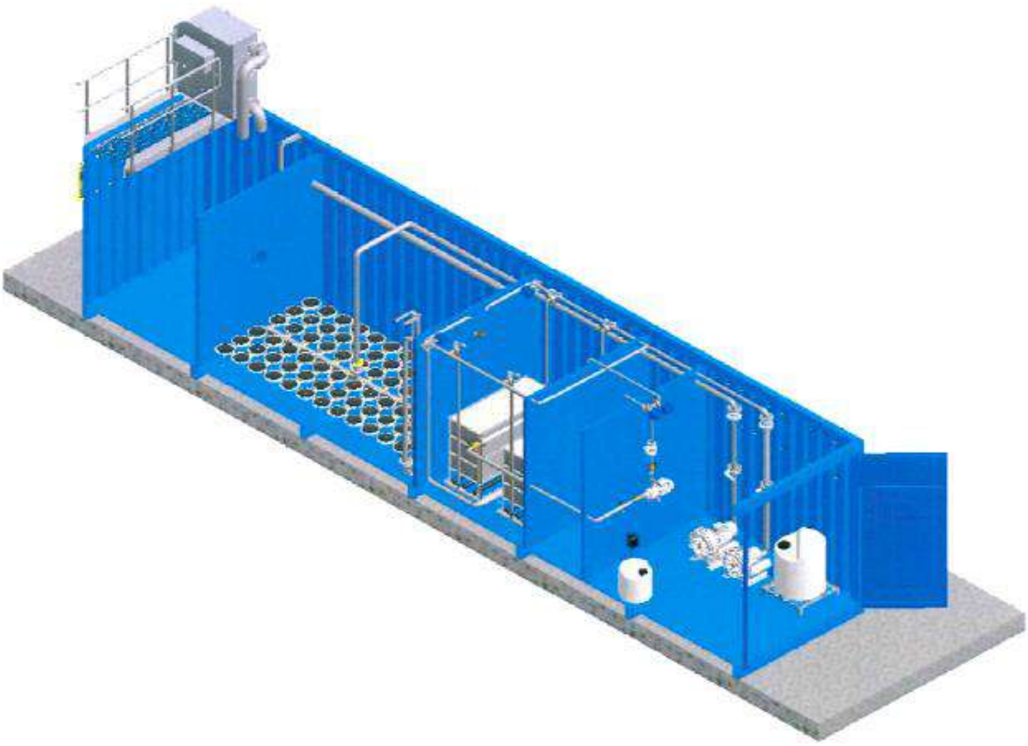


Figura 16. Compact MBR system (source: www.agridep.it)

4.4 Aerobic Trickling filters

Aerobic trickling filters are made of HDPE or prefabricated reinforced concrete tanks filled with filling bodies in plastic material with a high specific surface on which the biomass grows, wastewater is homogenously distributed through a perforated pipe at the top of the tank, and the treated effluent is collected by a pipe and conveyed to the exit. The aeration is provided by a compressor and the diffuser plates placed on the bottom, which diffuse the oxygen in the tank through micro bubbles. The application ranges between 6 and 240 AE, the width is generally around 1 – 2 m, with a height of about 1.2 – 2.2 m, for larger applications they can have a length up to 12 m. Aerobic trickling filters do not require energy nor skilled workers to operate, the operational costs are low, with higher investment costs, and they adapt quite well to flow variations.

Typical dimensions:

- width = 1 – 2 m
- height = 1.2 – 2.2 m
- length = up to 12 m

Figura 17. Aerobic trickling filter (source: www.rototec.it).

4.5 Wastewater and effluent quality

Depending on the country, region, or specific situation (type of agglomerates, presence of infiltration water, etc) the wastewater quality can be different, as well as the required quality of the treated water, which can depend on the capacity of the plant, the characteristics of the water body receiving the discharge, the national norms).

Concerning sea water quality, it is important to take into account:

- BOD_5 (Biochemical Oxygen Demand)
- COD_5 (Chemical Oxygen Demand)
- Total Suspended Solids
- Coliforms (Total or Faecal) or Escherichia Coli

Nitrogen and phosphorus can be less important in small treatment plants considering the limited impact on the final destination; however, some removal should be considered in case of lakes and areas sensitive to eutrophication.

5 COMBINED SEWER OVERFLOW

The flow variability in combined sewer networks, with sudden and significant increases during rainfall events, leads to the necessity to create overflow structures that allow to discharge the excess rainwater and avoid the overload of both the pipeline network and the wastewater treatment plants.

Even though the overflow process is generally regulated by legislation that impose a minimum dilution coefficient (the ratio between the minimum discharge that must be taken to treatment during raining events and the average wastewater discharge in dry weather), the discharge from Combined Sewer Overflows (CSO) can be a significant source of pollution.

The organic load due to CSO can be significant: for example in Emilia Romagna, according to the estimates of the Regional Water Protection Plan, represents about 10% of the total civil and industrial organic load (counting both the untreated discharge and the discharge from WWTPs). This is due to various combined factors:

- the inefficiency of the overflow structures, which means that some may activate before the theoretical threshold, discharging polluted water into the sea;
- the residual organic load of the overflow from combined sewers;
- the stormwater pollution, especially in the so called “first flush”.

The figure below shows a typical trend of COD in stormwater (yellow curve) and combined sewer overflow (brown curve).

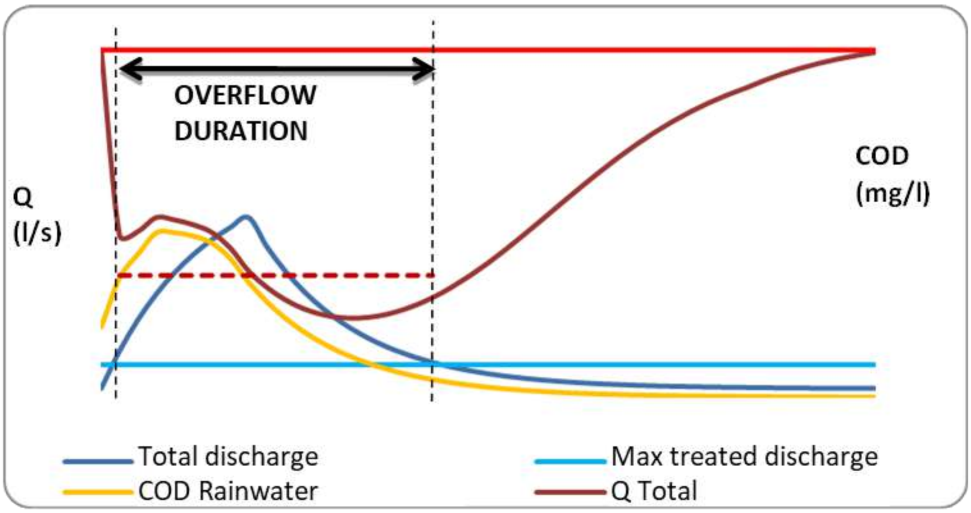


Figure 18. COD concentrations during a rainfall event for rainwater discharges (COD rainwater - yellow line) and CSO (COD tot - brown line). Source: Studio Majone- Iridra - T.A.T. Study Center, Integrated Study of Gornate Olona dell'Ato Varese: Proposal for guidelines

Moreover, CSOs emit pathogens and faecal indicator bacteria into the surface water, which the EU Bathing Water Directive addresses by giving threshold values for the indicators Escherichia coli and intestinal enterococci. In the European Union, the current legislation misses to address CSOs directly in its directives. CSO pollutant loads have been recognised as one of the most relevant loads remained untreated according to the Water Framework Directive (2006/7/EC), and CSOs are considered as one the main reasons of the failure in achieving good status of water bodies at European scale (European Commission, 2019) (Pistocchi et al., 2019). Moreover, CSOs are one of the most common causes of losing bathing water status set by the EU Bathing Water Directive (2006/7/EC) (Rizzo et al., 2020).

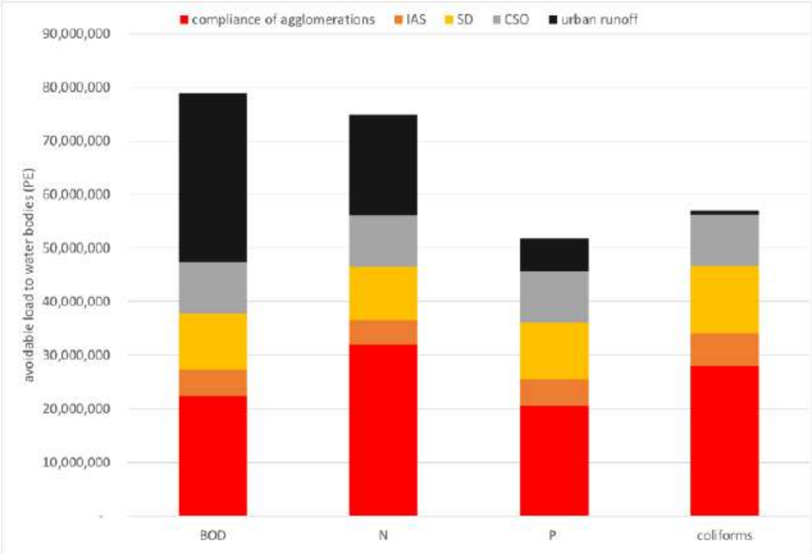


Figure 19 Loads that can be avoided by enforcing full compliance with the UWWTD - Urban Wastewater Treatment Directive (for agglomerations); an equivalent treatment level (for scattered dwellings, SD); full control of CSO (neglecting management measures currently in place); and effective enforcement of IAS (Individual and Appropriate Systems) treatment equivalent to the WWTP of the corresponding agglomeration (source: Pistocchi et al., 2019).

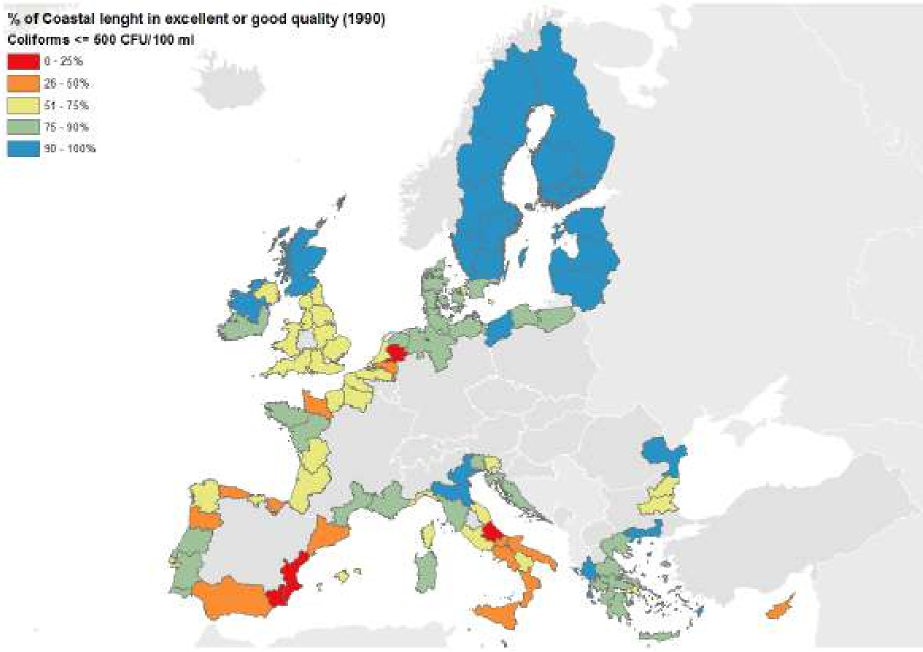


Figure 20. Percent of the coastline with faecal coliforms below the good quality threshold for E.Coli in bathing waters, circa 2015 and circa 1990 (source: Pistocchi et al., 2019).

Possible solutions to reduce the polluting impact of CSO include improving the efficiency of overflow structures, treating the overflow discharge either on site or in existing facilities, pumping the overflow discharge further at sea through underwater pipelines.
These solutions and the different available alternatives will be described in the following paragraphs.

5.1 Storage of overflow volume

A possible solution to avoid pollution from CSO is to accumulate the overflow in storage structures until the end of the stormwater event. The accumulated volume can then be pumped to the existing treatment facility with a flow rate compatible with the capacity of the network and of the treatment plant.
The main advantage of this solution is to completely avoid the discharge from CSO for any event whose volume does not exceed the storage capacity.
Once the available volume is full, all the excess flow is discharged directly in the final receptor.
Analysis on various experimental catchments in Italy have confirmed that accumulation basins can effectively reduce the polluting load of urban drainage water.
For example, the image below shows the average annual TSS concentration (total suspended solids) variation with the tank specific volume, for different dilution coefficients of the overflow (R), at the site of Cascina Scala (Lombardy region).

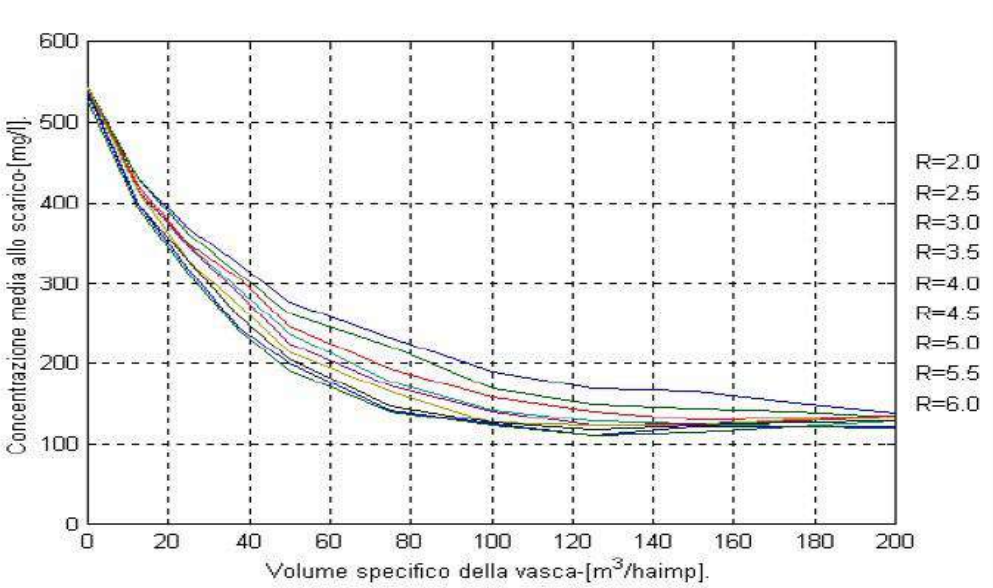


Figure 21. Sistema fognario misto con scaricatore ideale e vasca off-line con bypass a completo riempimento [Papiri, 2005]

5.1.1 Main features

Storage tanks consist in waterproof concrete structures which can accumulate the overflow discharge before the treatment. The structures usually include electromechanical parts such as sluice gates to regulate the flow, pumping stations to empty the tank at the end of the event, automatic cleaning systems for better maintenance. The tanks are usually built completely underground, thus with limited visual impact.

The image below shows a typical section of a storage tank for overflow discharge and its main components. The structure of course may differ depending on the characteristics of the site, depth, number and dimension of the inlet and outlet pipes, level of automatization required, environmental conditions, etc...

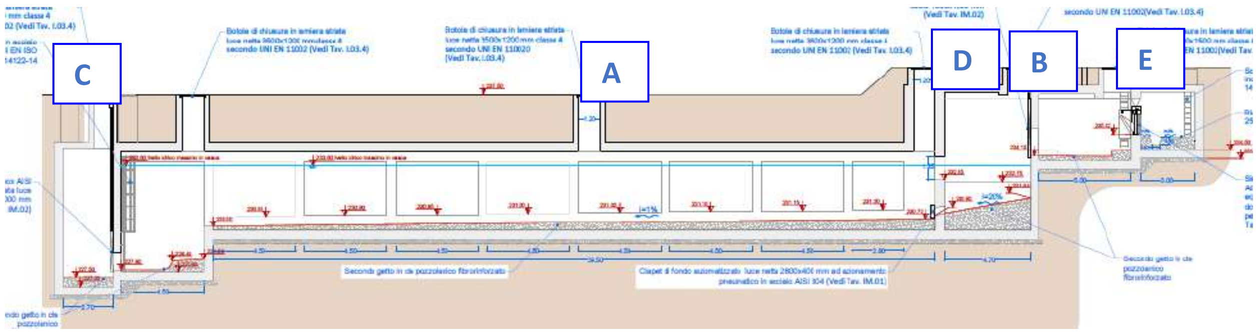


Figure 22. Schema di vasca di raccolta delle acque di pioggia

A. Main storage volume: usually separated in 2 or more sectors, to be filled subsequently depending on the scale of the event, avoiding the use of the whole structure for each event and thus reducing maintenance. The shape of the tank should facilitate the water flow and avoid deposit;

B. Sluice gates: used to block the flow to the tank when the volume is full, to separate different sectors and in general to regulate and manage the storage flow;

C. Pumps: used to empty the tank (unless the depth of the tank allows emptying by gravity flow)

D. Cleaning system: it is recommended to equip the tank with automatic cleaning systems, at least for the first sectors that are more frequently filled, in order to avoid deposit that would reduce the available volume and cause unpleasant odors;

E. Screens: for large structures an automatic screen can be installed at the inflow to avoid transported materials to enter the tank.

