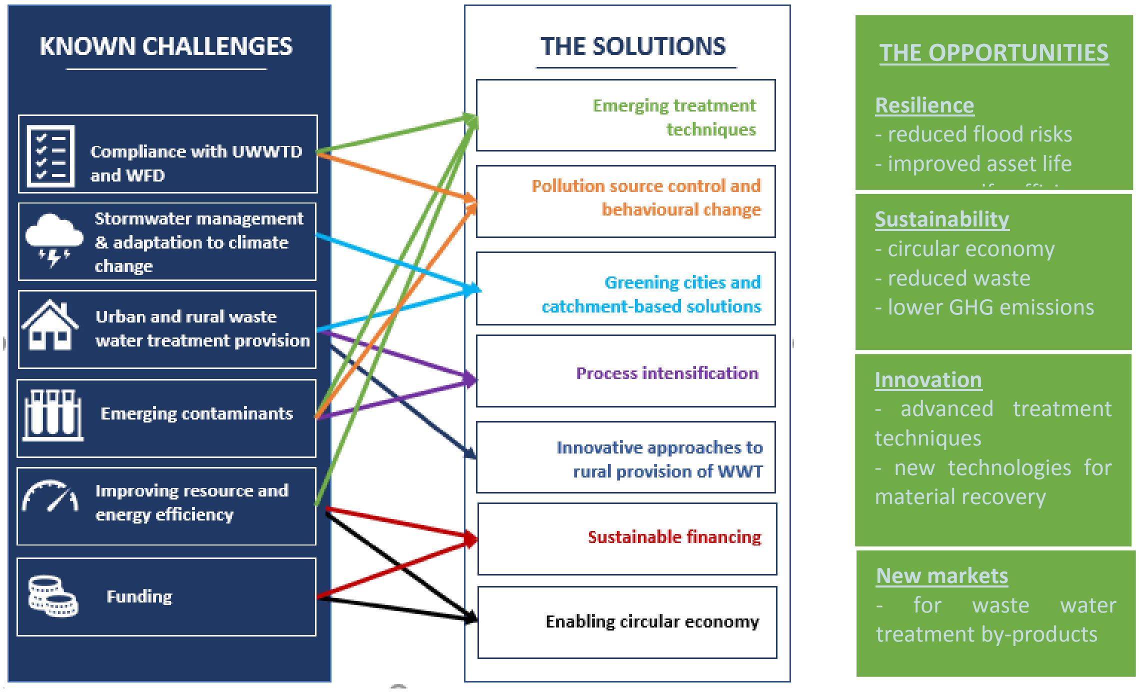
# Urban Waste Water Treatment:

## Existing approaches, challenges and opportunities

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# Disclaimer

# Acronyms

| | |
|---|---|
| UWWT | Urban Waste Water Treatment |
| UWWTP | Urban Waste Water Treatment Plant |
| UWWTD | Urban Waste Water Treatment Directive |
| IED | Industrial Emissions Directive |
| WFD | Water Framework Directive |
| RBMP | River Basin Management Plan |
| RBMPs | River Basin Management Plans |
| RBD | River Basin Districts |
| BWD | Bathing Water Directive |
| DWD | Drinking Water Directive |
| BOD | Biological Oxygen Demand |
| COD | Chemical Oxygen Demand |
| TSS | Total Suspended Solids |
| POP | Persistent Organic Pollutant |
| uPBT | ubiquitous, Persistent, Bio-cumulative and Toxic |
| pBDE | poly Brominated Diphenyl Ethers |
| PAH | Polycyclic Aromatic Hydrocarbon |
| GHG | Greenhouse Gas |
| AMR | Antimicrobial Resistance |
| IAS | Independent Appropriate Systems |
| MBBR | Moving Bed Biofilm Reactor |

# Executive summary

Urban waste water treatment (UWWT) plays a crucial role in protecting human health and the environment in Europe. The operation of urban waste water treatment plants (UWWTPs) and the overall protection of the aquatic environment in Europe is guarded by the EU environmental *acquis*, in particular by the Urban Waste Water Treatment Directive (UWWTD) and the Water Framework Directive (WFD). In view of recent findings that 18% of surface bodies in the EU are still under pressure from point source emissions, including from secondary sources such as UWWTPs and storm overflows (EEA, 2018), the aims of this report were: 1) to analyse the current status of UWWTPs in Europe (including the process and benefits of UWWT); and 2) to identify future challenges and opportunities for the UWWTP sector and practical solutions that could lead to significant improvements in the quality of waste water effluents.

### *Existing approaches to urban waste water treatment in Europe*

UWWTPs deliver multiple benefits to society and the environment through collection and treatment of waste water, eliminating health hazards, safeguarding drinking water supplies, bathing waters and fisheries. In delivery of this service, UWWTPs need to cope with a range of different conditions which determine their technology choices and operations. These concern variations in the quality of effluent received, seasonal changes to the population served, climatic conditions such as hot and cold temperatures, heavy rainfalls or water scarcity. A summary of these existing challenges is presented in Figure 1.

**Figure 1 Selected focus areas for the analysis of existing approaches to UWWT in Europe**

| Focus area | Description |
|---|---|
|  | **Receiving waste water from highly industrialised areas** - These plants, located near major industrial parks or ports, must cope with high influent concentrations of pollutants declared as priority substances, priority hazardous pollutants and other specific pollutants under the WFD, such as heavy metals, nonylphenol, TCE, DDT, etc. |
|  | **Using their waste water/sludge to derive added benefits for other sectors** – UWWTPs around Europe have found it beneficial and cost-effective to utilise the sludge resulting from the treatment process to produce biogas, recover phosphorus and/or use sludge in agriculture, rather than disposing it. |
|  | **Operating within cities/regions experiencing high seasonal tourist influx** – High variation in population size throughout the year can create challenges for UWWTP which are generally designed to serve a specific population size. These challenges are prevalent in cities and regions popular with tourists. |
|  | **Discharging into Nutrient Sensitive Areas, Bathing Waters or watercourses with European level designations (Special Area of Conservation, Ramsar, Special Protected Area) -** These plants need to treat effluent to a very high standard in order to comply with the stringent requirements for effluent discharged to designated watercourses. |
|  | **Operating within regions experiencing high annual rainfall averages (>700 mm/year) -** These plants must overcome challenges imposed by: high peak flows and diluted urban waste water and difficulty in controlling hydraulic conditions (with high in-flows at times of heavy rainfall) and biological treatment. |
|  | **Operating within regions experiencing low ambient temperatures for most of the year** - These plants must overcome challenges imposed by inefficiencies in biological treatment due to low water temperatures which inhibit degradation of organic matter. |
|  | **Operating in water scarce regions** - To allow direct or indirect water re-use, UWWTPs operating in water scarce regions must overcome challenges imposed by: higher influent concentrations due to reduced dilution of waste water streams; the need to deploy advanced treatment techniques to treat water to a higher standard and to have reduced dry weather flows to avoid gross pollution problems in receiving watercourses. |