F. Deodorization system: a deodorization system may be included for structures located near densely populated or particularly sensitive areas

G. Monitoring system: the storage tank should be equipped with a monitoring system including at least water level and flow sensors. More advanced monitoring systems, such as automatic water quality sampling and analysis, could be used to define a real time management system of the storage, allowing a much more effective use of the available volume.

5.1.2 Dimensioning parameters

The main parameter for the design of this solution is the volume of the tank.

Depending on the situation and the baseline parameters of the site, the tank may be designed to accumulate a specific volume proportional to the basin drainage area, or even the total overflow volume for a given return period.

On one side of this range, we have first flush basins, which aim to accumulate the event initial runoff volume, generally defined as 50 mc per hectare of drainage surface. This criterium is more indicated for catchments where a clear first flush phenomena con be detected, typically small to medium basins (generally with S < 10 ha) with regular shape and with a separate stormwater network.

For wider or more irregular catchments and for CSOs, there isn't always clearly defined first flush phenomenon and a higher concentration of pollutants is not limited to first part of the flow. This is due in part to the fact that the initial runoff of the distant parts of the basin will reach the tank at different times, and in part to the higher concentration of organic load in the final part of the hydrograph, when there is less rainwater contribution compared to the wastewater flow.

To effectively reduce pollution, the storage tank aims at intercepting the whole overflow volume and eliminate the discharge in the receiving body. To design the tank it is thus necessary to estimate the critical runoff volume corresponding to a given return period.

The data required for the hydrological analysis are the catchment surface, land use information, statistical parameters concerning rainfall in the area.

Since the runoff volume strongly depends on the shape of the hydrograph it important to simulate the catchment response with different rainfall-runoff models. Simplified methods can also be used to calculate the maximum volume for a given return period.

However, due to the complexity and uncertainty of the statistical evaluations of the peak volume, it is strongly recommended to calibrate the analysis with the support of real data such as measured overflow discharge and volume whenever available.

5.1.3 Field of application

The construction of storage tank for the accumulation of CSO volume has the advantage of avoiding or strongly reducing any discharge at the CSO location, sending instead the whole volume to treatment.

On the other hand, this solution has an impact on the wastewater network and on the WWTP receiving the additional volume:

- energy and management costs needed to send the additional volume to the treatment facility;
- energy and management costs needed to treat the additional volume;
- more variable pollution load at the Wastewater treatment plant due to overflow discharge, which reduces the treatment's efficiency.

Other factors to be considered are the land occupation required for the storage tank, the construction and management cost of the structure and its impact on the surrounding territory.

All these elements must be evaluated when considering the possible application of this solution and comparing it with other alternatives in a cost-benefit analysis.

5.2 Treatment of combined sewer overflow

An alternative solution to manage overflow water is to treat the flow on site before the discharge, either with static structures, with mechanical treatments or with nature based solutions.

On site treatment of overflow water, though usually less rigorous than it could be done sending them to a wastewater treatment plant, is usually adequate for overflow discharge, generally characterized by smaller pollution load compared to wastewater. In addition , treating the discharge on site allows to return the treated water directly at the same site without burden on the drainage network.

The choice of the best type of treatment depends on the overflow water quality and on the type of pollutants, as well as the requirements due to the final receptor.

The treatment of overflow water presents some specific characteristics, that affect both the efficiency and the field of application:

- extreme variability of the flow;
- extreme variability of the pollutant load;
- long periods of inactivity during dry weather;
- sites which are generally less controlled and staffed than wastewater treatment plants

These characteristics are obviously a factor affecting the diffusion and the field of application of the different treatments and in the definition of the possible schemes.

Among the most used technological options are:

- **Settling tank;**
- **Mechanical sedimentation**
- **Sand and oil separators**
- **Mechanical fitration**

Another treatment option is the use of the so-called **Nature-based Solutions**, that regarding the CSO pollution control regard mainly the use of constructed wetlands (CW). Since a uniform legislation for CSO is generally lacking, both in EU and in US, varying CSO-CW designs have been proposed in different countries, in order to meet local needs in water pollution control and/or effluent water quality targets. Therefore, a couple of successful schemes are here proposed, according to the recent review work of Rizzo et al., (2020).

- **German approach**
- **French approach**
- **Italian approach**

5.2.1 Settling tank

This solution is based on the removal of suspended solids by a sedimentation section, preceded by preliminary treatments that intercept the bigger transported material. It is a very simple scheme, with requires limited management: cleaning and disposal of the sludge. The treatment is basically limited to the abatement of suspended solids and the effect on the organic load depends on how much the latter is adherent to suspended particles.

ADVANTAGES	DISVANTAGES
- No moving parts and without need of intervention during the process; - Suitable for undergournd installment, limiting land use; - Solution widely studied and experimented	- Sedimentation has only effect on suspended particles and not directly on the organic load; - Need to dispose the sludge produced

A higher treatment efficiency can be achieved using chemical additives that cause the formation of bigger sludge flakes, improving the sedimentation process (sedimentation with clariflocculation).

The use of chemical additives can result in greatly increase the treatment performance, doubling the rate of suspended particles removal and with an effect also on phosphorus removal, but it requires additional volumes for mixing and contact with chemical and more complex disposal of the resulting sludge.

The treatment efficiency of these systems is linked to suspended particles removal rate (30-50%), while the organic load removal rate is lower (15-25%), and basically due to the fact that the organic pollutants are partly adherent to the suspended particles. The nutrients (phosphorus and nitrogen) removal efficiency is very low. These parameters are referred to the basic static system and may be improved with the use of chemical additives.
The main dimensioning parameters are the ascent rate and retention time. Typical values for these parameters (referred to maximum discharge) are:

- Retention time: > 1.0 h;
- Ascent rate: < 4 m/h.

The use of chemical additives (clariflocculation) allows a reduction of about 50-60% of the tank volume, but an additional volume must be considered for contact and mixing of chemicals. In that case, an average value of retention time can be assumed to be about 20 min.

Maintenance activity required:

- Removal and disposal of material removed with preliminary treatment;
- Removal and disposal of material removed with sedimentation;
- Inspection of overflow structure
- Checking the correct operation of the dosing system and additives consumption (ony with clariflocculation)
- Checking the mixing system and timing of the contact phase (ony with clariflocculation)

5.2.2 Mechanical sedimentation

A higher interception rate and pollution removal can be achieved using, in addition to the ordinary pretreatments, a micro-screening or “mechanical sedimentation” section. The use of an electromechanical device requires much less space compared to static solutions, such as the settling tank described in the previous paragraph. On the other hand, it requires higher energy consumption and a more complex operation and maintenance due to the presence of moving parts.

One of the most common technologies for mechanical sedimentation is the slope bed filter with endless belt. Filtration belts are usually in polymeric or metallic materials, with spacing of about 200/350 µm. The formation of a "cake" of intercepted material increases the removal efficiency, intercepting even smaller particles. The increase of the raw water level upstream the filter, due to clogging by the intercepted sediment, cause the belt to advance, moving the clogged part towards the discharge zone where the accumulated "cake" is detached, and the free part of the belt towards the filter zone.

ADVANTAGES	**DISADVANTAGES**
- Land occupation significantly lower than the static options; - Treatment efficiency can be amplified with the use of chemical additives (flocculants); - Requires the same level of pre-treatments of the static option;	- Treatment efficiency is the same as the static option; - Higher energy consumption; - Possible impact of the noise during the filter cleaning operation, specially if done with compressed air; - Higher complexity of the maintenance operations due to the presence of moving parts.

The treatment efficiency of this solution is comparable to the one obtainable with static solutions.

The dimensioning of the process is based on the technical specifications provided by the manufacturers, which differs depending on different available technologies, and the hydraulic parameters of the flow.

Maintenance activity required:

- Removal and disposal of material removed with preliminary treatment;
- Removal and disposal of material removed with sedimentation;
- Inspection of overflow structure
- Inspection of mechanical parts and substitution of damaged parts, when needed;
- Checking the automatic systems for sludge removal.

5.2.3 Sand and oil separator

Sand and oil separators are mechanical treatments that remove coarse particles (>95% for particles with diameter 0,1mm - 1,0 mm) and oil and grease removal (> 85% depending on the system), but with no specific effect on BOD and COD reduction.

ADVANTAGES	DISVANTAGES
- Low space occupation; - Does not require more advanced pretreatments compared to the static sedimentation option;	- Lower treatment efficacy compared with static treatments; - Higher energy consumption; - Possible noise during cleaning phase, if compressed air systems are used; - Higher complexity of the maintenance operations due to the presence of moving parts. - No effect on BOD/COD reduction

The dimensioning of the process is based on the technical specifications provided by the manufacturers, which differs depending on different available technologies, and the hydraulic parameters of the flow.

Maintenance activity required:

- Removal and disposal of the removed material;
- Inspection of overflow structure
- Inspection of mechanical parts and substitution of damaged parts, when needed;
- Checking the automatic systems for sludge removal.

5.2.4 Mechanical filtration

Mechanical filtration have a high efficacy in the removal of suspended solids, with a significant effect on the organic load. Different technologies are available, such as cloth filters, sand filters or others in synthetic materials. These are technologies that require complex maintenance operations, to be performed by qualified personnel.

Upstream the filtration section it is important to install a fine sieve or settling tank to avoid the entrance of coarse particles that could clog the filters.

The filters can be cleaned using a backwash flow and the resulting sludge is less concentrated than with the other previously described systems; thus, it can be either be further treated before disposal or discharged in the wastewater system.

ADVANTEGES	DISADVANTEGES
- Significant reduction of land occupation; - High treatment efficacy, up to 90% of suspended solids and 35-40 % of the organic load; - Can be built as a modular system for further expansion; - Automatic cleaning with backwash water.	- Requires more rigoreous pre-treatments compared to the previous schemes; - Higher complexity of the maintenance operations due to the presence of moving parts; - Need to manage the backwash flow (about 5% of the treated flow) with further treatment or discharge.

The efficacy,of this kind of treatment is particularly high, close to 90%, for the removal of suspended solids, resulting in a reduction of 35-40 % of the organic load. The removal of nutrients, such as phosphorous and nitrogen, is of about 10%.

The dimensioning of the process is based on the technical specifications provided by the manufacturers, which differs depending on different available technologies, and the hydraulic parameters of the flow.

Approximately, for cloth filters the maximum filtration velocity is about 8-10 $m^3/m^2/h$.

Maintenance activity required:

- Removal and disposal of the removed material;
- Inspection of overflow structure
- Inspection of mechanical parts and substitution of damaged parts, when needed;
- Checking the automatic backwash system.

5.2.5 CSO-CW: German approach

The German approach consists in the use of a CSO tank and a RSFs ("Retention Soil Filters") to treat CSO, RSFs are vertical subsurface flow (VF) wetlands filled with a filter material (usually 0.063-2.0 mm sand) and planted with reeds to prevent clogging, they also provide a detention volume on top of the filter level. The influent percolates through the filter material and is collected by perforated drain pipes, and the filter is drained after each loading event to allow optimal aeration, the outflow rate is limited by a throttle orifice.

The system is designed to guarantee a filtration speed in the range 0.036–0.180 $m \cdot h^{-1}$.

VANTAGGI	SVANTAGGI
- Soluzione compatta rispetto ad altri schemi con soluzioni naturali - Soluzione con 30 anni di esperienza in Germania e centinaia di impianti realizzati - Alti rendimenti depurativi su COD, BOD, TSS, N-NH4 e TP, stimati dal monitoraggio di un ampio numero di impianti - Monitorata capacità di rimozione di microinquinanti e patogeni - Presenza di software per il dimensionamento di dettaglio (RSF_Sim o Orage)	- L’utilizzo di sabbia nel VF comporta un maggiore rischio di occlusione del letto nel caso di non appropriata manutenzio-ne dei trattamenti preliminari e della va-sca di sedimentazione

Interventi manutentivi necessari:

- Rimozione e smaltimento del materiale grigliato
- Rimozione e smaltimento del materiale accumulato nelle vasche di sedimentazione
- Ispezione manufatto scolmatore e controllo delle luci di regolazione per la suddivisione delle portate tra fognatura ed impianto di trattamento
- Ispezione delle vasche VF
- Verfica presenza di erosioni e ristabilizzazione delle sponde e/o della superficie del letto
- Verifica della presenza di piante infestanti e rimozione delle stesse
- Verifica corretto funzionamento bocca tarata

- Sfalcio essenze vegetali

5.2.6 CSO-CW: French approach

The French approach treats CSO in VF wetlands without CSO tanks or sedimentation basins. The VF is filled with coarse sand (d10>0.4 mm) with the bottom layer saturated and an aeration pipe above the saturate level. Also in this case a detention volume is provided above the filter material and the outflow rate is limited by a throttle orifice. There usually are two filter cells that are alternatively fed, and the cells in operation are switched on a monthly frequency.
The system is designed to guarantee a filtration speed in the range 0.036–0.180 $m \cdot h^{-1}$.

VANTAGGI

- Trattamenti preliminari minimi
- Soluzione mutuata dai "sistemi alla francese", soluzione per il trattamento di acque reflue domestiche con 30 anni di esperienza in Francia e migliaia di impianti realizzati
- Assenza di fanghi da smaltire annualmente, dato che i fanghi e i sedimenti sono accumulati sopra il letto VF, di cui ne è prevista la rimozione solo ogni 10-15 anni
- Alti rendimenti depurativi su COD, BOD, TSS, N-NH4 e TP, stimati dal monitoraggio di 3 anni dell'impianto a scala reale di Marcy-L'Etoile

SVANTAGGI

- Maggiore complessità nella gestione (necessità di alternare l'alimentazione di diversi settori del letto)
- Tuttora solo un impianto a scala reale monitorato

Interventi manutentivi necessari:

- Rimozione e smaltimento del materiale grigliato

- Rimozione e smaltimento del materiale accumulato nel disoleatore
- Ispezione manufatto scolmatore e controllo delle luci di regolazione per la suddivisione delle portate tra fognatura ed impianto di trattamento
- Ispezione delle vasche VF
- Verfica presenza di erosioni e ristabilizzazione delle sponde e/o della superficie del letto
- Verifica della presenza di piante infestanti e rimozione delle stesse
- Verifica corretto funzionamento bocca tarata
- Sfalcio essenze vegetali
- Rimozione dei fanghi stabilizzati in superficie e spandimento in campi agricoli come compost in assenza di eccessive concentrazioni di metalli depositati (atteso ogni 10-15 anni)

5.2.7 CSO-CW: Italian approach

The Italian approach is based on the CSO-CW of the Gorla Maggiore park, where a preliminary treatment removes oil, grit and sand, then a VF wetland works as a fist stage to treat first flush, and a Free Water Surface (FWS) is used as second stage to polish the effluent from the VF. The VF bed is filled with a coarse media (2-6 mm gravel), and the outflow rate is limited by a throttle valve, the FWS also works as a retention basin and receives both the effluent from the VF and the CSO surpassing the first flush.

The system is designed to guarantee a filtration speed in the range 0.036–0.180 $m \cdot h^{-1}$ for VF 1st stage, and a minimum hydraulic retention time of 6 – 12 hours for 2nd FWS stage.

VANTAGGI	SVANTAGGI
- Possibilità di sfruttare al meglio i servizi ecosistemici messi a disposizione dalle soluzioni naturali (qualità delle acque, sicurezza idraulica, biodiversità, fruizione)	- Maggiore area richiesta rispetto all'approccio tedesco e francese per la presenza del sistema a flusso libero, che però garantisce anche un trattamento delle acque di seconda

- Possibilità di limitare il volume di detenzione nello stadio VF al solo volume di trattamento delle prime piogge, usando il FWS per la laminazione di portate maggiori
- Ridotte operazioni di gestione e manutenzione
- Alti rendimenti depurativi su COD e N-NH4, stimati dal monitoraggio dell'impianto di Gorla Maggiore (VA)

pioggia nel caso di Gorla Maggiore

Interventi manutentivi necessari:

- Rimozione e smaltimento del materiale grigliato
- Rimozione e smaltimento del materiale accumulato nel dissabbiatore
- Ispezione manufatto scolmatore e controllo delle luci di regolazione per la suddivisione delle portate tra fognatura ed impianto di trattamento
- Ispezione delle vasche VF e FWS
- Verfica presenza di erosioni e ristabilizzazione delle sponde e/o della superficie del letto
- Verifica della presenza di piante infestanti e rimozione delle stesse
- Verifica corretto funzionamento bocca tarata
- Sfalcio essenze vegetali VF e FWS
- Rimozione dei fanghi stabilizzati in superficie e spandimento in campi agricoli come compost in assenza di eccessive concentrazioni di metalli depositati (atteso ogni 10-15 anni)

5.2.8 Main characteristics of the different treatment options

Il trattamento in continuo delle acque di sfioro offre la possibilità di intercettare sempre buona parte del carico inquinante, anche per eventi più gravosi di quello di progetto, al contrario dei sistemi di accumulo che esaurito il volume disponibile scaricano tutta la portata in arrivo nel recettore.

Di seguito si riporta una tabella riassuntiva delle efficienze dei vari sistemi di trattamento analizzati

Tipo di trattamento	**COD/BOD**	**TSS**	**N**	**P**	**Patogeni**
Sedimentazione	15-25%	30-50%	< 5%	< 5%	log 1 (<90%)
Sedimentazione con chiariflocculazione	35-40%	65-75%	< 10%	<25%	log 1 (<90%)
Grigliatura e microgrigliatura	15-25%	30-50%	< 5%	< 5%	log 1 (<90%)
Dissabiatura / disoleatura	-	85-90%	-	-	-
Filtrazione Meccanica	30-40%	> 90%	< 10%	< 10%	log 2 (< 99%)
Fitodepurazione: Approccio Tedesco	60-80%	>90%	90% (nitrification)	30-40%	log 1 (<90%)
Fitodepurazione: Approccio Francese	60-80%	>90%	70% (nitrification)	30-40%	log 1 (<90%)
Fitodepurazione: Approccio Italiano	60-90%	>90%	70-90% (nitrification)	30-40%	log 1 -2 (90%-99%)

Table 2. Removal rate (%) of technology options

5.3 Submerged discharge of the overflow

The sea has a great self-purifying capacity, thanks to the dilution that lowers the levels of pollutants and the activity of microorganisms, algae, plankton and fish, but the disposal of wastewater into the sea must be carefully evaluated. It is important that the discharge into the sea takes place with long pipes that discharge far from the coast, in order to obtain a thorough dilution of the sewage. Hygienic conditions must be guaranteed for bathers and for the cultivation of mussels and seafood, therefore the main parameter of reference is the **bacterial load**, measured with the colimetric index.

Therefore, this option could be recommended for CSOs, where the pollutant load of the water is already reduced by dilution with rainwater and for water at least subjected to a preliminary treatment before introducing it into the sea through a pipe with a diffuser positioned perpendicular to the sea current. The system must be designed in such a way that:

- the bacterial concentration near the coast is reduced
- no annoying smells and colours are perceptible
- diffusion on the surface of oily and floating substances is avoided

The main aspects to be defined when considering this solution are:

- The hydraulic head required to allow the discharge from the last diffuser. In case the natural hydraulic head of the pipe is not enough to guarantee a proper flow, a pumping station should be considered;
- The distance of the discharge from the cost and the pipeline length: this parameter should be accurately evaluated to avoid the possibility that pollutants are conveyed back near the shore;
- Depth of the sea bottom at the diffusers location: this parameter is linked to the pipeline length and should be adequate to ensure the dilution process;
- Location and path of the submarine pipeline, depending on the bathymetry and the geology and morphology of the seabed;
- Materials to be used for the pipes, diffusers, valves and all parts of the system, considering the high level of stress due to the location under sea water, currents,

possible impacts etc..

5.3.1 Main features

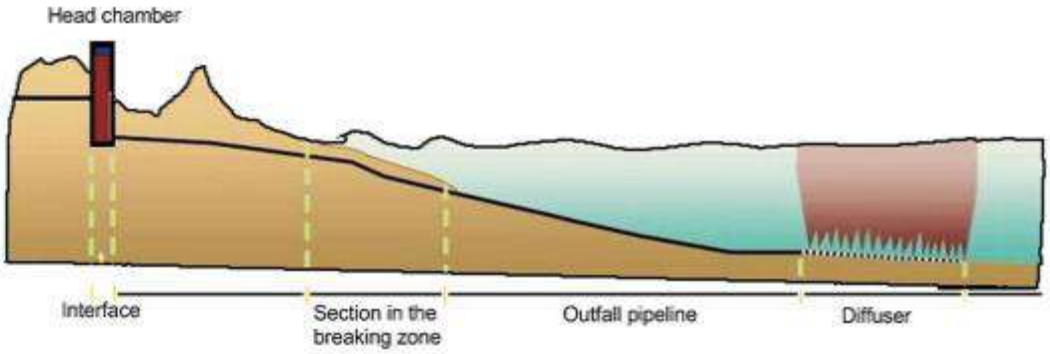


Figure 23. Schematic layout of a submarine discharge system (source: Mendonça et al., 2013)

The main parts of the system are:

A head chamber or a pumping station to ensure the correct hydraulic head and uniform flow conditions. A pumping station, while requiring a more complex design and higher maintenance and operational costs, is normally better suited to regulate the flow and control both these conditions.

Outfall pipeline: diameter, materials and type of joints of the pipeline are the main design elements. The velocity in the pipeline (depending on the diameter) should be enough to avoid sedimentation but also avoid high head loss in the pipe. Suitable materials include stainless steel (with cathodic protection), cast iron (with coating for corrosion protection), GRP or HDPE the 2 latter ones. Pipes in steel or cast iron are more mechanically resistant and have higher specific weight but are also less flexible and are highly susceptible to corrosion.

Diffusers: the number, distance and type of these elements is designed to have the correct velocity of the outgoing flow, both in the diffuser to avoid sedimentation and at the nozzles to ensure the dilution of the discharge in the sea water. The diffusers must have check valves to avoid sea water entering the system. This terminal part of the pipeline must be adequately signalled and protected from fishing nets or anchors and other objects that could damage them.

5.3.2 Dimensioning parameters

The main dimensioning elements for the design of submarine discharge pipes are:

Hydraulics: design discharge, hydraulic head required for the flow;

Dilution process: this process can be schematized in 3 phases: the first is the initial dilution, when the pitfall water, less dense than seawater, follows an upward trajectory with turbulent motion that facilitate mixing with the surrounding water and the spreading of the jet. The second phase involves the further mixing of the plume resulting from the initial dilution, mainly due to currents and waves and finally the third phase is the bacterial decay, depending on the external conditions surrounding the outfall.

Evaluation of the forces acting on the pipe, such as the pipe weight, buoyancy, hydrodynamic actions, friction between the seabed and the pipe.

In order to evaluate all these aspects, it is necessary to collect data concerning at least:

- Topography;
- Bathymetry;
- Seabed geology and morphology;
- Flow evaluation;
- Analysis of the currents, waves and wind conditions in the area;
- Environmental and biological conditions of the area;

- Evaluation of the pollutant load of the outfall.

6 UPGRADING OF EXISTING DRAINAGE NETWORKS

6.1 General aspects

Gli interventi descritti fino ad ora fanno parte delle soluzioni “di valle”, focalizzate sulla riduzione degli impatti dovuti agli scarichi di acque urbane, in particolare nelle acque di balneazione, mediante il trattamento o l’allontanamento delle acque di scarico.

Questo tipo di soluzioni possono e devono essere integrate con un approccio che miri a mitigare “a monte”, riducendo la contaminazione delle acque meteoriche di drenaggio, sia attraverso la separazione delle reti che attraverso la riduzione dell’apporto di acque meteoriche in rete attraverso l’utilizzo di soluzioni di drenaggio sostenibile.

Sebbene si tratti di soluzioni che difficilmente possono essere estese a tutto il bacino, soprattutto in contesti già urbanizzati, questo tipo di interventi hanno il vantaggio di poter essere realizzati in modo graduale nell’ambito di una pianificazione più generale relativa alla gestione delle acque urbane.

6.2 Sewer network separation

The separation of rainwater from wastewater collection allows to reduce or altogether avoid the need of CSOs.

The separation of drainage networks is not always possible or convenient; some conditions are to be verified in the preliminary phases of a feasibility study.

The separation of rainwater and wastewater networks should be considered when:

- The site is a new or a low density urbanization, where the separation is physically possible;

- It is possible to frequently discharge rainwater, without the need of conveying all the flow to the site of wastewater treatment;
- There is enough space for a dual network, without interference between the main pipes and the connections from households and drains;
- The works can be carried out during road or pavement restorations or other works that could be needed on the existing network (for exemple if the existing pipes have insufficient flow capacity);
- Low available slopes and unfavorable topography: in this case it could be convenient to separate the networks and install pumping stations on the wastewater network only, which has lower and less variable flow rates. The rainwater drainage could then be separately managed, without interfering on wastewater collection;

From an operational point of view, converting a combined network in a separate one can be done either installing a new rainwater network and using the existing one for wastewater only or vice versa.

In case the existing combined network is found to be inadequate from an hydraulic point of view, with insufficient flow capacity, the first option could be convenient. The design of a new rainwater network will take into account the higher drainage flow. This can frequently be the case when considering areas with growing urbanization.

This choice has the advantage of not needing the displacement of wastewater connections, but only drains and other stormwater collection items, thus requiring far lesser involvement of the population. The conditions of existing network should be investigated to verify the need for remediation works to avoid wastewater leaks and infiltration in the surrounding ground.

If on the contrary the existing combined network presents is deemed adequate for the rainwater discharge, it can be converted in a stormwater network, laying new wastewater pipes, smaller and with adequate slopes to avoid deposit. The works will also entail the shift of all wastewater connections to the new network. In this case, it is important to perform a final monitoring of the existing network after completion of works, to look for possible undetected remaining wastewater connections.

When considering the convenience of this works, in addition to operational difficulties and costs, it is important to evaluate all the elements that can limit their efficacy.
The first element to consider is that rainwater, especially if from road surfaces or productive areas, can have a high pollution load, as shown in the table below.

Parameters (mg/l)	**AVERAGE COMPOSITION OF DRAINAGE WATER FROM:**				
	Urban areas	**Industrial areas**	**Residential/commercial areas**	**Agricoltural areas**	**Green areas**
BOD_5	20 (7-56)	9.6	20	3.8	1.45
COD	75 (20-275)	-	-	-	-
TSS	150 (20-2890)	93.9	140	55.3	11.1
NH_4-N	0.582	-	-	0.48	-
TN	2	1.79	2.8	2.32	1.25
TP	0.36	0.31	0.51	0.344	0.053
Copper	0.05	-	-	-	-
Lead	0.18	0.202	0.214	-	-
Zinc	0.2	0.122	0.170	-	-
Iron	8.7	-	-	-	-
Mercury	0.00005	-	-	-	-
Nickel	0.022	-	-	-	-
Cyanides	0.0025	-	-	-	-
Phenols	0.0137	-	-	-	-
Oil and grease	2.6	-	-	-	-

Table 3. Compairason of the chemical quality of rainwater from the drainage of areas with lan use (Kadlec and Knight, "Treatment Wetlands", 1996)

It is thus important to manage first flush water with storage or treatment systems.
Finally, separate networks are exposed to the risk of irregular connections of rainwater to the wastewater network (with risk of overcharging the pipes) or wastewater connections to the stormwater network, which would result in the untreated discharge of polluted water.

6.3 Sustainable Urban Drainage Solutions (SUDS)

The urbanization processes developed in recent decades have profoundly changed the natural water cycle due to the increase in impermeable surfaces, decreasing evapotransporation phenomena, superficial and deep infiltration and the recharge of the aquifers, and increasing the volumes of the runoff waters, i.e. surface runoff waters that are not infiltrated into the ground.

The conventional approach of draining and collecting rainwater from the waterproofed surface and conveying it away from urbanized areas as quickly as possible has resulted in the collection of all runoff from impermeable surfaces, regardless of their degree of pollution, and their introduction in mixed or separate sewers, to then be discharged into surface water bodies (rivers, lakes, seas). This has strongly reduced local infiltration and transferred a whole series of problems from upstream to downstream, being a contributing cause of overloading of sewers and urban surface flooding, river flooding, erosive processes, water pollution (in particular when the collection of rainwater occurs in mixed sewers together with wastewater, with frequent activation of flood spillways).

Recently a different type of approach is being imposed, aimed at the separation of rainwater in the networks, at slowing down flows by reducing flood peaks, at reducing impermeable surfaces. Techniques for the sustainable management of urban drainage have been studied and developed to be used to replace or integrate existing sewers, these techniques are known as SuDS (Sustainable urban Drainage Systems).

6.3.1 Characteristics, properties and benefits of Sustainable urban Drainage Systems

Sustainable urban Drainage (SuDS – Sustainable urban Drainage Systems) aims to manage rainwater falling in urban areas in order to:

- rebalance the hydrological balance and reduce the polluting load towards the water bodies, recreating the conditions existing on the territory before urbanization;

- build green infrastructures capable of exploiting all the benefits provided by the ecosystem services of natural solutions (Nature-Based Solutions).

Sustainable urban drainage techniques provide various ecosystem services in addition to improving water quality by intercepting the most polluted part linked to the first flush and reducing water peaks and consequently reducing the activation frequencies of combined sewer overflows:

- atmospheric regulation
- climatic regulation
- water regulation
- water recovery
- erosion control and sediment retention
- soil formation
- balancing nutrient cycles
- reduction of pollutant load by exploiting natural processes
- pollination
- increase in biodiversity
- biomass production
- increase in recreational areas
- environmental education

The SuDS approach through sustainable urban drainage systems can be applied to different contexts, from individual homes to an entire urban and sub-urban area, and with different levels of naturalness and ecosystem services offered. Unlike a traditional engineering approach, to which a problem often corresponds to a single technical solution, the SuDS approach is integrated and provides, for natural solutions only, a large number of techniques with which to design an integrated system, with a multidisciplinary and multi-objective approach, the most appropriate tailored technical solution.

6.3.2 Scales of application of SuDS

In highly urbanized areas, **car parks** often represent extensive waterproof surfaces, which make an important contribution to the development of runoff volumes and the imbalance of the pre-urbanization hydrological balance. Consequently, the conversion of existing car parks, or the construction of new ones, represents an opportunity to help restore the pre-development balance, as well as provide an opportunity for redevelopment and urban furniture.

Different approaches to drain, laminate and infiltrate the rainwater falling on the parking lots can be adopted: as you can see in **Errore. L'origine riferimento non è stata trovata.**, different SuDS techniques can be used, from pavements, to vegetated ditches, from filter trenches to ponds.

Figure 24.. Different SuDS approaches for the sustainable drainage of rainwater from parking lots. Source: Huber, J., 2010. Low Impact Development: a Design Manual for Urban Areas (adapted)

Figure 25.. Pixelated Parking example. Source: Huber, J., 2010. Low Impact Development: a Design Manual for Urban Areas

Figure 26. Garden Parking example. Source: Huber, J., 2010. Low Impact Development: a Design Manual for Urban Areas (adapted)

Streets occupy 25 percent of the urban impermeable surface (Huber, J., 2010). They are usually designed, from the hydraulic point of view, through the installation of drains and white sewers which have the purpose of efficiently draining the rainwater falling on them. In this way, however, the roads have a strong impact on the water bodies receiving the drained rainwater, both by raising the hydraulic peaks during significant rain events, and by contributing to the deterioration of the quality status due to the pollutants carried into the first flush waters. In analogy to the case of car parks, also in this case it is possible to identify less invasive interventions for conventional roads rethought from a SuDS perspective and, following the classification of the LID manual (Huber, J., 2010), more intensive interventions with roads designed as *Greenways*.