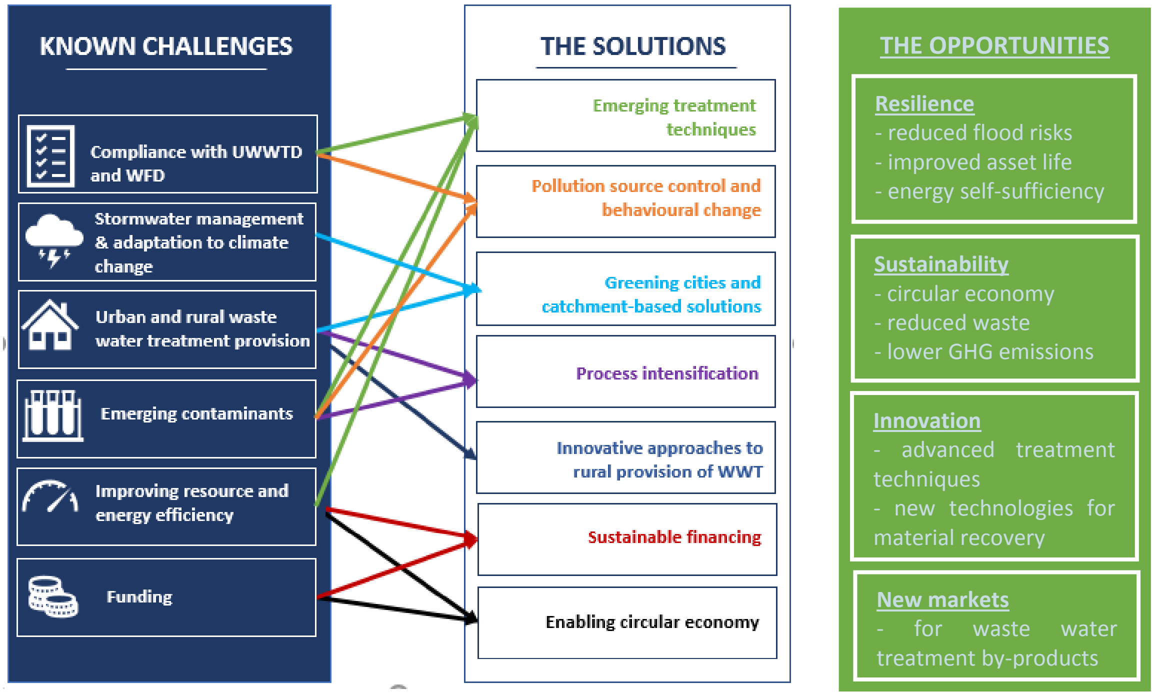
In order to better understand these conditions, a set of case study UWWTPs were identified across the EU and were analysed in detail. In total, 22 UWWTPs were selected representing a wide range of geographical conditions and capacity. The analysis highlighted that many of these challenges will continue to increase in significance over the next 50 years.

### *Challenges and opportunities for urban waste water in the 21st century*

Drawing on the conditions that UWWTPs currently face, further literature was reviewed, and interviews were conducted with waste water experts from industry, academia and national authorities to identify those challenges and opportunities that UWWTPs are expected to face in the future. While compliance with the UWWTD is currently challenging for a number of Member States it is expected to continue to be a key challenge in the future as well. On the other hand, some of the newer issues such as climate change and emerging contaminants are expected to intensify in the coming years.

The interviewed experts also provided an insight into potential solutions tackling the identified future challenges, some of which offer great opportunities for the overall improvement of UWWT. A summary of these linkages is presented in Figure 2 and discussed further below.

**Figure 2 Potential opportunities and solutions to the identified challenges for UWWTPs**




- Urban waste water treatment plans (UWWTPs) across the EU have to cope with a wide range of conditions while complying with the Urban Waste Water Treatment Directive (UWWTD) and the Water Framework Directive (WFD). These concern **variations in the quality of effluent received, seasonal changes to the population served, climatic conditions such as hot and cold temperatures, heavy rainfalls or water scarcity**. Some of these drivers will continue to increase in significance over the next 50 years.
- Full compliance with the UWWTD would lead to better protection of the quality of the water environment, however new connections to the sewage collection systems and modernisation of UWWTPs are expensive and take time. **Achieving compliance with the UWWTD remains a key challenge for the sector in the short to medium term**.
- Key known challenges for the sector include: (i) storm water management and adaptation to climate change; (ii) urban and rural waste water treatment provision; (iii)

emerging contaminants; (iv) improving resource and energy efficiency; (v) funding; as well as (vi) compliance with the UWWTD and WFD. Practical solutions to these challenges are already available and upgrades to existing treatment techniques are an obvious solution to achieving better level of treatment at UWWTPs.

- Advanced treatment techniques at UWWTPs will not deliver better outputs for water quality in isolation and the **implementation of a mixture of approaches is needed**. These include: pollution source control measures, greening of cities and implementation of catchment-based solutions, intensification of the waste water treatment processes, techniques and management options enabling shift to circular economy and sustainable financing of infrastructure investments.

New issues are likely to arise over time. For example, the possibility of antimicrobial resistance being dispersed into the environment through discharges from UWWTPs poses a possible, but as yet unquantified, risk. Meanwhile, evidence needs confirmed through this project include: the impact of emerging contaminants and antimicrobial agents on aquatic environments; innovation related to energy-efficient treatment technologies; and, enabling cost-effective recovery of waste water treatment by-products.

### *Conclusions and recommendations*

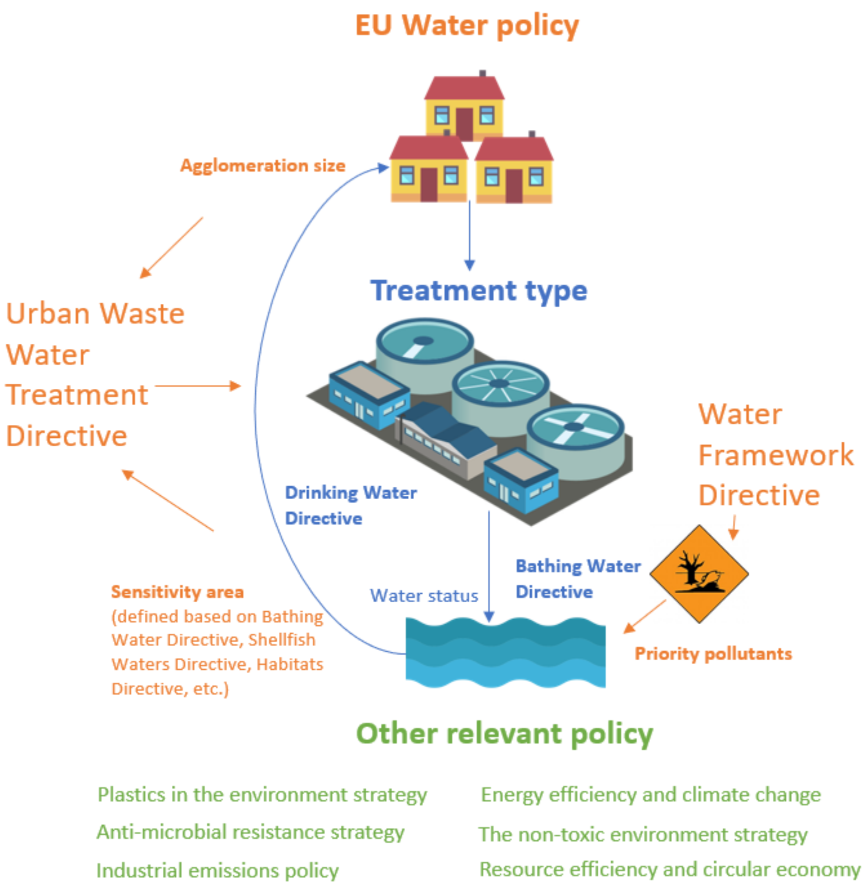
Based on the findings of the report, overall conclusions and recommendations were drawn concerning the practical solutions that could lead to the future improvement to the quality of waste water, effluents and the realisation of opportunities in responding to the expected challenges.