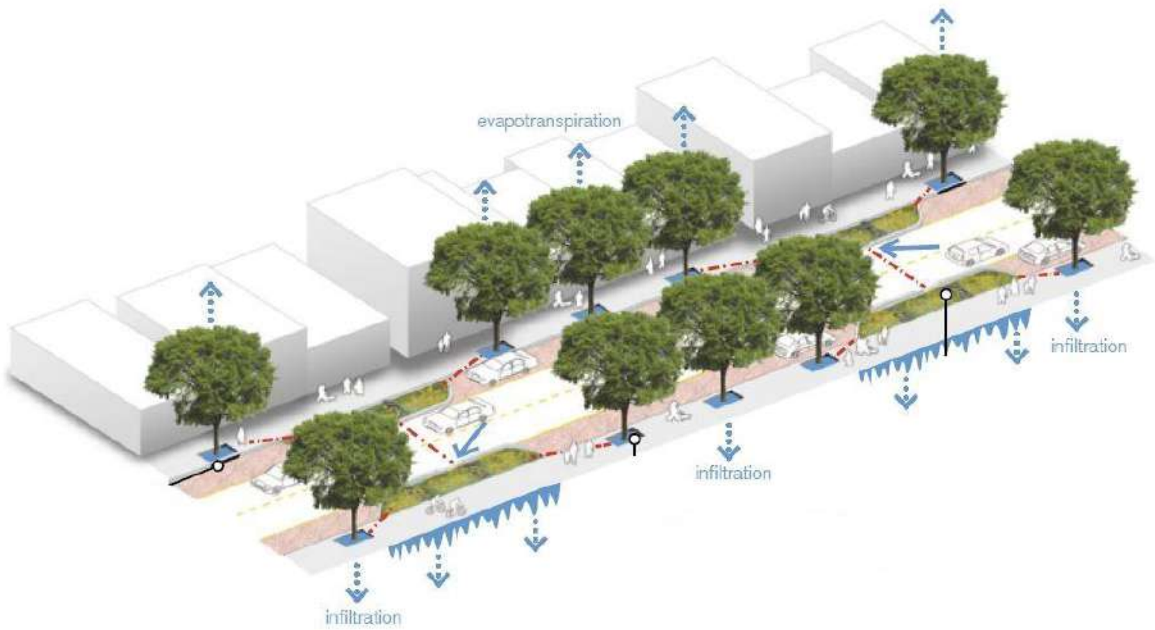


Figure 27.. Example of conventional roads rethought from a SuDS perspective. Source: Huber, J., 2010. Low Impact Development: a Design Manual for Urban Areas (adapted)

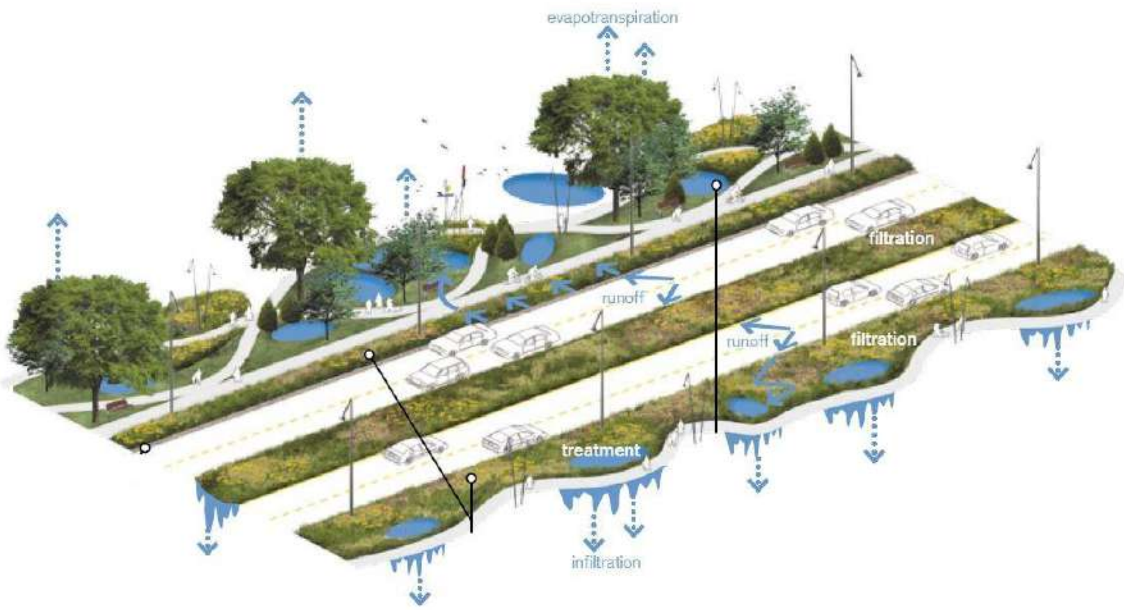


Figure 28.. Greenway example. Source: Huber, J., 2010. Low Impact Development: a Design Manual for Urban Areas (adapted)

Figure 29.. Example of a road without curbs for conveying rainwater to the infiltration areas. Source: Woods Ballard et al. 2015. "The SuDS Manual"

6.3.3 SUDS techniques

This paragraph mainly analyses solutions based on the implementation of natural systems, given the major benefits provided in adapting water management to climate change:

- Infiltration trenches
- Filter strips
- Filter drains
- Swales
- Bioretention areas
- Detention basins
- Ponds and Wetlands

SuDS technique	Peak runoff rate	Small event runoff volume	Large event runoff volume	Water quality	Amenity	Biodiversity
Rainwater harvesting		●	●		●	
Green Roofs	○	●		●	●	●
Infiltration systems	●	●	●	●	●	●
Filter strips		●		●	○	○
Filter drains	●	○		●	○	○
Swales	●	●	●	●	●	●
Bioretention systems	●	●	●	●	●	●
Detention basins	●	●		●	●	●
Ponds and wetlands	●			●	●	●

Table 4. SuDS natural solutions and expected effect for various design criteria: ○ limited expected contribution; ● high expected contribution. Adapted from Woods-Ballard et al., (2015).

6.3.4 Retrofitting with SuDS

The term *retrofit* is used when SuDS techniques aim to replace and increase an existing drainage system in a developed catchment area, exploiting existing areas without changing their intended use. Examples of retrofit SuDS could be the insertion of rain gardens in home gardens, the deviation of the roof drainage in a collection and storage system, or the channelling of road runoff into green areas of street furniture converted into a bioretention area. A functional scheme of a retrofitting is shown below in **Errore. L'origine riferimento non è stata trovata.**. The road curbs are raised in some points, so as not to activate the existing manholes, and removed in others, to allow the entry of rainwater into the green area; the existing manhole is maintained with an overflow function in the event of heavy rains. In this way an existing flowerbed is able to accumulate the intercepted runoff volume on the surface and in the pores, infiltrating it into the subsoil in the following 24-48 hours, while the existing sewer is by-passed for almost all the annual runoff waters.

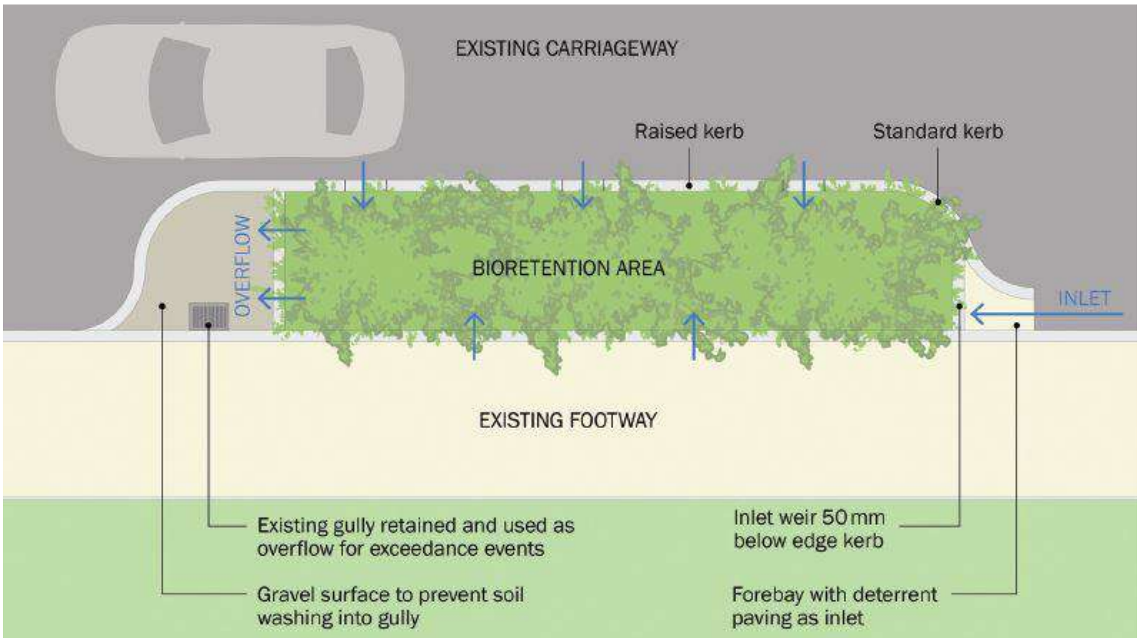


Figure 30.. Example of a green area subject to retrofitting from a SuDS perspective, transforming it into a plant retention area (Woods Ballard et al. 2015. "The SuDS Manual")

Below is a table showing some examples of SuDS retrofitting with bioretention areas in the UK.

SUDS RETROFITTING EXAMPLES	
Embleton Road SuDS, Bristol	
Before the intervention	After the intervention
	
Location	Little Mead Primary Academy, Gosforth Road, Southmead, Bristol, BS10 6DS; 51°30'16.9"N 2°36'21.6"W
Technical solution adopted	Rain garden and vegetated swales
Year of construction	2016
Road surface extension	
Extension of retrofitting elements	5 rain gardens of about 10 m^2 each
Marylebone Low Emission Neighbourhood (LEN), London	
Before the intervention	After the intervention
	
Location	Marylebone High Street, Paddington Street and New Cavendish Street in Westminster, London, UK.
Technical solution adopted	Rain garden
Year of construction	2016-2019
Road surface extension	7000 m^2
Extension of retrofitting elements	129 m^2

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D.4.3.1 – Guidelines to assess the quality of urban wastewater and coastal system

VOLUME 3 - The decisional process to identify the best solution and the relevant concept design

Document Control Sheet

Project number:	10044130
Project acronym	WATERCARE
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Duration	36 months

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Author (s)	Marco Romei (PP 1 ASET) Andrea Marinelli (PP 1 ASET) Matteo Lucertini (PP 1 ASET) Enrico Esposto Renzoni (PP 1 ASET) Marina Simonetti (PP 1 *STUDIO MAJONE INGEGNERI ASS.*) Riccardo Bresciani (PP 1 *IRIDRA SRL*)
Version	1
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INDEX

1 INTRODUCTION

ASET is the WP4 responsible and has in charge the redaction of a Guide-Line for the execution of Feasibility Studies to implement innovative solutions in the WATERCARE sites.

ASET will elaborate a set of documents to be used by any PP in carrying out a proper feasibility study specific for the relevant project site and the foreseen deliverable list consists of:

- Volume 1: basics on the pollution monitoring and collected data analysis;
- Volume 2: identification of a set of possible solutions to remove the pollution and/or to mitigate the pollution effect;
- **Volume 3**: the decisional process to identify the best solution and the relevant Concept Design;
- Volume 4: site-specific reference;
- Typical drawings of the possible solutions to solve the pollution of the bathing area;

Volume 3 discusses the steps needed for a proper decision making of the solutions proposed in Volume 2. Particularly, two decision making tools are presented, Multicriteria Analysis (MCA) and S.W.A.T. analysis. Subsequently, a simplified MCA is proposed for the targeted subjects: (i) new wastewater treatment for urban wastewater; (ii) upgrading of existing wastewater treatment for urban wastewater; (iii) small wastewater treatment; (iv) combined sewer overflow; (v) upgrading of existing drainage systems. The proposed simplified MCAs aim to help identifying most proper solutions in preliminary decision making phases, guiding the development of detailed feasibility studies and basic design for site specific conditions.

2 DECISION MAKING TOOLS

To evaluate the potential impact of a wastewater treatment solution, by addressing the calculation of social and environmental indicators, it may not be feasible or simple to quantify them all at a preliminary phase. A more visual and simpler method could comprise their representation in tables by associating their individual impact with a colour or with a score associated with a colour.

In this way, the overview of the impacts of all indicators could give an idea of the general assessment of each alternative and an impression of the overall impact of the project. However, the absence of weights in the indicators can lead to incorrect conclusions. Therefore, the main elements required to face a semi-quantitative assessment by a Multi Criteria Analysis (MCA) using key indicators are an expert knowledge to evaluate the impact reflected in the result, and the weights assigned to different categories (i.e. environmental, social and economic) that should be established by the project promoters and decision makers.

For small interventions, S.W.O.T analysis can be a more simplified approach.

2.1 Multi Criteria Analysis (MCA)

The **Multi-criteria** (or multi-attribute) **analysis** involves the use of different types of variables aimed at providing a framework that allows preferences to be quantified. This is particularly useful in the field of sustainability, where variables with different units are involved. One widely accepted framework for standardising different units is the value function (Beinat & Nijkamp, 1998).

The MCA analysis provides for the definition of:

- Alternative
- Scenario
- Evaluation criteria

- Value functions
- Weights

The term **Alternative** refers to the definition of a precise intervention solution for the problem treated.

By **Scenarios** we mean conditions that can influence the project from the outside, but which are not a direct choice of the designer (e.g. different regulatory context, a significant change in socio-economic conditions, etc.).

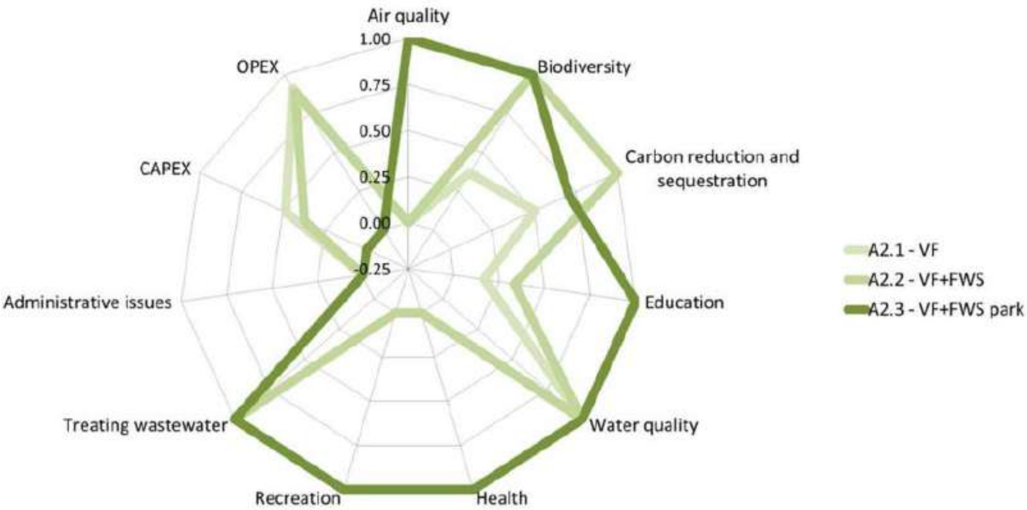
The **Evaluation Criteria** express what interests about the problem that must be treated: first of all, the objectives that want to be achieved, but also the other "secondary" aspects that interest us (e.g. costs, impacts environmental, etc.), which must be quantified in order to proceed with the assessment of the Alternatives.

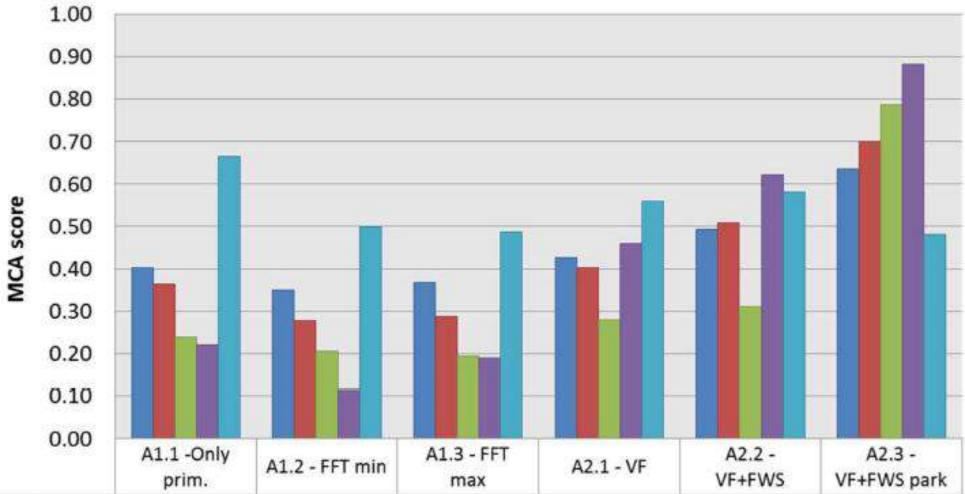
Defining the **value function** requires measuring preference, or the degree of satisfaction produced by a certain alternative option for a measurement variable (indicator). Each measurement variable may be given in different units; therefore, it is necessary to standardise them into units of value or satisfaction, which is basically what the value function does. To determine the satisfaction value for an indicator a few preliminary steps must be guaranteed (Alacron et al., 2010):

- Definition of the orientation (increase or decrease) of the value function;
- Definition of the points corresponding to the minimum (e,g., Smin, value 0) and maximum (e.g., Smax, value 1) performance/satisfaction;
- Definition of the kind (ordinal or cardinal) and of the shape (linear, concave, convex, S-shaped) of the value function;
- Definition of the mathematical expression of the value function.