# 1 Introduction

## 1.1 Policy background

Urban waste water treatment (UWWT) plays a crucial role in protecting human health and the environment in Europe. Operation of urban waste water treatment plants (UWWTPs) and the overall protection of the aquatic environment in Europe is influenced by the EU's comprehensive package of water and other related policies as presented in Figure 1-1 and described below.

**Figure 1-1 Summary of EU policy relevant for Urban Waste Water Treatment**




Source: Own compilation

### 1.1.1 *Urban Waste Water Treatment Directive*

The main instrument regulating the operation of UWWTPs at an EU level is the Urban Waste Water Treatment Directive (UWWTD). The Directive was introduced in 1991 and its main objective is to protect the environment from the adverse impacts of waste water discharges from urban areas, the agriculture, food processing industry and other industrial discharges into urban waste water collection systems. It regulates the collection, treatment and discharge of urban waste water, and sets the following key requirements:

- Collection and treatment in all agglomerations of more than 2 000 p.e.[1];
- Secondary treatment in all agglomerations of more than 2 000 p.e.;
- More stringent treatment in all agglomerations of more than 10 000 p.e. discharging in designated sensitive areas or their catchment, thus contributing to the reduction of pollution of these sensitive areas;
- A requirement for pre-authorisation of all discharges of urban waste water, of discharges from the food-processing industry and of industrial discharges into urban waste water collection systems;
- Monitoring of the performance of treatment plants and receiving waters; and
- Controls on sewage sludge disposal and re-use, and treated waste water re-use whenever it is appropriate.

Table 1-1 below summarises the key principles and requirements of the UWWTD regarding management of urban waste water.

**Table 1-1 The main principles of the UWWTD**

| Principle | Management strategies |
|---|---|
| Planning | • Designating sensitive areas<br>• Identifying catchment areas<br>• Establishing programmes for constructing sewage collection systems (technical and financial)<br>• Identifying needs for more stringent treatment |
| Regulation | • Authorisation and regulation of waste water<br>• Limiting pollution from storm water overflows in the design, construction and maintenance of collection systems<br>• Considering technical requirements for the design, construction, operation and maintenance of the UWWTPs |
| Monitoring | • Establishing monitoring programmes corresponding to the requirements in the UWWTD covering discharges of waste water as well as the receiving waters |
| Information and reporting | • Exchange of information on discharges with cross-boundary impacts<br>• Reporting on the implementation the Directive (every 2 years) |

Source: Based on the text of the UWWTD and European water policies and human health (EEA, 2016)

The ninth report on the implementation status and programmes for implementation of the UWWTD was published by the Commission in 2017 (European Commission, 2017a), covering the situation in the EU Member States in 2014. A summary of the key successes and challenges with implementation of the UWWTD described in that report is presented in Table 1-2.

[1] As per the definition provided in the UWWTD, 1 p.e. (population equivalent) means the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day;

**Table 1-2 Successes and challenges from the implementation of the UWWTD**

| Successes | Challenges and implementation gaps |
|---|---|
| Overall compliance trends are positive, with compliance rates increasing since 2009/10. | Lack of sufficient clarity of some provisions. Insufficient definition of "appropriate treatment". |
| On average, EU Compliance rates with waste water collection requirements under UWWTD (Article 3) are 95 %. | The Directive has limited coverage of rural areas not connected to sewerage systems. |
| Around 89 % of EU waste waters were treated by secondary treatment, with 17 Member States achieving 90-100 % compliance under the secondary treatment requirement of the UWWTD. | The newer EU-13 Member States[2] overall have lower compliance rates, owing to the different transition periods. These range from October 31, 2006 for Malta to December 31, 2023 for Croatia, with most Member States having had to comply by 2015. |
| 76 % of EU territory was covered by more stringent treatment, with 15 Member States applying more stringent treatment across their entire territory | Regarding distance to compliance, 1.8 % of the total EU load was not properly collected and thus treated, 7.2 % of the total EU load requiring secondary treatment was not treated to that level, 11.9 % of the total EU load requiring more stringent treatment was not meeting performance requirements |

### 1.1.2 *Water Framework Directive*

Since 2000, the UWWTD has been operating in the wider EU water policy acquis set by the Water Framework Directive (WFD). The WFD was introduced to establish a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. It aims to ensure that all surface water bodies meet good overall status and sets ambitious deadlines for this. Achieving this requires waterbodies to be at good chemical and ecological status, hence the waterbody's chemistry and biology should closely mirror the conditions expected in a natural pristine waterbody and display only minor signs of impact from human development. To this end, the ecological status comprises certain elements against which the river's status is assessed and could be classed as High, Good, Moderate, Poor and Bad. On the other hand, the chemical status is a measure of the waterbody's compliance with Environmental Quality Standards (EQS) for a set list of priority pollutants and dangerous substances, with the compliance assessment expressed either as Good or Failing to achieve Good Status. The final assessment is always based on the lowest classed element and follows the concept of 'one out, all out'.

Member States are required to develop a set of cost-effective measures summarised in comprehensive River Basin Management Plans (RBMPs) that are updated every six years. The Directive specifies two key types of measures: basic and supplementary measures. Basic measures refer to all measures that are required for the implementation of other EU water legislation preceding the WFD, including compliance with the UWWTD, as well as some additional requirements such as cost recovery in the water sector (Article 9). Supplementary

[2] Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia.

measures refer to all additional measures that can be introduced to attain the objectives set in the WFD. In a report reviewing the progress of implementation of the programmes of measures, it was observed that the most commonly implemented measure was the construction and improvement of UWWTPs with regard to surface water bodies (reported by 25 Member States in 2016[3]) (European Commission, 2019).

The WFD aims for coherence in all EU water policy, referring to, amongst others, the UWWTD, the Bathing Water Directive (BWD) and the Drinking Water Directive (DWD) as basic measures. It outlines a list of priority substances that should be phased out, and therefore influences the choice of treatment techniques in UWWTPs.

| Fitness Check of the UWWTD, WFD and its daughter Directives |
|---|
| At the time of writing this report the UWWTD and WFD were subject to REFIT evaluations to consider environmental, technological, socio-economic and legal changes that have occurred during the existence of the Directives. The UWWTD Evaluation considers the effectiveness, coherence, relevance and EU added value of the Directive since its entry into force 25 years ago. It may identify areas where simplifications or improvements to the legislation or implementation are needed.<br><br>The WFD Fitness check looks at the relevance, effectiveness, efficiency and coherence of the WFD, its daughter Directives (the Groundwater Directive (2006/118/EC) and the Environmental Quality Standards Directive (2008/105/EC)) and the Floods Directive (2007/60/EC) and includes an assessment of the potential for regulatory simplification and burden reduction. The WFD Fitness Check covers the performance in all Member States and over their whole lifespan to date, meaning the two cycles of RBMPs and Programmes of Measures and the first cycle of the flood risk management plans. Both Fitness Checks are due to conclude by the end of 2019. |

Source: (European Commission, 2017b)

### 1.1.3 *Bathing and Drinking Water Directives*

In 1976, the first Bathing Water Directive (BWD) 76/160/EC came into force to protect human health and the aquatic environment in coastal and inland areas from faecal pollution and was later on updated with the revised BWD adopted in 2006 (2006/7/EC). It requires Member States to create integrated management plans for each site to minimise risks to bathers based on an assessment of the sources of contamination that are likely to affect it. It also imposes a monitoring requirement and an obligation on Member State authorities to inform the public about the status of the waters they bathe in. Furthermore, if the quality standards are not met, remedial measures must be taken which may include the construction or improvement of sewage treatment works (EEA, 2016). The Directive is implemented in coordination with other Community legislation on water, such as the UWWTD and WFD. Waters in the scope of the BWD may be assigned “sensitive areas” status under the UWWTD.

The Drinking Water Directive (DWD, 98/83/EC) concerns the quality of water intended for human consumption and sets out the essential water quality standards at EU level. It requires a total of 48 microbiological and chemical indicator parameters to be monitored and tested regularly. Member States can include additional requirements such as to regulate additional substances that are relevant within their territory or set higher standards. Where monitoring reveals problems, Member States are required to take remedial actions to improve water

[3] Information reported by Greece, Ireland and Lithuania was not included in the assessment due to delays in reporting.

quality. These could again relate to construction or improvements of UWWTPs, as well as to drinking water treatment facilities.

In 2017, a proposal was published for a revised Drinking Water Directive to improve the quality of drinking water and provide greater access and information to citizens (European Commission, 2017). The proposal updates drinking water standards in line with the World Health Organization recommendations, empowers authorities to better deal with risks to water supply and engage with polluters, ensures more information is provided to consumers, and contributes to the transition to circular economy.

### 1.1.4 *Other policies influencing current and future operations of UWWTPs*

Besides securing cleaner waters and protecting health, UWWT plays a role in contributing to a broader range of policy objectives including:

- Resource efficiency, the EU Circular Economy Action Plan and EU Circular Economy Package (European Commission, 2018b)
- Climate change mitigation and energy efficiency
- Anti-microbial resistance and pharmaceuticals in water
- Plastics in the environment
- Industrial emissions policy

Considering growing pressures on resource availability, WWTPs are playing an increasingly important role enabling water reuse (to address water scarcity), nutrient recycling and production of biogas from sewage sludge (to support a circular economy and mitigate GHG emissions from waste water treatment).

With regard to water reuse, the recent proposal for a Regulation on minimum requirements for water reuse (European Commission, 2018a) was developed with the objective to address water scarcity across the EU, in the context of urbanisation, population growth and climate change. It aims to increase water reuse for agricultural irrigation while ensuring high level of public health and environmental protection. The regulation would set harmonised minimum requirements on the quality of reclaimed water and monitoring. The proposal is in line with the objectives of the UWWTD, WFD, and the EU Circular Economy Package (European Commission, 2018b) since:

- The UWWTD states that reuse of waste water should be applied whenever possible;
- It is in line with the WFD objective to limit groundwater abstraction;
- It promotes water savings through water reuse implementing the principles of circular economy.

Nutrient recycling from UWWTPs has been supported in the EU through the Sewage Sludge Directive 86/278/EEC, which was introduced to encourage the use of sewage sludge in agriculture. It also regulates its use by prohibiting the use of untreated sludge on agricultural land unless it is injected or incorporated into the soil. The Directive further specifies treatment requirements and prohibits the use of sewage sludge on soil in specific circumstances, namely:

- Application on grassland or forage crops if the grassland is to be grazed or the forage crops to be harvested before a certain period has elapsed. This period is set by the Member States taking account of their geographical and climatic situation and is a minimum of three weeks;
- Application on soil in which fruit and vegetable crops are growing, except for fruit trees;

- Application on ground intended for the cultivation of fruit and vegetable crops which are normally in direct contact with the soil and normally eaten raw, for a period of 10 months preceding the harvest of the crops or during the harvest itself.

More recently, focus on nutrient recycling has been placed in the 7th Environmental Action Programme (European Parliament and Council, 2013). Furthermore, the EU Fertiliser Regulation EC 003/2003 is currently under review with the aim for the updated regulation to harmonise standards for fertilisers produced from organic or secondary raw materials in the EU, opening new possibilities for their production on a large scale (European Council, 2018). In addition, the regulation will set harmonised limits for a range of contaminants contained in mineral fertilisers.

In the context of climate change mitigation and energy efficiency objectives, more attention is being paid to the overall impact of waste water treatment operation on resources and how these could be mitigated, particularly in relation to energy consumption and greenhouse gas (GHG) emissions. This involves generating renewable energy through anaerobic digestion of the sludge and providing space for other renewable generation such as solar panels.

The ability of microorganisms to resist antibiotics, also known as antimicrobial resistance (AMR), is a growing health concern in Europe that is responsible for an estimated 25 000 deaths per year in the EU (European Commission, 2017c), EUR 1.5 billion per year in healthcare costs and productivity losses (European Commission, 2017c). As a part of its European One Health Action Plan on antimicrobial resistance (European Commission, 2017c), the release of antimicrobials into the environment through waste water streams from the health and food sectors has been identified as an area that requires further research. In this plan, the European Commission also sets the goal to support development of new waste water treatment technologies to enable efficient and rapid degradation of antimicrobials.

In terms of other substances of emerging concern, they have been too recently identified for most EU regulations concerning water quality and waste water treatment to include provisions. Only the WFD has included three pharmaceuticals[4] in the European Watch List (Decision 2015/495) with the aim to monitor them and gather additional data to draw conclusions about the actual risk posed by them and support future prioritisation. In addition, following a decision of the European Court of Justice (case T-521/14), the European Commission has started the development of a regulation dealing with endocrine disruptive compounds (European Commission, 2016).

## 1.2 Purpose of this report

The EEA report 'European waters: assessment of state and pressures 2018' (EEA, 2018) specified that 18 % of surface water bodies reported by Member States in the 2nd RBMPs are under pressure from point emission sources, including from secondary sources such as UWWTPs and storm overflows. In this context this report provides information on:

1. The current status of UWWT in Europe.
2. The challenges and opportunities for the UWWT sector moving forward, looking at short, medium and longer-term timescales.
3. Practical solutions that could lead to significant improvements in the quality of waste water effluents, and as a result the quality of Europe's waters.

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[4] The natural hormone oestradiol (E2), the anti-inflammatory diclofenac and the synthetic hormone ethinyl oestradiol (EE2)

## 1.3 Methodology

A systematic literature review has been conducted focusing on:

- current policy requirements affecting the operations of the UWWTP;
- current status of waste water treatment operations in Europe and the value it brings to European citizens;
- individual UWWTP which operate in the conditions selected for case study topics (see below);
- drivers for selection of treatment type;
- current and future challenges and opportunities for UWWT.

Existing approaches to UWWT have been illustrated using case studies, which brought together examples of specific plants operating in various socio-economic, geographical and climatic conditions across Europe. These focused on UWWTP:

- operating within cities and regions experiencing high seasonal tourist influx;
- operating in water scarce regions;
- in regions experiencing high annual rainfall averages;
- experiencing low ambient temperatures for most of the year;
- receiving waste water from highly industrialised areas;
- discharging into Nutrient Sensitive Areas, Bathing Waters or watercourses with European level designations; and
- using their waste water/sludge to derive added benefits for other sectors.

The compilation of the case studies has been elaborated through information provided by members of EIONET and directly by operators of UWWTP.

Building on the information collated via the literature research and case studies, a focussed set of semi-structured interviews with a sample of UWWT experts in Europe have been conducted. This gathered experts' feedback on a draft list of challenges and opportunities developed based on the literature review and potential solutions to these challenges. The outcomes of the interviews have been integrated with the findings of the literature research to characterise potential solutions identified in terms of their applicability across Europe, contribution to sustainability, impact on resilience of the infrastructure and the investment and feasibility of their implementation. This was used to inform qualitative conclusions on the opportunities for better water quality in Europe moving forward.