Value functions can be built, usually, with two different approaches, function of the level of details of available information: (i) quantitative or (ii) qualitative. **Quantitative value functions** are usually built when a forecast of the performance based on existing data and models (e.g., costs, nutrient recovery) can be done in a reliable way. In other cases, it could be more safe to use a **qualitative value functions**, which provide prediction of the effects relying on the so called Expert judgement. Expert knowledge has gained momentum as a source of information for decision making, particularly in contexts where empirical information is sparse or unobtainable (Sutherland 2006). MCA is naturally suited to incorporate expert knowledge through value functions. These are expert preferences for objectives on a standardised scale.

The **Weights** define the preferences for the different criteria, which are site-specific and can be different according to the different stakeholders involved (do I prefer to spend less or be more attentive to environmental impacts?). By applying the weights to the normalized values of the value function, a unique score can be obtained for each Alternative, which is a summary of the effects for each criterion and the preferences of the stakeholders involved.





	A1.1 -Only prim.	A1.2 - FFT min	A1.3 - FFT max	A2.1 - VF	A2.2 - VF+FWS	A2.3 - VF+FWS park
W1 - Expert-based case study	0.40	0.35	0.37	0.43	0.49	0.64
W2 - equal weights	0.36	0.28	0.29	0.40	0.51	0.70
W3 - citizens	0.24	0.21	0.19	0.28	0.31	0.79
W4 - environmentalists	0.22	0.11	0.19	0.46	0.62	0.88
W5 - grey infrastructure professional	0.67	0.50	0.49	0.56	0.58	0.48

Figure 1. Examples of graphical representation of MCA results: above, spider web graph for highlighting criteria evaluation for different alternatives; below, sensitivity analysis for alternative evaluation function of weights from different stakeholder groups. Source: Rizzo et al., (2021)

2.2 S.W.O.T. analysis

The SWOT analysis is a simplified assessment tool that can be used to support a decision making. The SWOT analysis is a tool used to evaluate the Strengths, Weaknesses, Opportunities and Threats of the different treatment solutions. The strengths and weaknesses are identified through an internal analysis, and identify the resources that can be exploited. Opportunities and threats refer to the external environment and serve to determine future developments and implications (Sammut-Bonnici & Galea, 2015).

This analysis evaluates the internal and external factors that may be favourable or unfavourable to the achievement of the project objective (Sadhukhan, 2020). In the field of treatment systems, with the SWOT analysis both technical and non-technical elements are investigated. The SWOT analysis identifies the advantages that support the decision to implement a system (strengths), the aspects that can be improved or what needs to be investigated before implementation (weaknesses), the possible chances and positive improvements (opportunities), and the risks and obstacles for the future (threats) (Starkl et al., 2015).

The main aspects that can be analysed in the SWOT analisys are (Starkl et al., 2015):

- Energy requirements
- Land requirements

- Operation and management requirements
- Environmental aspects
- Health aspects
- Safety aspects
- Economic aspects
- Social aspects
- Institutional aspects

3 SIMPLIFIED MULTICRITERIA ANALYSES

3.1 New wastewater treatment for urban wastewater

Once the different project alternatives have been identified, it is possible to perform an MCA; the evaluation criteria are established and the value function is defined and therefore the evaluation matrix, which provides support in the choice of the best alternative.

The Multi-Criteria Analysis proposed here is a simplified version, as the weights to be attributed to each criterion are not defined. In fact, the specific MCA cannot be done at a general level, as the weighing is site-specific, and is therefore feasible only for each single case. The purpose of this simplified analysis is simply to guide the choice of the solution to be adopted.

The possible **Alternatives** in reference to new wastewater treatment for urban wastewater are listed below:

1. Activated sludge plant
2. SBR (Sequencing Batch Reactor)
3. MBR (Membrane Biological Reactor)
4. MBBR (Moving Bed Bio Reactor)
5. Constructed Wetlands
6. WSP (Waste Stabilization Pond)
7. Trickling filters
8. Rotating Biological contactors

The **Evaluation Criteria** chosen for the alternatives are defined as follows:

No.	Selection Criteria
1	Cost of treatment (c = capital; om = operation and maintenance)
2	Effluent quality achieved and intended reuse application
3	Reliability
4	Land required

5	Ease of operation and maintenance
6	Resources requirement
7	Quantity and quality of sludge (waste) produced
8	Adaptability to upgrade
9	Adaptability to varying flow rate
10	Adaptability to varying quality
11	Ease of construction
12	Power requirements
13	Chemical requirements
14	Odour generation
15	Impact on health, risks
16	Social acceptance

These criteria were evaluated through a **value function** on the basis of whether they are considered positive or negative aspects of the different alternatives. Score of the value function were given by expert judgment.

Value	Score
Null	/
low	+
medium	++
high	+++

Based on the evaluation criteria and the alternatives defined in the previous section, the **evaluation matrix** is compiled and is visible in Table 1. The evaluation matrix shows the score of each alternative with respect to the chosen criteria.

If a score is associated to a positive and negative aspects, it depends by the type of criteria; for example low operational cost (1 – om) are always desirable, and therefore a low score (+) is more positive than a higher score.

		EVALUATION CRITERIA																
		1 (c)	**1 (om)**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
ALTERNATIVES	Activated sludge plant	++	+++	++	++	+	+++	++	+++	+++	++	++	+	+++	++	+	++	++
	SBR	++	+++	++	++	++	++	++	+++	+++	++	++	+	+++	++	+	++	++
	MBR	+++	+++	+++	+++	++	++	++	++	+++	+++	+++	+	+++	+++	+	++	++
	MBBR	++	++	++	++	+	++	++	++	++	+	+	+	++	+	+	/	++
	Constructed Wetlands	++	+	+	+	+++	+	+	+	+	+++	+	+	+	/	+	+	+++
	WSP	+	+	+	+	+++	+	+	+	+	++	+	+	+	+	+++	+	+
	Trickling filters	++	++	++	++	++	+	++	+	++	++	++	++	++	+	+	+	++
	Rotating Biological contactors	++	++	++	++	++	+	++	++	++	++	++	+	++	+	+	+	++

Table 1. Evaluation matrix of proposed solutions

As regards the quality and quantity of sludge produced, it is noted that the least suitable solutions are Trickling filters and Rotating Biological contactors, while their characteristics improve as regards operation and maintenance, energy consumption and remote control. WSPs and CWs show better performance in the production of sludge compared to the other solutions. Activated sludge plants, MBRs, SBRs and MBBRs require a greater effort for operation and maintenance, and for monitoring. They also have a higher energy consumption and require remote control. On the other hand, CWs and WSPs are characterized by ease of operation, maintenance is limited and energy consumption is low.

3.2 Upgrading of existing wastewater treatment for urban wastewater

Once the different project alternatives have been identified, it is possible to perform an MCA, therefore, the evaluation criteria are established and the value function is defined and therefore the evaluation matrix, which provides support in the choice of the best alternative.

The Multi-Criteria Analysis proposed here is a simplified version, as the weights to be attributed to each criterion are not defined. In fact, the specific MCA cannot be done at a general level, as the weighing is site-specific, and is therefore feasible only for each single case. The purpose of this simplified analysis is simply to guide the choice of the solution to be adopted.

The upgrading of existing wastewater treatment systems for urban wastewater must be considered specifically for each case, especially for the addition of tertiary treatments and for the improvement of secondary treatments, a site-specific analysis is therefore necessary to carry out the MCA. However, assuming that a disinfection phase is required in any case to comply with the legal limits, a simplified MCA analysis was carried out on the various solutions that can be adopted for disinfection in order to guide the design choice.

The possible **Alternatives** for the upgrading of existing wastewater treatment for urban wastewater with a disinfection phase are listed below:

1. UV
2. Chlorination
3. Peracetic Acid
4. Ozone
5. UF

The **Evaluation Criteria** chosen for the alternatives are defined as follows:

- <u>Safety</u>: evaluates the safety of use and management

- Bacteria removal: takes into account the average performance of the different techniques in removing bacteria
- Virus removal: takes into account the average performance of the different techniques in removing viruses
- Protozoa removal: takes into account the average performance of the different techniques in removing protozoa
- Bacterial regrowth: takes into account the average bacterial regrowth of the different techniques
- Residual toxicity: takes into account the residual toxicity left by the alternatives
- By-products: takes into account the by-products produced by the alternatives
- Operating costs: evaluates the average operating costs of the alternatives
- Investment costs: evaluates the average investment costs of the alternatives

These criteria were evaluated though the **value function** on the basis of the intensity of the effect of the chosen criteria for the different alternatives:

Intensity of effect	Score
Null	/
Low	+
Middle	++
High	+++

Based on the evaluation criteria and the alternatives defined in the previous section, the **evaluation matrix** is compiled and is visible in Table 2. The evaluation matrix shows the intensity of the effects of each alternative with respect to the chosen criteria.

	EVALUATION CRITERIA									
	Disinfection	Safety	Bacterial removal	Virus removal	Protozoa removal	Bacterial regrowth	Residual toxicity	By-products	Operating costs	Investment costs
ALTERNATIVES	UV	+++	++	+	/	+	/	/	+	++
	Chlorination	+	++	+	/	+	+++	+++	+	++
	Peracetic acid	+	+++	+	+	+	/	/	+	++
	Ozone	++	++	++	++	+	+	+	++	+++
	UF	+++	+++	+++	+++	/	/	/	+++	+++

(/ none; + low; ++ middle; +++ high)

Table 2. Evaluation matrix of proposed solutions for disinfection (adapted from Lazarova, 1999 and All. C, Reg. 6/2019)

Chlorination has proven to be a reliable means of removing bacteria, however, toxic by-products may present a risk for public health, and the presence of chlorine residuals represents a threat for the environment, so dechlorination must be implemented increasing the costs. Virus removal is low and protozoa are not affected by the commonly applied chlorine doses and residence times. UV disinfection is reliable for secondary and tertiary effluent disinfection, its main advantage is the absence of toxicity and by-products, and the costs are comparable to those of chlorination. Moreover, UV systems do not require specific safety control and equipment, making UV particularly suitable for wastewater disinfection. Ozonation is recommended for large plants where viruses and /or protozoa parasites are targeted. Membrane filtration is a highly effective process, and is the most suitable for high stringent reuse applications. It has relatively high costs, but it is the only technology that guarantees reliability, absence of toxicity and total disinfection (Lazarova, 1999).

3.3 Small wastewater treatment plants

Once the different project alternatives have been identified, it is possible to perform an MCA, therefore, the evaluation criteria are established and the value function is defined and therefore the evaluation matrix, which provides support in the choice of the best alternative.

The Multi-Criteria Analysis proposed here is a simplified version, as the weights to be attributed to each criterion are not defined. In fact, the specific MCA cannot be done at a general level, as the weighing is site-specific, and is therefore feasible only for each single case. The purpose of this simplified analysis is simply to guide the choice of the solution to be adopted.

The possible **Alternatives** in reference to new wastewater treatment for urban wastewater are listed below:

1. Imhoff and soil dispersion
2. Constructed wetlands
3. Compact activated sludge plants
4. Aerobic Trickling filters

The **Evaluation Criteria** chosen for the alternatives are defined as follows:

- Investment cost: construction cost
- Operation and maintenance cost: cost for ordinary checking, revision, spare parts, energy, sludge disposal
- Skilled workers requirement: request for specialized personnel
- Energy consumption: it compares the electricity demand of the different solutions.
- Requested space
- Adaptability to daily and seasonal flow peaks: in small plants, the flow peaks are more consistent than in large plants connected to extended sewers, therefore the capability to adapt to this condition is considered very important to ensure a good water quality level

These criteria were evaluated though the **value function** on the basis of whether they are considered positive or negative aspects of the different alternatives:

Intensity of effect	Score
Null	/
Low	+
Middle	++
High	+++

Based on the evaluation criteria and the alternatives defined in the previous section, the **evaluation matrix** is compiled and is visible in the table below. The evaluation matrix shows the positive and negative aspects of each alternative with respect to the chosen criteria.

	EVALUATION CRITERIA						
ALTERNATIVES	**Type of treatment**	**Investment cost**	**Operational cost**	**Skilled workers requirement**	**Energy consumption**	**Requested space**	**Adaptability to daily and seasonal flow peaks**
	Imhoff + soil dispersion	+	+	/	/	+	++
	Compact technological plants	++	++	++	++	+	+
	Constructed Wetlands	++	+	/	/	++	+++
	Aerobic filters	++	+	/	/	+	++

Table 3. Evaluation matrix of proposed solutions for small wastewater treatment plants

The choice between intensive (SBR, MBR, MBBR, etc.) and extensive treatments (constructed wetlands) must be made considering the availability of space and the permeability of the soils (All. C, Reg. 6/2019). It must be considered that in case of space availability, constructed wetlands can be considered the most suitable choices thanks to the lower management costs and the numerous secondary benefits they are able to provide.

3.4 Combined sewer overflow

Once the different project alternatives have been identified, it is possible to perform an MCA, therefore, the evaluation criteria are established and the value function is defined and therefore the evaluation matrix, which provides support in the choice of the best alternative.
The Multi-Criteria Analysis proposed here is a simplified version, as the weights to be attributed to each criterion are not defined. In fact, the specific MCA cannot be done at a general level, as the weighing is site-specific, and is therefore feasible only for each single case. The purpose of this simplified analysis is simply to guide the choice of the solution to be adopted.
The possible **alternatives** in reference to new wastewater treatment for urban wastewater are listed below:

1. Submerged discharge of the overflow
2. Storage tank
3. CSO treatment
    a. Constructed wetland: German approach
    b. Constructed wetland: French approach
    c. Constructed wetland: Italian approach
    d. Static sedimentation
    e. Micro-grid
    f. Mechanical filtration

The **Evaluation Criteria** chosen for the alternatives are defined as follows:

- <u>Reduction of pollutant load</u>: takes into account the average performance of the different techniques in the removal of organic load, nitrogen and microbiological parameters; it does not take into account the performance in terms of abatement of suspended solids

- Phosphorus abatement: takes into account the average performance of the different techniques in removing the phosphorus content
- Investment costs: strongly dependent on local conditions, the costs of the solutions were assessed on the basis of the difference with the average cost of the different alternatives
- Space occupation: the surface occupied and therefore made unusable by the techniques used
- Need of staff: takes into account the frequency of on-site visits by personnel for controls or management operations
- Energy consumption: compare the electricity demand of the different solutions
- Sludge products: sludge produced by the sedimentation of suspended solids; preliminary treatments and sands are not taken into account
- Integration / improvement of habitat and landscape: takes into account the additional ecosystem services provided by the proposed solutions

These criteria were evaluated though the **value function** on the basis of whether they are considered positive or negative aspects of the different alternatives:

Value	Score
Highly negative	---
Negative	--
Moderately negative	-
Non-relevant	*
Moderatively Positive	+
Positive	++
Highly positive	+++

Based on the evaluation criteria and the alternatives defined in the previous section, the **evaluation matrix** is compiled and is visible in Table 4. The evaluation matrix shows the positive and negative aspects of each alternative with respect to the chosen criteria.

	EVALUATION CRITERIA								
ALTERNATIVES	**Type of treatment**	**Reduction of pollutant load**	**Phosphorus abatement**	**Investment costs**	**Space occupation**	**Need of staff**	**Energy consumption**	**Sludge products**	**Integration / improvement of habitat and landscape**
	Submerged discharge	---	---	+++	+++	+++	+	+++	---
	Storage tank	+++	+++	-	*	+	-	+	+
	CSO-CW: German approach	++	+++	*	-	+	+	-	+
	CSO-CW: French approach	++	+++	*	--	-	+	++	+
	CSO-CW: Italian approach	++	+++	*	--	+	+	+	+++
	Static sedimentation	--	-	++	+	+	+	+	*
	Micro-grid	-	-	+	++	*	-	++	-
	Mechanical filtration	+	+	*	++	-	--	-	-

Table 4. Evaluation matrix of proposed solutions for different key indicators (adapted from: All. A, dgr 2723/2019)

Submerged discharge can be considered the business as usual solution, giving benefits only in terms of easy operation and installation, but leading to environmental pollution and none additional benefits. The selection of this solution may be taken into account after careful consideration of the pollutant load of the overflow discharge and the environmental, biological and geomorphological characteristics of the sea at the discharge location.