# 2 Benefits of Urban Waste Water Treatment

## 2.1 Waste water collection and treatment

### 2.1.1 *Waste water collection*

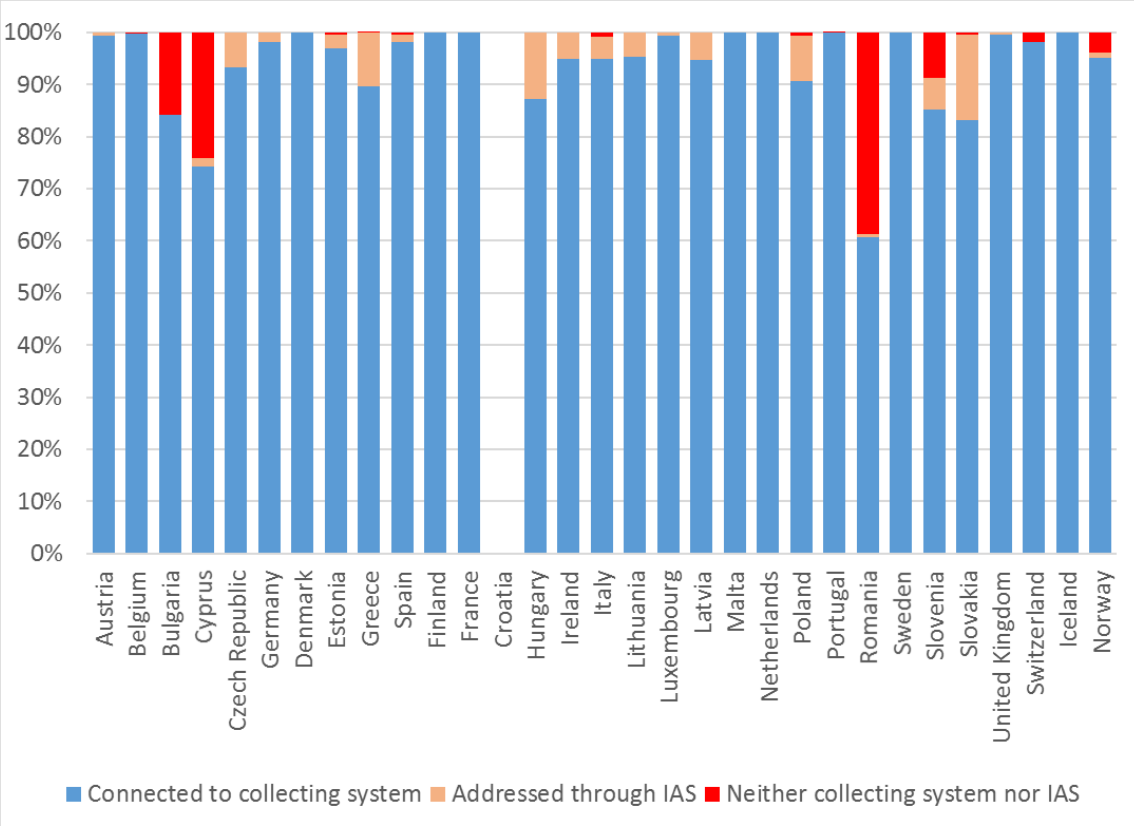
Article 3 of the UWWTD requires that waste water collection and treatment systems are installed in all agglomerations larger than 2 000 p.e. The main collection systems used in Europe divide into two key types - combined and separate.

Combined systems were designed throughout the 19th and 20th century as networks of underground pipes that collect rainwater runoff, domestic sewage and industrial waste-water all in the same pipe. While these are the most common type of collection systems in Europe, the key drawback of combined sewers is that when too much storm water is added to the flow of raw sewage, it can lead to overflows that may result in untreated effluent being released untreated (Environmental Health Perspective, 2005). Separate systems, on the other hand, separate sanitary (household) pipes from storm water. Storm water is released directly in water bodies without treatment thereby reducing the risk of storm water overflows in UWWTPs. However, the untreated storm water may have high pollutant content as it contains surface and drainage run-off.

In Europe, combined sewage systems are predominant in most big cities for historical reasons and replacing them with separate sewage systems is often not economically feasible. The UWWTD requires that Member States take other actions to limit pollution of receiving waters from overflows, however it provides no further guidance on what measures could be included. In practice, possible approaches could include an intermediate storage or an increased design capacity for the plant. In the Commission v United Kingdom [2012] EJECJ c-301/10 case, the European Court of Justice ruled that waste water collecting and treatment systems in London and Whitburn were not “appropriate” as they allowed to spill untreated waste waters from storm water overflows too frequently and in excessive quantities, and the capacity for treatment in London was insufficient. The ruling stated that failure to treat urban waste water could not be accepted under usual climatic and seasonal conditions.

Aside from traditional collection systems, independent appropriate systems (IAS) are applied to address discharges from smaller or disconnected dwellings. Article 3(1) of the UWWTD specifies that IAS could be installed where the establishment of a collecting system is not justified as it would produce “no environmental benefit or because it would involve excessive cost”. The IAS must be able to achieve the same level of environmental protection. Examples of IAS could be contained systems such as storage tanks, or uncontained systems such as septic tanks (European Commission, 2017a). Figure 2-1 presents the share of waste water load collected in Europe via collecting systems, IAS or discharged without treatment.

**Figure 2-1 Percentage of waste water load collected in collecting systems, addressed through independent auxiliary system (IAS) or discharged without treatment in Europe, 2014**




Source: European Commission (2017a)

### 2.1.2 *Waste water treatment*

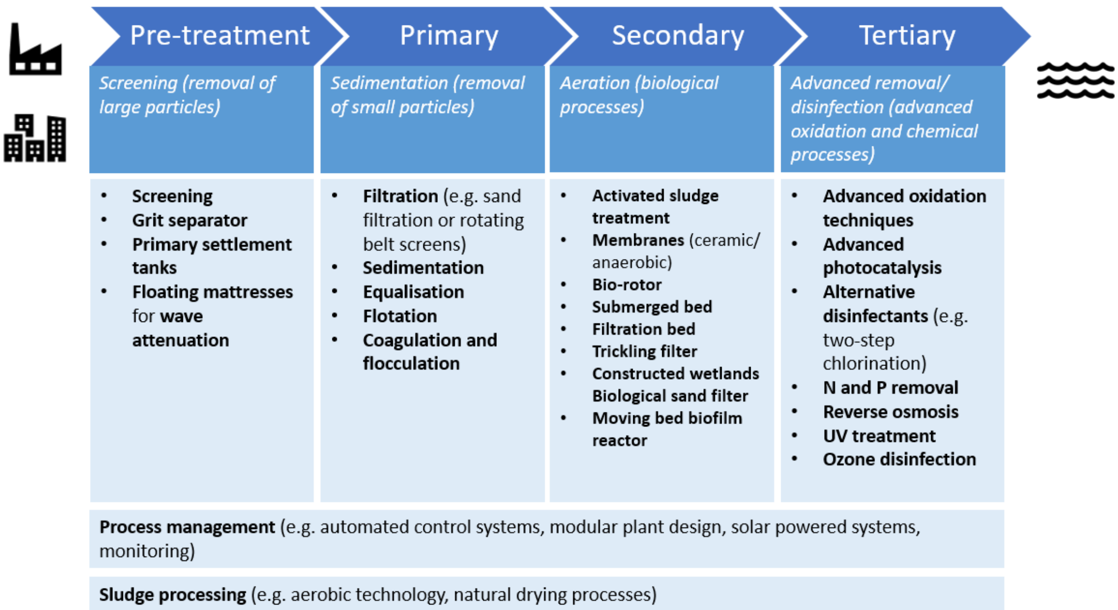
A WWTP is a combination of treatment devices using different techniques to reach a targeted treatment performance. These techniques are classified in four stages of treatment as follows (and further illustrated in Figure 2-2):