Storage tank permit to strongly reduce the environmental impact of CSO pollution. However, this solution has its impact on the wastewater network and treatment plant. Thus, the benefit in terms of more rigorous treatment must be weighted against the impact that this type of additional load will have on the downstream system.

In terms of reducing pollutants with CSO in-situ treatment, natural solutions have on average higher performance than traditional solutions, which are limited to the removal of suspended solids. Natural systems allow for organic load reductions of more than 80%. The situation is similar for the removal of phosphorus. The construction costs are comparable for most of the CSO treatment solutions but there are some that have costs on average about 30% higher, while the simpler primary treatment systems have costs significantly lower, with the lowest cost given by the simple marine discharge of CSO, if the sea is sufficiently close to the CSO. The occupation of space is a negative aspect for all natural systems, in particular the most extensive ones (FWS), and for some traditional systems. From the point of view of the need for personnel for control and management, all the solutions - being designed for decentralized facilities - have fair performance, but some require periodic checks. From the point of view of energy consumption, performance is on average good for all solutions, but some - if local conditions allow - can work "by gravity" without any recourse to external energy inputs. Natural solutions often do not produce sludge, while most of the simpler traditional solutions require some sludge management system. Finally, from the point of view of integration and improvement of the habitat and landscape, natural solutions are those that have the best performance.

3.5 Upgrading of existing drainage networks

3.5.1 Options for upstream solutions

The options described in the previous paragraphs can be integrated with an “upstream approach” aiming at reducing the contamination of drainage water:

- through the **separation of stormwater and wastewater networks**;

- reducing the rainwater intake in the drainage system with the use of **SUDS**.

Separation of rainwater from wastewater network reduces and even eliminates the need for CSO structures.

Sustainable drainage systems (SuDS) aims at managing rainwater in urban areas as to reduce the pollution load towards natural recipients recreating the natural conditions before urbanization. This approach can be applied to various contexts, from individual homes to entire urban areas and with different degrees.

3.5.2 Feasibility analysis

The upgrading works on existing drainage systems are not usually extended to all the network, especially in densely urbanized areas but can be applied locally or gradually executed within a broader program and general planning concerning the management of urban water.

The different options are not alternative to each other but can be complementary; this paragraph lists different indicators to be taken into account to evaluate the opportunity and feasibility of this type of works in different contexts.

Value	**-**
Highly negative	---
Negative	--
Moderately negative	-
Non-relevant	*
Moderatively Positive	+
Positive	++
Highly positive	+++

The main factors to be considered when evaluating the feasibility of possible options to upgrade the existing drainage networks are:

- **Urban fabric**: the degree to which the territory is urbanized has a strong impact on the feasibility of works on existing networks; the separation is easier in scarcely urbanized contexts;
- **Land use**: The presence of green areas, parks, parking lots can be a favorable condition for the design of SuDS;
- **Urban planning**: urban transformation plans and programs can be the occasion to promote more sustainable urban water management practices;.
- **Final receptor**: the presence of water bodies where the rainwater can be discharged;
- **Hydraulic capacity of the receptor**: the compatibility of discharge with the final receptor;
- **Hydrogeology**: The infiltration capacity and local groundwater levels are important elements to evaluate the feasibility of SuDS and the choice between different options;
- **Topography**: ground slopes and available spaces need to be analyzed in the preliminary study of works on the existing networks.

In the following table, for each option a value is assigned to the criteria listed above according to the value table from highly positive highly negative factor.

		EVALUATION CRITERIA							
SOLUTIONS	***UPGRADING OF DRAINAGE NETWORKS***	**URBAN FABRIC**		**LAND USE**		**URBAN PLANNING**		**FINAL RECEPTOR**	
		Urban density		***Green areas***		***New development areas***		***Proximuty to final receptor***	
		HIGH	*LOW*	*YES*	*NO*	*YES*	*NO*	*YES*	*NO*
	Separation	--	++	*	*	+	*	+	--
	SuDS	-	+++	+++	--	+++	-	*	++

(/ none; + low; ++ middle; +++ high)

	EVALUATION CRITERIA						
SOLUTIONS	***UPGRADING OF DRAINAGE NETWORKS***	**HYDRAULIC CAPACITY OF THE FINAL RECEPTOR**		**HYDROGEOLOGY**		**TOPOGRAPHY**	
		Hydraulic compatibility		***Infiltration capacity***		***Available space and slope***	
		HIGH	*LOW*	*GOOD*	*SCARCE*	*GOOD*	*SCARCE*
	Separation	++	---	*	*	+	-
	SuDS	-	++	+++	--	+	-

(/ none; + low; ++ middle; +++ high)

Table 5. Evaluation matrix of proposed solutions for upgrading drainage networks

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D.4.3.1 – Guidelines to assess the quality of urban wastewater and coastal system

VOLUME 4 – Site-specific reference

Document Control Sheet

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Duration	36 months

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Type of deliverable	Report
Language	English
Work Package Title	WATERCARE Pilot realization
Work Package number	4
Work Package Leader	ASET SPA

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Author (s)	Marco Romei (PP 1 ASET) Andrea Marinelli (PP 1 ASET) Matteo Lucertini (PP 1 ASET) Enrico Esposto Renzoni (PP 1 ASET) Marina Simonetti (PP 1 *STUDIO MAJONE INGEGNERI ASS.*) Riccardo Bresciani (PP 1 *IRIDRA SRL*)
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INDEX

1 INTRODUCTION

ASET is the WP4 responsible and has in charge the redaction of a Guide-Line for the execution of Feasibility Studies to implement innovative solutions in the WATERCARE sites.
ASET will elaborate a set of documents to be used by any PP in carrying out a proper feasibility study specific for the relevant project site and the foreseen deliverable list consists of:

- Volume 1: basics on the pollution monitoring and collected data analysis;
- Volume 2: identification of a set of possible solutions to remove the pollution and/or to mitigate the pollution effect;
- Volume 3: the decisional process to identify the best solution and the relevant Concept Design;
- **Volume 4**: site-specific reference;
- Typical drawings of the possible solutions to solve the pollution of the bathing area;

In questo volume vengono analizzate le informazioni ad oggi disponibili per i quattro siti pilota presi a riferimento. L'analisi riguarda sia gli aspetti costruttivi degli impianti e della rete esistente, sia le principali fonti di inquinamento presenti. Sulla base delle suddette informazioni vengono quindi individuate le principali criticità che possono inficiare sulla qualità delle acque scaricate. Terminata la fase di analisi vengono quindi suggerite delle possibili soluzioni di intervento da sviluppare a livello di studio di fattibilità indicando, per ciascuna di esse, i principali indicatori (individuati per la MCA descritta nel Volume 3) cui fare riferimento per la scelta della soluzione ottimale.

2 RAŠA RIVER SITE

2.1 Site Description

2.1.1 Geographic data

The site location is Crpna stanica Štalije upstream from mouth of river Raša. It is located on river Raša in Raša Bay. Raša Bay is a bay on the eastern coast of Croatian Istria southwest of City of Labin. It is the lower part of the former valley of the river Raša, which is submerged by the young postglacial sea level rise. It is about 12 km long, with an average width of about 1 km.

The depth of the bay varies from 44 m at the entrance to the bay to 10 m near the port of Bršica; further towards the mouth, shoals with depths of less than 3 m continue. With its deposits, Raša gradually fills the bay, which is especially noticeable along the west coast. The sides of the Raša Bay are steep and inaccessible, built mostly of limestone, and overgrown with sparse Mediterranean vegetation.

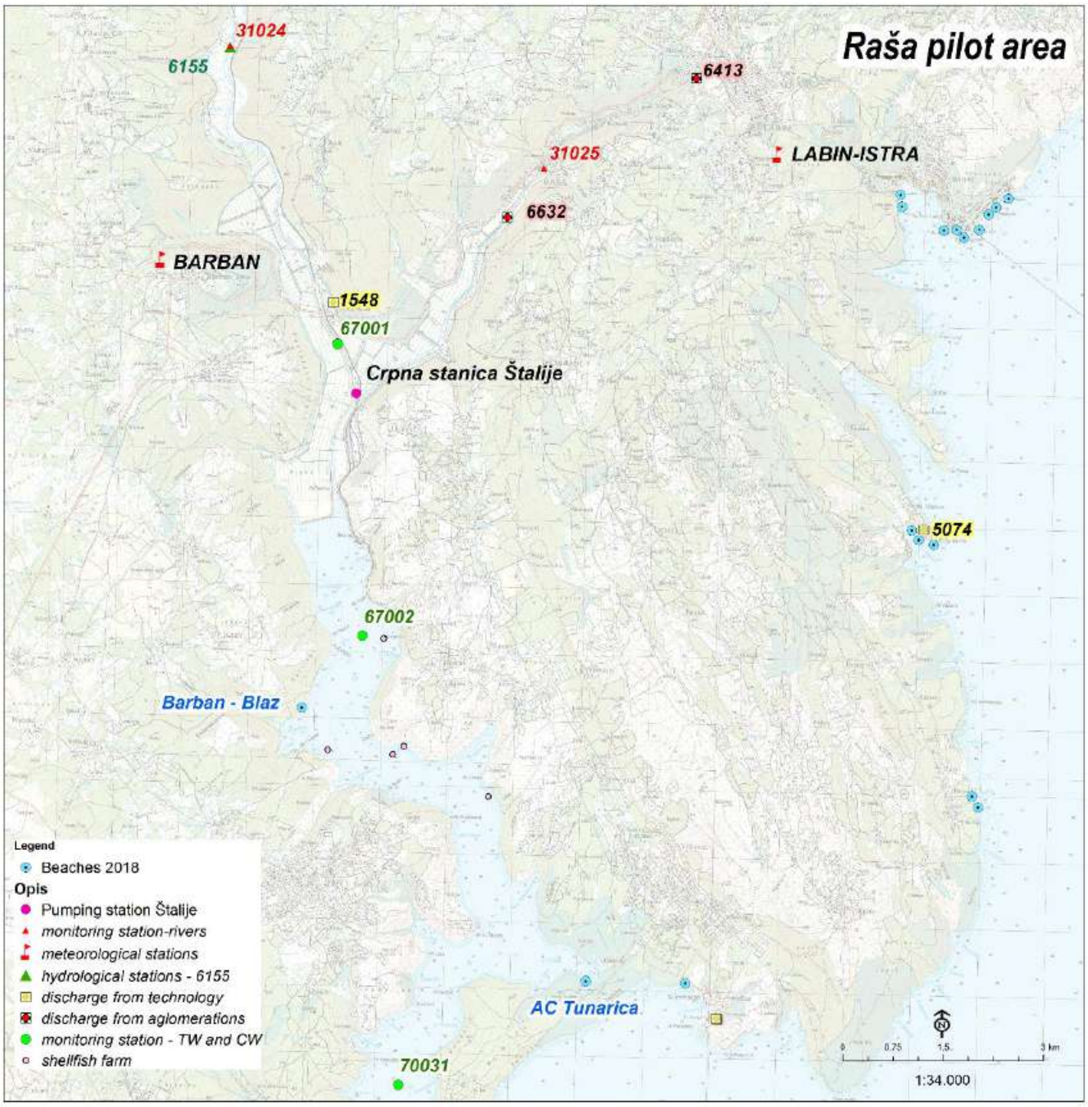


Figure 1. Rasa pilot site area

2.1.2 Existing Drainage Network

The main drainage system in the Rasa area is a combined system. The serviced area includes the old town of Labin, the old center of Podlabin (Vilete, Nove zgrade, Kazarmon, Kazakape), Kature, Marcilnica, Starci, Vinež and the service zone Vinež.

The total length of the network is over 40 km. The existing combined sewage system includes quite old and dilapidated gravity collectors (DN300 to DN1000). Only the residential zone Katura which has a planned separated sewer system solution, which was largely realized during the construction of the Katura settlement.

The town of Labin has 10’740 inhabitants, 5’600 of which are connected to the sewerage system. The rest of the inhabitants have their own individual drainage systems, mostly permeable. Only recently some small sanitary devices are being installed.

The main collector in the area of the old town and Podlabin is located in Rudarska Street. At the end of it there is an overflow shaft, from which a DN400 mm pipeline leads to the WW treatment plant. The overflow from this structure is discharged into the Krapanj canal.

In the Raša municipality only 1’590 inhabitants are connected to the municipal drainage network, while 550 inhabitants discharge directly at the mouth of the Raša river.

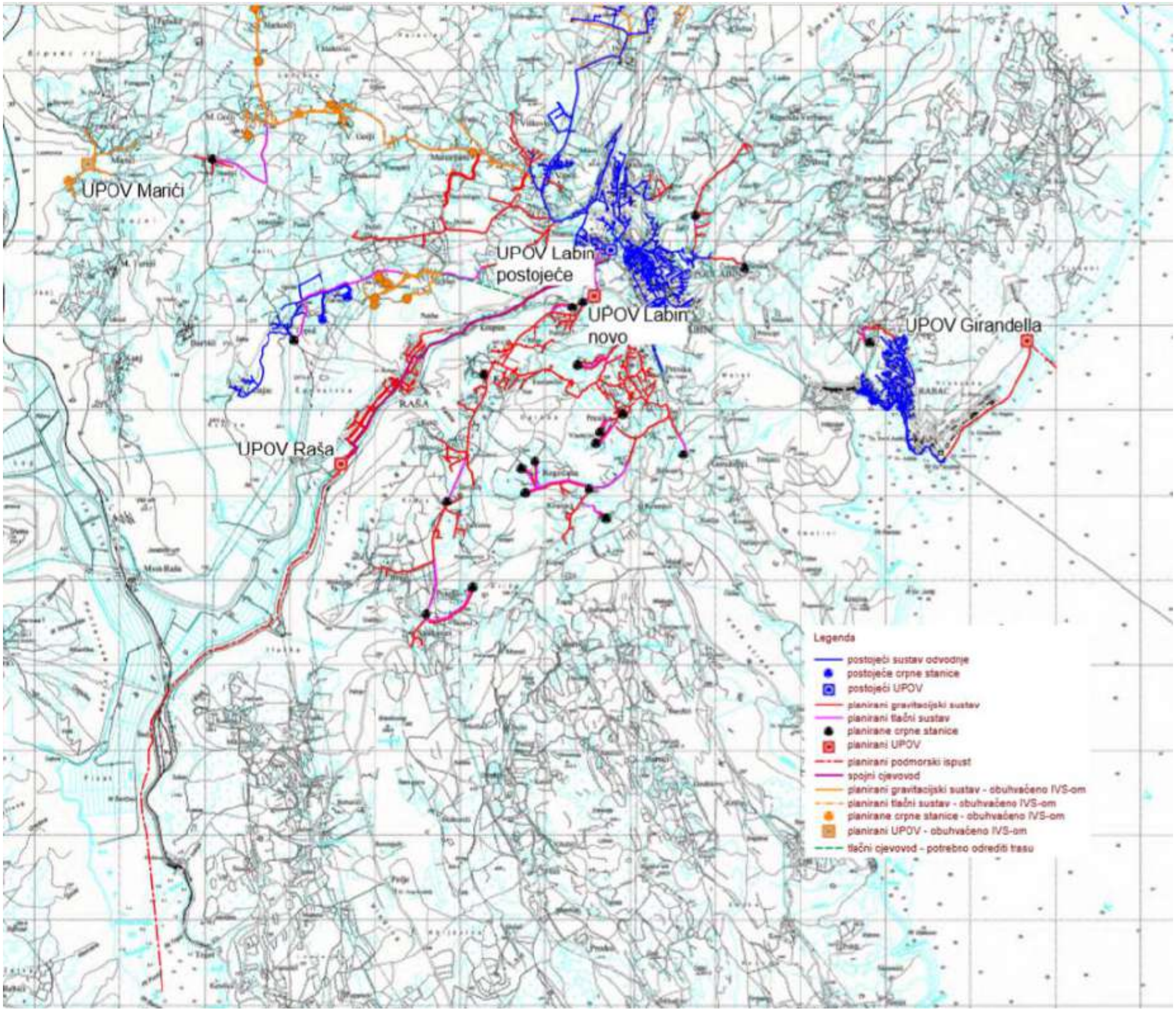


Figure 2. Existing Drainage Network in the Raša area

2.1.3 Source and type of pollution

The main source of pollution is the discharge of untreated or poorly treated domestic wastewater. In addition, productive and industrial activities are present in the area, as well as agricultural activities with use of pesticides and herbicides.

In the transition waters in the Raša bay immediately downstream the river mouth, there is the commercial harbour of Bršica, with possible pollution from oil and chemical pollution from the use of antifouling used on ships.

The following map shows the sampling points in the case study within the Watercare project, whereas the table below indicates the code and coordinates for each of them.

Figure 3. Location of the main watercare monitoring points in the Raša area

Nr.	STATION CODE	MEASURED COORDINATES					
		X	Y	LONG		LAT	
1	AP_Raša	307005	4992833	14°2'59.8"	14,04994	45°2'57.1"	45,04919
2	Krapanj	307026	4992700	14°3'0.9"	14,05025	45°2'52.8"	45,04800
3	PV_0	306818	4990986	14°2'53.8"	14,04828	45°1'57.1"	45,03253
4	PV_T1_200m	306655	4990867	14°2'46.5"	14,04625	45°1'53.1"	45,03142
5	PV_T1_400m	306480	4990801	14°2'38,6"	14,04406	45°1'50.8"	45,03078
6	PV_T1_600m	306271	4990740	14°2'29.2"	14,04144	45°1'48.6"	45,03017
7	PV_T2_200m	306669	4990768	14°2'47.3"	14,04647	45°1'49.9"	45,03053
8	PV_T2_400m	306582	4990591	14°2'43.6"	14,04544	45°1'44.1"	45,02892
9	PV_T3_200m	306839	4990794	14°2'55.0"	14,04861	45°1'50.9"	45,03081
10	PV_T3_400m	306851	4990558	14°2'55.9"	14,04886	45°1'43.3"	45,02869
11	PV_GET_1	307076	4989732	14°3'7.3"	14,05203	45°1'16.8"	45,02133
12	PV_GET_2	307372	4989603	14°3'21.0"	14,05583	45°1'12.9"	45,02025
13	PV_GET_3	307610	4989395	14°3'32.1"	14,05892	45°1'6.4"	45,01844
14	PV_BLAZ_1	306243	4988129	14°2'31.5"	14,04208	45°0'24.1"	45,00669

2.2 Evaluation of the main sources of pollution

2.2.1 Wastewater treatment plants

The existing wastewater treatment plant has a capacity of 8’000 ES. In 1996, the plant was reconstructed by adding buildings with equipment for mechanical pre-treatment of wastewater, waste collection and collection pits. In 1999, a system for mechanical dehydration of sludge was installed, and in 2003, the aeration system was replaced, within which new mechanical and measuring and regulating equipment for blowing air into aeration pools was installed. The treated wastewater flows out of the plant through the outflow discharge pipeline to the Krapanj canal, and the final recipient is the river Raša.

Frm the available data on the plant, it appears that a significant cause of pollution may be the inadequacy of the treatment for the existing pollution load, since the treatment sections are limited to mechanical pre-treatments and activated sludge and do not appear to include nutrient removal.

In addition, it must be noted that at present only a fraction of area inhabitants are connected to the plant; in a scenario where more inhabitants are connected, the plant capacity in terms of equivament inhabitants will have to be increased.

2.2.2 Combined Sewer Overflows

Combined Sewer Overflows are present on both the Labin and Raša networks. No significant problems concerning the CSOs have been reported.

The feasibility study should analyse the information collected during the monitoring campaign: hydraulic data (discharge frequency, maximum and minimum discharge, overflow volumes …) and the data concerning the pollution load, type and concentration of pollutants, correlation with meteoric events.

2.2.3 Drainage networks

Wih reference to the drainage networks, the majority of it is combined and most reported critical issued concern hydraulic insufficiency during intense rainfall events.

With regard to the pollution problems, many residential areas are not connected to the main network, relying instead on individual discharges that convey untreated or poorly treated wastewater. A significant part of the site drainage area is not connected to the existing wastewater treatment plant.

With regard to Raša drainage system, a large part of the network is in poor conditions and would require restoration works; the pumping station downstream Raša town and the treatment plant no longer exist.

2.3 Indications and criteria on possible solutions

In the development of the feasibility study, in order to compare different solutions, weights will be attributed to the indicators chosen for the MCA analysis.

In the present case study, considering the available elements summarized above, it is possible to suggest the most significant elements and criteria to be to evaluated.

- **Analysis of the WWTP capacity and peformance both in the present conditions and with further enlargement and upgrade,** considering the possible increase of the incoming load due to the extension of the wastewater network and connection to the plant. The most important indicators to be considered are the investment and operation costs for the different technologies, as well as the treatment efficacy of the different available options.
- It is advisable to evaluate the costs and benefits of building a **new, smaller wastewater treatment plant** for the town of Raša compared to the option of connecting the town to the existing main plant. Investment and operational cost, and requested space are the most important indicators when comparing these two options.
- **Upgrading of existing drainage networks** extending the serviced area. Separate networks should be considered especially in newly connected areas, as well as the use of SuDS to reduce the rainwater intake in the drainage network. When evaluating these options land use, degree of urbanization should be evaluated, as well as the possibility of include these works within the area urban planning strategy and maintenance program for the existing networks. Another key indicator is the presence of adequate existing receptor for the rainwater and treated wastewater discharge.

3 CETINA RIVER SITE

3.1 Site Description

3.1.1 Geographic data

The site location is at the mouth of the river Cetina. The Cetina River is a typical karst watercourse in the deep and well-developed Dinaric karst. Cetina has a length of about 105 km and it is the longest and most water-rich river in Dalmatia. Its basin covers an area of 1,463 km^2. From its source in Dinara mountain, at the height of 385 metres above sea level, Cetina flows into the Adriatic Sea in the town of Omis. Location at the mouth of the river Cetina has enabled the town of Omis to gradually develop a very important traffic position between Split and Makarska.

Since 16th century, the energy of the Cetina has been used for the purpose of running watermills and since the middle of the 20th century valorisation of the hydropower potential of the Cetina is increasing.

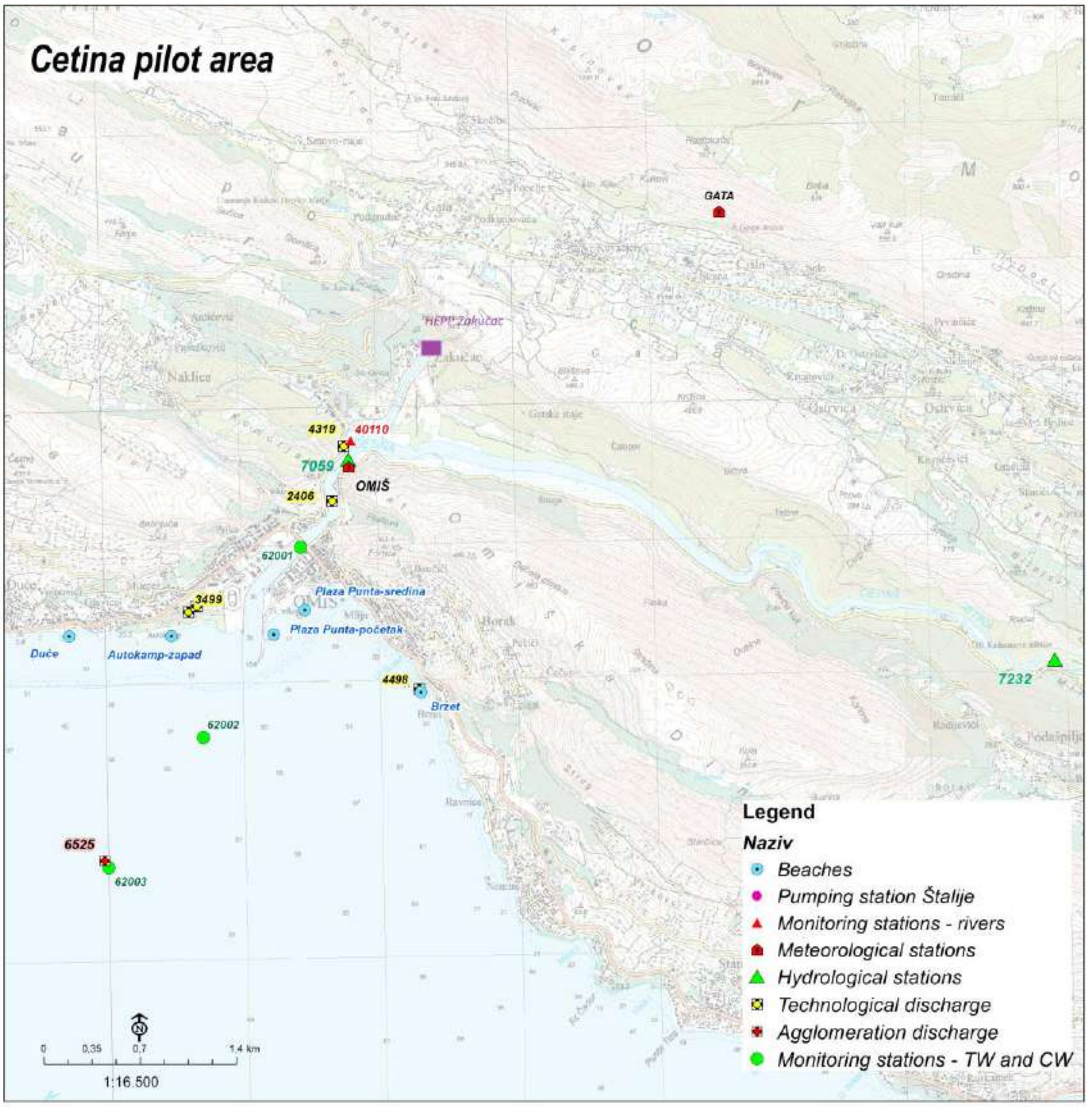


Figure 4. Cetina pilot site area

3.1.2 Existing Drainage Network

The existing drainage system in the Omis agglomeration is a combined network. The settlement of Duce, which is territorially under the municipality of Dugi Rat, also belongs to the Omis agglomeration. The network is present in the central part of the town of Omis, in the old town area, in Punta on the left bank and in the area of Priko on the right bank of the river Cetina. A new network has been built in the western part of the agglomeration. The new system consists in 8 pumping stations, 35 km of gravity sewerage (25 km of separated and 10 km of combined network) and 2 km of pressure pipelines.

In the eastern part of the agglomeration, a sewage system has not yet been built. This area is very urbanized, and wastewater collection takes place through septic tanks. Septic tanks are emptied at UWWTP Priko in Omis.

11’745 ES inhabitants are connected to the drainage system out of the total population of the agglomeration of 14’986 ES.

In the town of Trilj the drainage system is mainly a separated network; the combined network part has overflow structures discharging the excess rainwater in the river Cetina.

Figure 5. Existing Drainage Network in the Raša area

3.1.3 Source, type and intensity of pollutions

The major causes of pollution appear to be untreated domestic wastewater and industrial activities directly connected to the network without previous treatment. Another significant impact comes fro maritime activities with frequent discharge of polluted waters, such as oil, used water from tank cleaning, etc..

The following map shows the sampling points in the case study within the Watercare project, whereas the table below indicates the code and coordinates for each of them.

Figure 6. Location of the main watercare monitoring points in the Cetina area

Nr.	STATION CODE	***MEASURED COORDINATES***					
		X	**Y**	**LONG**		**LAT**	
1	AP_Cetina_1	515172	4811276	16°41'14.8"	16.687431	43°26'28.5"	43.441238
2	AP_Cetina_2	515766	4812338	16°41'41.3"	16.6948	43°27'2.8	43.450785
3	PV_C_0 m	514985	4810921	16°41'6.4"	16.685111	43°26'16.9"	43.438046
4	PV_C_T1_150m	514840	4810960	16°40'59.9"	16.683321	43°26'18.2"	43.4384
5	PV_C_T1_300m	514699	4811011	16°40'53.7"	16.681581	43°26'19.9"	43.438862

Nr.	STATION CODE	*MEASURED COORDINATES*					
		X	Y	LONG		LAT	
6	PV_C_T2_200m	514804	4810837	16°40'58.3"	16.682873	43°26'14.3"	43.437294
7	PV_C_T3_150m	515011	4810773	16°41'7.5"	16.685429	43°26'12.2"	43.436713
8	PV_C_Autokamp Zapad	514502	4810976	16°40'44.9"	16.679146	43°26' 18.8"	43.438551

3.2 Evaluation of the main sources of pollution

3.2.1 Wastewater treatment plants

In the area of the sewage and treatment system of the Omis agglomeration, there is a wastewater treatment that was put into operation in 2009. The UWWTP has a capacity of 30,000 equivalent inhabitants. The mechanical treatment consists of two fine sieves - the first with a 10 mm spacing and the second with 2 mm spacing. The treated wastewater is discharged into the Brac Channel by a submarine outlet, at about 1’600 m from the shore to a depth of 60 m.

As was the case for Raša site, the treatment is not adequate for the site, lacking biological treatment and removal of nutrient, even thought in this case the existing sections have sufficient capacity in terms of equivalent inhabitants, also with the prospect of collecting all the site inhabitants to the plant.

3.2.2 Combined Sewer Overflows

The available dcuments indicate only one CSO on the site. Further investigation should be planned for the feasibility study.

The feasibility study should also analyse the information collected during the monitoring campaign: hydraulic data (discharge frequency, maximum and minimum discharge, overflow volumes …) and the data concerning the pollution load, type and concentration of pollutants, correlation with meteoric events.

3.2.3 Drainage networks

Many areas of the site are not connected to the existing network, relying onstead on septic tanks and other individual systems. This is especially true for the eastern part of the agglomeration, that lacks a proper wastewater network.

3.3 Indications and criteria on possible solutions

In the development of the feasibility study, in order to compare different solutions, weights will be attributed to the indicators chosen for the MCA analysis.

In the present case study, considering the available elements summarized above, it is possible to suggest the most significant elements and criteria to be to evaluated.

- **Upgrading of existing wastewater treatment plants:** considering that the existing plant only includes mechanical treatments, it is suggested to upgrade the treatment with biological activated sludge systems and primary/secondary sedimentation.

  The most important indicators to be considered are the investment and operation costs for the different technologies, as well as the treatment efficacy of the different available options.

- **Small wastewater treatment plants:** small treatment plants should be considered in isolated settlements to avoid construction of long connection sewers and possibly pumping stations, which would be required to convey all the site wastewater to the existing plant. A cost benefit analysis is to be carried out to compare these two possibilities.

  The key indicators to be considered are the investment costs and annual operational cost for both the constriction of isolated small treatment plants of the connection to the existing one (also depending on the topography of the site and the need of pressure pipes for the connection). Another important indicator when comparing centralized and not centralized options is the requested space for the construction of new treatment facilities.

- **Upgrading of existing drainage networks**: extending the serviced area to the eastern part of the agglomerate and other areas still not connected. Separate networks should be considered especially in newly connected areas, as well as the use of SuDS to reduce the rainwater intake in the drainage network.

  When evaluating these options land use and the degree of urbanization should be the main indicators to be evaluated, as well as the possibility of include these works within the area urban planning strategy and maintenance program for the existing networks. Another key indicator is the presence of adequate existing receptor for the rainwater and treated wastewater discharge.

4 NERETEVA RIVER SITE

4.1 Site Description

4.1.1 Geographic data

The case study is located at the estuary of the Neretva river, near the city of Ploče.

The Neretva River basin is shared by Bosnia and Herzegovina (with a catchment area of about 10,100 km^2) and Croatia (about 280 km^2). It is about 220 kilometres long, and only the final 20 kilometres are in Croatia forming an extensive delta with large areas of reedbeds, lakes, wet meadows, lagoons, sandbanks, sandflats and saltmarshes. The Neretva Delta is surrounded by karst hills rich with underground water that supplies numerous springs, streams and lakes.

A large number of drainage channels characterize the river estuary area, contributing to create a complex ecological ecosystem, rich in birdlife and fish species. The Delta is the most fertile area of the middle Dalmatia oriented on commercial agricultural production (mostly tangerine plantations and vegetable greenhouses).

The municipalities that can interest directly the site area are Ploče, Metković and Opuzen.

Maps of the rivers and channels are available at http://www.bioportal.hr/gis/. Also on the geoportal of Hrvatske vode it is possible to view different information, from the register of agglomerations and protected areas to flood risk maps.

Figure 7. Aerial site view in correspondence of the estuary of Neretna river

4.1.2 Existing Drainage Network

The sewerage network in Ploče was built in parallel with the construction of the settlement and has not been reconstructed since its creation (50-55 years ago). The newest part of the system was built in the 80s. The drainage system operates with two pumping stations, multiple collectors and three coastal outlets to the sea. The estimated length of the network is approximately 3 km. The diameter of sewer pipes ranges from Ø200 mm at the beginning to Ø600 mm at the end (outlet in the Port of Ploče). 6,486 inhabitants are connected to the drainage system out of the total load of the agglomeration of 8,577 ES. The rest of the households not connected to the public drainage system mostly have septic tanks or a direct outlet to Lake Birina. The sewer systems seem to be combined, considering that a diameter of 600 mm is much higher than the real requirement of 6500 P.E.; nevertheless, this information needs to be verified.