- **Pre-treatment** is applied to remove large objects from the effluent through separation techniques.
- **Primary treatment** is the removal of fine particles from the waste water. Waste water is temporarily held in a tank where heavier solids can settle to the bottom, while any lighter solids and scum float to the surface. The settled and floating materials are de-sludged or held back and the remaining liquid may be discharged or put through a secondary treatment process.
- **Secondary treatment**, also known as biological treatment, removes residual organics and suspended solids but also bacteria, viruses and parasites and to some extent nutrients and chemical substances (e.g. activated sludge treatment removes nitrogen as well as organics). Under the UWWTD, this level of treatment is required in all agglomerations of more than 2 000 p.e.;
- **Tertiary treatment** (or more stringent treatment) is the final cleaning process which removes remaining nutrients such as nitrogen and phosphorus. Bacteria, viruses and

parasites, which are harmful to public health, can also be further removed at this stage. Remaining organic or inorganic compounds and harmful substances, may be also removed through dedicated treatment techniques, at this stage. Under the UWWTD, this level of treatment is required in all agglomerations of more than 10 000 p.e., or of more than 2 000 p.e. discharging into sensitive areas.

In Europe, most urban waste water is subject to secondary or more stringent treatment (76 % of the territory of Europe is connected to tertiary treatment (European Commission, 2017)). The most common techniques used in each stage of waste water treatment are listed in Figure 2-2. Further explanation about these techniques is available in Annex 1 Current and emerging treatment techniques in WWTPs. It should be noted that not all stages of treatment are always applied. For instance, according to the UWWTD, urban agglomerations in the EU are only required to apply tertiary treatment if they are larger than 10 000 p.e. and discharge into sensitive areas, catchment of sensitive areas and coastal waters.

**Figure 2-2 Common techniques used in each waste water treatment stage**




Source: Own compilation

Apart from policy requirements, there are several other factors influencing the choice of technique at an UWWTP. A selection key factors is presented below (WECF, 2010) (Dale at al., 2015) (EEA, 2016) (AOSTS, 2018) (Wang et al., 2017):

- **Influent stream composition -** Specific technologies are required for the treatment of different pollutants. WWTPs receiving influent from industry and urban agglomerations often need to install tertiary treatment technologies and disinfection facilities and extend their biological treatment facilities to accommodate the wide range of pollutants present in the incoming load.

- **Low ambient temperatures -** Some biological treatment types such as the activated sludge are sensitive to temperature and have reduced efficiencies in colder climate. Alternative treatments can be applied, such as moving bed biofilm reactor (MBBR) or waste water treatment wetlands.

- **Receiving waters and health considerations** - In some cases, issues with receiving waters such as eutrophication or high heavy metals content can impose serious threat to human health and aquatic life. In these cases, intensive treatment should be applied to reduce these pollutants in the effluent. Where the receiving water body has become eutrophicated, extensive treatment is required to remove nitrogen and phosphorus before the effluent is discharged. In some cases, that may mean that smaller UWWTPs go beyond their UWWTD obligations and opt to install extensive tertiary treatment. Different nitrogen and phosphorus removal technologies or hybrid technologies may be installed. In addition, ultraviolet light technologies may be required to reduce microbiological bacteria.

- **Load and pollutant concentration variations** - Some technologies are more sensitive to incoming load or pollutant concentration variations than others. In WWTPs where such variations are likely due to seasonal tourism or other factors, technologies that are less sensitive to fluctuations in load should be installed. Secondary treatment technologies such as trickling filter or rotating disc contactors are less sensitive to load and pollutant concentration variations than other treatments such as the activated sludge one.

- **Space demand -** Waste water treatment technologies for the same level of treatment may substantially vary in size. While technologies such as waste water ponds have high performance as a biological treatment technology (especially in hot climates), low-cost and low-energy, they have very high space demands. In such cases, more compact treatments such as activated sludge treatment are more suitable.

- **Energy-efficiency** - Some same level technologies are less energy-intensive than others. In the context of the Climate and Energy agenda, as well as operational cost savings, energy-efficiency is becoming an increasingly important factor in the choice of waste water treatment technologies. Aerobic and anaerobic biological treatment technologies have similar removal efficiency rates. While aerobic treatment is less sensitive to temperature change, it requires higher energy inputs for oxidation. In suitable warmer climates, anaerobic treatment can be given preference due to the better energy-efficiency rates.

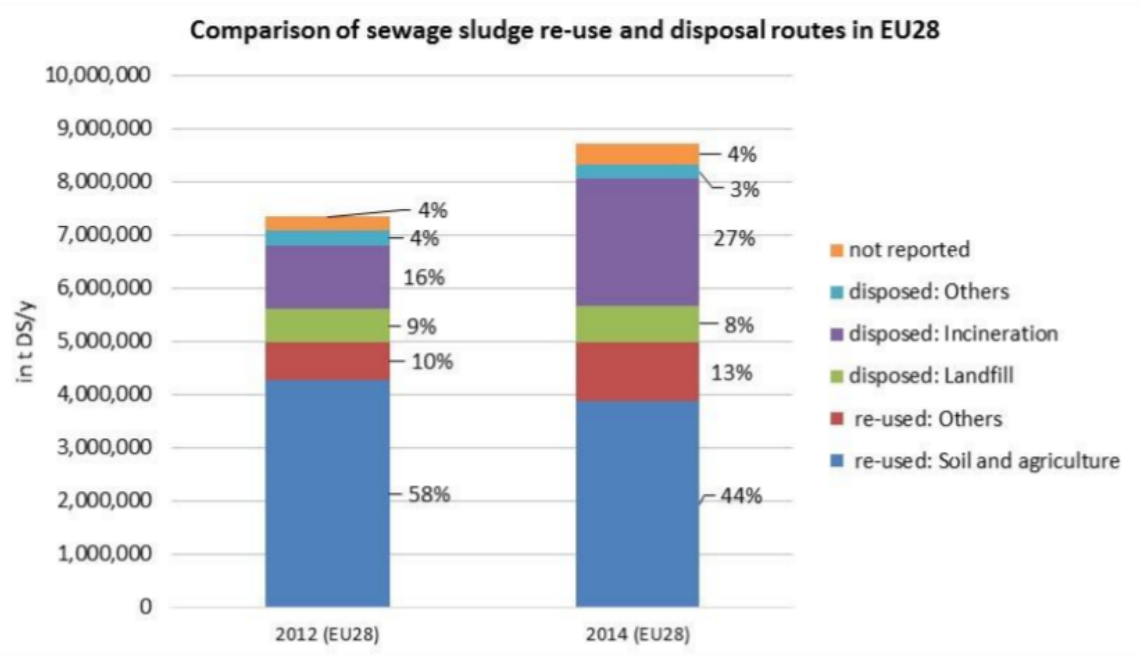
### 2.1.3 *Sludge management*

Sewage sludge results as a by-product from waste water treatment. It is usually produced in very large amounts (in 2012, the EU produced 8 million tonnes of sludge based on Eurostat data (Eurostat, 2018)) and can contain high concentrations of heavy metals, pathogens, and poorly biodegradable trace organic compounds as well as microplastics and pharmaceuticals (European Commission, 2018). When extracted, it usually contains a low proportion of dry substance and therefore requires treatment before leaving the WWTP. This pre-treatment aims to reduce the amount of water via various types of dehydration processes. Following this, the dewatered product is disposed in landfill, incinerated or reused in agriculture. In light of the EU objectives related to resource efficiency and circular economy, and recognising the high nutrient content of sewage sludge, alternative sludge management routes include phosphorus recovery from sewage sludge ash, anaerobic digestion for production of biogas or its use in agriculture (as fertilizer or soil improver). All these methods require some treatment of the sewage sludge prior to application. In some instances, the additional treatment could pose financial burden to smaller WWTPs, and therefore less environmentally friendly approaches such as landfilling may be adopted.

It is noteworthy that while the Sewage Sludge Directive 86/278/EEC regulates the usage of sewage sludge in agriculture, there are nevertheless concerns over the pollutant content of the sludge and its impact on the agricultural land. Therefore, its use should only be taken up after careful environmental consideration.

A short description for phosphorus recovery from sewage sludge ash and anaerobic digestion for production of biogas is included below, with more detail for sludge management options available in Annex 1. Information on sewage sludge re-use and disposal routes is available in Figure 2-3.

**Figure 2-3 Sewage sludge management in EU-28 in 2012 and 2014**




Source: European Commission (2017)

***Phosphorus recovery from sewage sludge ash***

Sewage sludge ash is the by-product of combustion of dewatered sewage sludge in an incinerator. Phosphorus can be recovered from this ash through thermal hydrolysis or mono-incineration (Herzel et al., 2016). The benefit of this method is that the thermal treatment secures safe destruction of organic pollutants. However, heavy metals are not removed, and further treatment should be pursued to secure the safe application of the sewage sludge ash as a fertiliser (Herzel et al., 2016).

There is ongoing research around the removal of heavy metals from dried sewage sludge. For instance, the RecoPhos project that ran between 2012 and 2015 brought together European universities, small and medium - sized enterprises and industry to develop a sustainable and highly efficient process for recovering phosphorus from sewage sludge ash through the application of a thermo-chemical process (RecoPhos, 2012). The developed technology is under way to become commercially available. It is estimated that 37% of all generated sludge will be treated via mono-incineration followed by P-recovery in the year 2030 (European Commission, 2018).

***Biogas production***

Sewage sludge can be used to produce biogas through the application of anaerobic digestion (Bachmann, 2015). The process takes place in approximately 20 days in which microorganisms break down part of the organic matter that is contained in the sludge and produce biogas. Following drying and cleaning of the biogas, it could be upgraded to biomethane or it can be combusted in a combined heat and power plant to generate electricity and heat simultaneously. The remaining sludge can be further treated and spread on land for agricultural purposes. Aichinger et al. (2015) observed that in Europe, especially in Central- and Northern European countries, most WWTPs have anaerobic digestion facilities and infrastructure for biogas utilisation for heating and electricity generation. In many cases, the facilities that capture biogas only partly satisfy the on-site electricity and heat demands using combined heat and power (CHP) technology. Other possible applications include upgrading the biogas to natural gas or transport fuel quality. However, this option is more suitable to plants processing loads of more than 100 Nm3/h whereas technologies for smaller plants are still under development (Bachmann, 2015).

Using CHP, larger plants achieve higher levels of autonomy due to more efficient processes (higher production, lower losses). According to a study by Bachmann (2015), plants smaller than 10 000 p.e. have electricity autonomy of only 37% whereas plants larger than 100 000 p.e. achieve 68-100% electricity autonomy. Complete heat autonomy is however achieved in plants of all sizes (Bachmann, 2015).

### 2.1.4 *Energy use*

Although the waste water treatment industry is of crucial importance to protecting water quality and human health, it is an energy intensive industry in the EU, accounting for approximately 1 % of total EU electricity consumption (European Commission, 2018, ENERWATER, 2019). The most energy intensive processes are pumping, circulation and aeration. The total energy consumption at each stage of treatment depends on the selection of technologies, as well as the size of the plant and the incoming load (Soares et al., 2017).

A statistical analysis performed on 19 074 plants in Europe estimated overall energy consumption of 24 747 GWh (less than 2.5 % of the total industrial electricity consumption of the EU in 2016[5])and concluded that under the current operating conditions of the installations (Ganora et al., Upcoming):

- Installations serving 2-10 000 p.e. consumed approximately 3 812 GWh/y (11 046 installations);
- Installations serving 10-50 000 p.e. consumed approximately 6 754 GWh/y (5,824 installations);
- Installations serving 50-100 000 p.e. consumed approximately 3 399 GWh/y (1,180 installations);
- Installations serving 100-500 000 p.e. consumed approximately 6 358 GWh/y (899 installations);
- Installations serving over 500 000 p.e. consumed approximately 4 424 GWh/y (125 installations).

Small plants (less than 50 000 p.e.) represented around 90 % of the total number of plants assessed but processed only 31 % of the p.e. and used 42 % of the electricity. Plants from mid to very large size, around 10 % of the plants assessed, processed about 70 % of the p.e. with 58 % of the total electricity used (Ganora et al., Upcoming).

Plants can improve their energy performance through producing biogas from anaerobic sludge management on site. More information about the process is presented in **Annex 2 Sewage sludge management.** Currently, there are many examples of UWWTPs in Europe that are energy

[5] The EU final energy consumption of electricity by industry in 2016 was 1 013 TWh (EEA, 2019).

neutral, producing all the energy required for their operation on site, as illustrated in some of the case studies in Chapter 3.

Currently there is no legislation, norms or standards on WWTP energy efficiency to be followed in the EU. The ENERWATER project funded by Horizon 2020 has aimed at developing, validating and disseminating an innovative standard methodology for continuously assessing, labelling and improving the overall energy performance of WWTPs in the EU (ENERWATER, 2019). The project is devoting important efforts to ensure that the methods are widely adopted. Subsequent objectives are to impulse dialogue towards the creation of a specific European legislation following the example of recently approved EU directives, to establish a way forward to achieve EU energy reductions objectives for 2020, ensuring effluent water quality, environmental protection and compliance with the WFD.

## 2.2 Value of Waste Water Treatment

Traditionally, urban waste water collection and treatment has been viewed as a means for the waste water streams to be collected and disposed of, liberating citizens from the burden of managing their waste streams themselves. It has also been seen by health authorities to control diseases by taking away one of its key sources. Nevertheless, over the past few decades, there has been increasing awareness over the impact of waste water effluent discharges to water bodies and therefore, it has been recognised that this process should be regulated to manage these impacts. The adoption of various legislative measures such as the UWWTD and WFD has highlighted the value that waste water treatment provides for society, such as safeguarding drinking water supplies, bathing waters and fisheries. To this end, this Chapter discusses the added value of UWWT with regards to human health and the environment. It explores the temporal trends in key water quality indicators as well as changes in water bodies ecological status between the first and second River Basin Management Plans, based on the most recent EEA assessment (EEA, 2018).