The public drainage system of the town of Metković is mainly combined, 12,3 km long in total (of which only 1,5 km is separated system) and it consists of:

- 3 pumping stations without overflows and incident outlets: PS Kneza Domagoja (Q = 12.9 l/s), PS Zrinski and Frankopan (Q = 45.0 l/s), PS Neretvanskih gusara (Q = 8.1 l/s);
- 4 bank outlets into the Neretva River.

9,617 P.E. are connected to the drainage system out of the total load of the agglomeration of 15,979 P.E.. There is no industrial wastewater.

The contents of the septic tanks are emptied into the public drainage system on the shaft - within the PS Zrinski Frankopan, which is located upstream of the outlet Put Narone, in the amount of approximately 1.500,00 m^3/year.

The public drainage system of the town of Opuzen is separated; 1,770 inhabitants are connected out of the total load of the agglomeration of 3,902 ES. The system consists of:

- 8,345 m of primary collecting network and 4,185 m of secondary collecting network;
- 1,000 m of pressure pipelines;
- 3 pumping stations (PS Prantrnovo, PS Spomenik, PS Zagrebačka - all three are Q = 17.5 l/s),
- wastewater treatment plant for 1300 P.E., equipped only with preliminary treatment (fine automatic grid) and a pumping station that discharges into the Neretva river.

The contents of the septic tanks are emptied at the receiving shaft on the city wastewater treatment plant.

4.1.3 Source, type and intensity of pollutions

In the 3 towns there are no wastewater treatment systems and the sewerage covers only a part of the settlements; in total about 17.873 persons are connected to the sewer and 10.585 are not.

Due to the absence of treatment plants, the main source of pollution is untreated wastewater, corresponding to a total load of 28458 inhabitants. Additionally, the load produced by touristic activities should be evaluated if present.

In case of combined sewers, pumping stations can also produce an impact during rainfall events by discharging part of the flow (mixed stormwater and wastewater) in the river.

Municipality	Type of sewer	Total P.E.	P.E. connected to sewer	WWTP
Ploce	Mainly combined (to be verified)	8577	6486	NO
Metkovic	Mainly combined	15979	9617	NO
Opuzen	separated	3902	1770	NO (*)
TOTAL		28458	17873	

(*) only mechanical pre-treatment

Table 8. Type of sewer, available facilities and n° of Population Equivalent (P.E.)

Ploce wastewater is discharged into the sea without pre-treatment in the port via coastal outlets:

- Central outlet, 466.00 m3/day
- Coastal outlet n°1, 55 m3/day
- other discharges to be verified

Pumping stations generally have no incident overflows except PS 1, which has an incident overflow in the port of Ploče.

Metkovic wastewater is discharged into the Neretva River without treatment via 4 bank outlets:

- Outlet MERCATOR DEPARTMENT STORE 685 m^3/day

- Outlet PUT NARONE, 150 m^3/day
- UNKA outlet, 99 m^3/day
- Outlet KNEZA DOMAGOJA STREET, 50 m^3/day

In total 984 m^3/d are estimated to be produced, with a specific load of 102 l/P.E. x day.

Opuzen wastewater is discharged into the Neretva River via a central bank outlet after only a pre-treatment, 192 m^3/day

Pumping stations generally have no incidental overflows except for PS Spomenik, which has an incidental overflow into the drainage channel that flows into the Neretva.

In conclusion the intensity of the pollution produced by the inhabitants is not high (less than 30.000 P.E.) considering also that the discharge is distributed on a wide area and the river can ensure a partial self-purification capacity.

Nevertheless, all the produced wastewater is un-treated and it can generate several impacts both on the river quality and on sea bathing water. This can happen especially during the summer season if the number of presences increases due to the tourism, and the self-purification capacity of the river can be limited by the natural decreasing of the flow in the dry season and the increase of the withdrawal for irrigation practices.

The incoming load to the case study from the river itself should also be carefully evaluated, considering that there are several settlements upstream which can probably produce higher quantities of untreated wastewater.

4.2 Evaluation of the main sources of pollution

The main sources of pollutions are:

- Untreated wastewater
- Combined sewer overflow (only in Ploce and Metkovic)

4.3 Indications and criteria on possible solutions

In the present case study, it is suggested to concentrate the actions on the following tasks:

- WWTP preliminary design for existing outlets; it is suggested to maintain a decentralized approach, in order to limit the construction of long sewers and pumping stations to connect the different outlets in a single point. In this way the capacity of the different plants would remain low, allowing to select the simplest systems with the lowest grade of complexity and operational cost. The technical options to be considered could be Constructed wetlands or compacted technological plants, depending on the land availability;
- Where it is not convenient to extend the sewer network, a strategy to cover small settlements and single households wastewater production should be adopted, promoting the recourse to the systems proposed in Vol. II chapter 4;
- Evaluation of the functioning of the few pumping stations during rainfall events individuating the catchment area, the n° of P.E. in the catchment area, the flow related to different rainfall intensities. In order to limit overflows especially during the summer season, it could be considered to increase the pump flow, or to provide a CSO treatment according to Vol. II chapter 5; considering that volumes are likely to be low, it is advisable to consider the recourse to NBS solutions (according to Vol. II chapter 5, par 5.2.5-5.2.6-5.2.7) and a multiple objective approach with the aim of improving water quality and to increase biodiversity, natural/urban landscape or opportunity of fruition.

In the MCA analysis of the different alternatives for wastewater treatment plants, there are stand-alone systems with small capacity, less need of skilled workers for operation and maintenance and easy to operate that offer clear advantages to take into account.

5 PESCARA SITE

5.1 Site Description

5.1.1 Geographic data

The case study is localized in the municipality of Pescara, along the final part of the Pescara river up to the Pescara Canal Port, as represented in the following aerial view. The site is characterized by a relevant urban density, even if both along the river than within the city, there are several green areas

Figure 1. Case study area

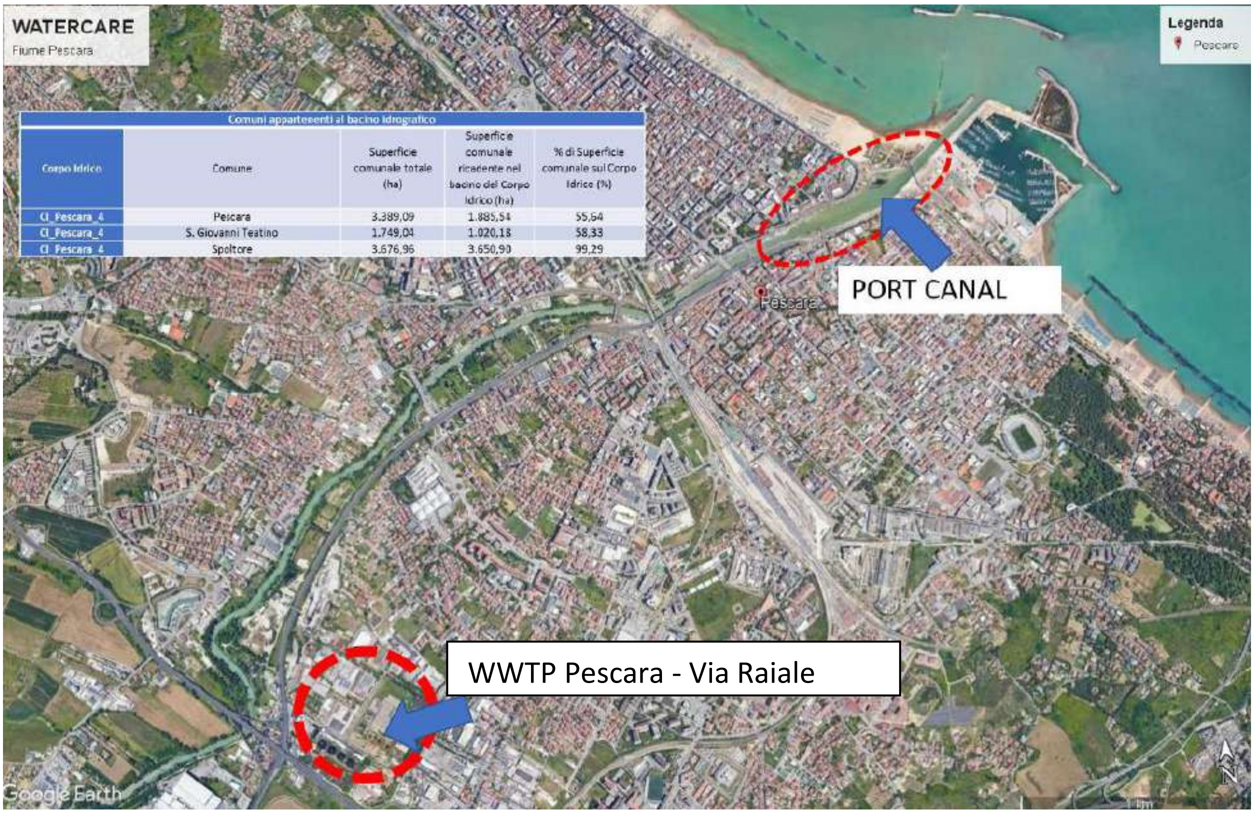
The Pescara River is the main stream in the Abruzzo Region, with a length of 67km, flowing into the Adriatic Sea, after receiving various tributaries (Aterno, Tirino, Orta, Lavino) and crossing the city of

Pescara. The average flow rate at the discharge point into the sea is about 57 m^3/s, the minimum about 18 m^3/s; the maximum flow values exceed 1000 m^3/s, leading to several flooding issues to the city of Pescara.

5.1.2 Existing Drainage Network

About 6500 ha of urban surface is drained towards the Pescara River from the municipalities of Pescara, San Giovanni Teatino e Spoltore.

Pescara, San Giovanni Teatino e Spoltore are provided with a combined sewer network, connected to the WWTP of Via Raiale which discharges the treated water into the Pescara river.



Comuni appartenenti al bacino idrografico				
Corpo Idrico	Comune	Superficie comunale totale (ha)	Superficie comunale ricadente nel bacino del Corpo Idrico (ha)	% di Superficie comunale sul Corpo Idrico (%)
CI_Pescara_4	Pescara	3.389,09	1.885,54	55,64
CI_Pescara_4	S. Giovanni Teatino	1.749,04	1.020,18	58,33
CI_Pescara_4	Spoltore	3.676,96	3.650,90	99,29

Figure 2. Position of WWTP and catchment areas

As showed by the following figure and the collected data, along the urban section of the Pescara river there are 24 combined sewer overflows that during rainfall events can discharge polluted water (wastewater mixed to the urban runoff stormwater), impacting severely on the river and coastal water quality. Most of them are pumping stations that convey the wastewater from the east side of the city back to the WWTP by pressure; the most impacting ones are Pescara Bo La madonnina and the CSO upstream the WWTP.

Figure 3. CSOs localized in the final section of the Pescara river

The recorded data of the CSO in Via Raiale during april 3-15 april 2021 show an extended duration of the overflow and variable outflows, with a peak of 3500 m^3/h and up to 37.000 m^3/day discharged into the Pescara river.

DATE	DAILY VOLUME (M3)	H	HOURLY FLOW (M3/H)
03/04/2021	21000	6	3500
04/04/2021	18555	24	773
05/04/2021	9800	24	408

06/04/2021	37200	24	1550
07/04/2021	6400	24	267
08/04/2021	2200	22	100
09/04/2021	919	1	919
10/04/2021	2322	8,5	273
11/04/2021	3394	15,5	219
12/04/2021	3350	23,3	144
13/04/2021	10141	24	423
14/04/2021	1831	8	229
15/04/2021	2471	18	137
16/04/2021	1069	18	59
18/04/2021	5900	18	328
AVERAGE	8437	17,2	622
MAX	37200	24	3500
80°PERC	11824	24,0	802
MEDIAN	3394	18,0	273

Table 1. monitoring data of the CSO in Via Raiale during april 3-15 april 2021

5.1.3 Source, type and intensity of pollutions

The following map shows the sampling points in the case study, evidencing during the event of 12-07-2021 a slight bacteriological pollution both in the river and in the sea.

	Azoto ammoniacale - Hanna HI3826 - mg/l	Azoto Totale - UNI 11658 - micromoli/l	BOD 5 - Metodo manometrico - mg O2/l	COD - HACH-LANGE 1814 - mg/l	E.Coli - IRSA-CNR n. 7030/F - UFC/100 ml	Enterococchi - IRSA - CNR n. 7040 - C - UFC/100 ml	Fosforo totale - Fosforo Totale Macherey-Nagel - micromoli P/l
River PPR1	0	2642,86	0	0	300	98	2,26
River PPR2	0	1528,57	0	0	160	92	3,87
River PPR3	0	1492,86	0	20	150	87	**3,87**
River PPR4	0	111,43	0	14	120	84	3,55
Sea PPS1	0	931	0	18	4	18	10
Sea PPS2	0	1457	0	20	7	18	14
Sea PPS3	0	389	0	16	38	48	14
Sea PPS4	0	220	0	8	63	80	20
Sea PPS5	0	366	0	11	60	67	14
Sea PPS6	0	189	0	69	3	13	12
Sea PPS7	0	366	0	14	58	80	20
Sea PPS8	0	1093	0	28	3	7	15
Sea PPS9	0	373	0	37	1	19	23

In other recorded events, the impact on the bathing sea water is evident near the Pescara Port, showing Escherichia Coli in the range of 50-906 MPN/100 ml on the Via Leopardi seafront, whereas south from the port the values are almost always less than 10 MPN/100 ml, probably due to the geometric conformation of the port.

There is not data on the WWTP effluent (180.000 P.E.), which it is suggested to collect in order to have a complete figure of the pollution intensity. The WWTP upgrading is on-going and it will reach a capacity of 210.000 P.E.

5.2 Evaluation of the main sources of pollution

It is very difficult to evaluate the main sources of pollution without a consistent data set; there is only one complete chemical analysis referred to one single day, which moreover is not associated to the monitoring of the CSO and WWTP outflows.

The only parameter with a more consistent data set is Escherichia Coli, which evidences a fairly significant bacterial pollution of the Pescara river and of the coastline north of the port.

The presence of Escherichia coli in the river and consequently into the sea can be related to:

- the numerous combined sewer overflows located on the pumping stations along the Pescara river;
- the WWTP effluent; the plant is under renovation and in the future will probably ensure a better quality of the effluent and the reduction of untreated water released into the river.

5.3 Indications and criteria on possible solutions

In the present case study, it is suggested to concentrate the actions on the following tasks:

- Verification of the functioning of the WWTP in the current operation mode and in the future after the upgrading will be completed; evaluation of the overflow conditions upstream the WWTP after the upgrading;
- Characterization of each combined sewer overflow in the urban area, individuating the catchment area, the n° of P.E. in the catchment area, and possibly collecting chemical analysis during different stormwater events associated with duration of the stormflow

and rainfall intensity;

- Hydraulic risk analysis along the Pescara river, individuating flooding areas for different return times;
- Selection of possible areas for allocation of a combined sewer treatment;
- Where space is available in safe hydraulic conditions, preliminary determination of required areas for NBS according to Vol. II chapter 5, par 5.2.5-5.2.6-5.2.7; in this case it is suggested a multiple objective approach with the aim of improving water quality, of reducing sewer peak flow, of increasing biodiversity, natural/urban landscape or opportunity of fruition;
- Where space for NBS is not available, a storage overflow volume (according to Vol. II chapter 5, par 5.1) should be considered;
- a mechanical treatment with adequate screening option can be evaluated in the case of the most significant overflow and where the installation of a treatment plant is suitable

In the MCA analysis of the different alternatives, it is advisable to consider in the assignment of the weights more relevance to the reduction of pollutant loads and to the space occupation considering that we are in a densely urban area; where there is the opportunity, the integration/improvement of habitat and landscape is also important. Considering that there are stand-alone systems to be managed additionally to the existing WWTP, the less need of skilled workers for operation and maintenance and the ease of operation are clear advantages to take in account.

To optimize the functioning of the combined sewer overflows, it is suggested to evaluate if:

- there are situations where is possible to separate rainwater from the combined sewer, directing it directly to the river (Vol. II chapter 6, par 6.2.)
- it can be technically convenient to introduce SuDS interventions as retrofitting of the

existing drainage systems in roads and parkings (Vol. II chapter 6, par 6.3.).