The report also details the remarkable improvements achieved within the River Rhine and River Seine, as a consequence of UWWTD and WFD implementation. Due to the geographical coverage of the underlying data sources, this Chapter primarily summarises evidence for the EU-28 Member States. It is important to note that although this report considers industrial effluents derived from lighter industry and SMEs, industrial emissions from large heavy industries who benefit from their own treatment plants are outside of the scope of this report and have been covered in a previous report (EEA, 2018).

### 2.2.1 *Protecting human health*

The presence of pollutants in Europe's waters continues to raise concerns for public health (EEA, 2016). Untreated urban waste water entering waterbodies can include nutrients, microbes, parasites and viruses and other potentially harmful contaminants, risking human health impacts especially in waterbodies designated as Bathing Waters. Microorganisms can cause severe health problems when ingested, including gastrointestinal diseases, cholera, typhoid and hepatitis. Indirect effects relate to the proliferation of toxic blue-green algae resulting from excessive nutrient and organic matter inputs to waterbodies. This type of algae can cause rashes, skin and eye irritation as well as allergic reactions in both humans and animals (EEA, 2016). In addition, humans can catch water-based infections when bathing in contaminated water.

Most WWTPs do not discharge directly into designated waters, however there are some which discharge into Bathing Waters and some which discharge in proximity of designated sites. Waste water treatment processes may eliminate the vast majority of microorganisms and parasites found in effluent, which would otherwise render surface waters unsafe for use as drinking water sources or recreational areas. However, due to the diversity and quantity of contaminants

UWWTPs, it is increasingly difficult to remove these through conventional treatment processes and subsequently, increasingly challenging to maintain good water quality within receiving watercourses.

To this end, much effort has been focused on modernising treatment plants and sewerage networks across Europe, to improve compliance with the UWWTD and other directives such as the Nitrates Directive, BWD, DWD and WFD. This has led to an increase in waste water collection rates and improved waste water treatment processes, including nitrogen and phosphorus removal, UV disinfection, micro and ultrafiltration (European Commission, 2017). This resulted in a sustained reduction in nutrient concentrations in rivers, with average nitrate concentrations in European rivers having reduced by over 20 % between 1992 and 2012, whilst orthophosphate concentrations more than halved (EEA, 2015). Where effluent is discharged to bathing waters, complete disinfection is required in order to eliminate all microorganisms (Wakelin et al, 2008). This, coupled with the increased dilution and dispersion factor afforded by the size and wave dynamic characterising coastal waterbodies, results in much lower *E.coli* counts than those encountered in riverine waters, where dilution is more limited.

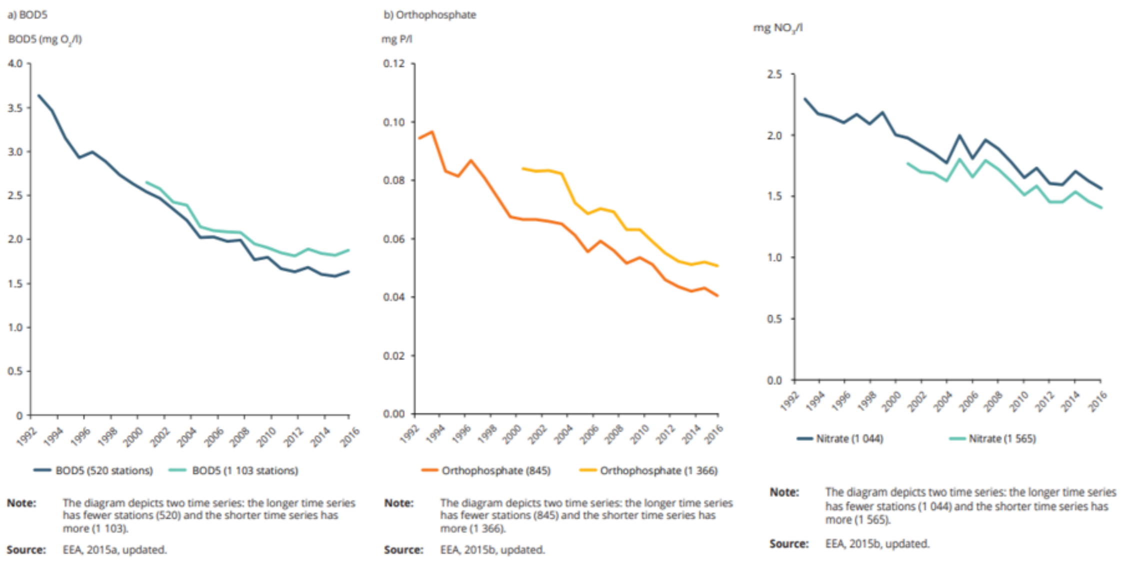
In addition, WWTPs which receive effluent from industrialised areas or large cities sometimes employ additional treatment steps (ultrafiltration, sand filters, reverse osmosis, chemical phosphorus removal, etc) in addition to activated sludge process, in order to achieve higher removal efficiencies with regard to harmful chemicals such as heavy metals. This is particularly true for plants discharging effluent to protected watercourses or those processing their waste water for indirect potable reuse, this requirement often being driven by EU or national legislation. An overview of the most important parameters for the protection of the water environment is provided in Chapter 2.2.2 below.

### 2.2.2 *Protecting the water environment*

The requirements of the UWWTD include basic measures to protect the water environment from sewerage discharges. On the other hand, the WFD is a risk-based approach designed to help waterbodies achieve Good Ecological Status (for natural water bodies) or Good Ecological Potential (for artificial or heavily modified water bodies). With respect to waste water, the key obstacle in achieving Good Status/Potential is the discharge of effluents which are rich in suspended solids, nutrients, organic matter and may contain hazardous pollutants or priority substances, as classified under the WFD. Organic matter and nutrients enter surface water bodies from a variety of sources, most notably agricultural runoff and UWWTPs, which process organic rich waste water from households and some industries. This is particularly true for rivers where waste water effluents represent a major proportion of their flow, especially during summer and drought periods when natural dilution capacity can be severely restricted.

Biochemical Oxygen Demand (BOD), ammonia and orthophosphate represent some of the key water quality parameters which are monitored in rivers, under the requirements of the WFD. BOD is a key indicator of the amount of dissolved oxygen required by aerobic bacteria to degrade organic matter within waterbodies. Increases in nutrient concentrations can lead to rapid increases in BOD and consequent de-oxygenation of the water column, rendering fish and aquatic invertebrates unable to survive. Ammonia is a reduced form of nitrogen and is extremely toxic to fish even in low concentrations. Orthophosphate represents the fraction of phosphorus which is readily utilised by plants in the aquatic environment. Excessive amounts of orthophosphate can result in algal blooms which can rapidly reduce oxygen levels in water bodies, resulting in the death of aquatic organisms. Since the implementation of the UWWTD in 1991, positive results have been achieved with respect to reductions in nutrient inputs to rivers, especially orthophosphate, BOD and ammonia (Figure 2-4). The decline in nitrate, phosphate and BOD concentrations reflects the effect of measures to reduce agricultural inputs of nitrates under the Nitrates Directive as well as improvements in UWWT under the EU UWWTD. The decrease in phosphorus concentrations reflects both improvements in UWWT and the reduction of phosphorus content in detergents, as a result of provision made under the Detergents Regulations, introduced in 2004 (EEA, 2016).

**Figure 2-4 BOD, orthophosphate and nitrate trends in European rivers**




Source: EEA (2018)

Note: The data series for BOD, nitrate and orthophosphate are calculated as the average of annual mean concentrations for groundwater bodies, river stations and lake stations in Europe. Only complete series after inter- and extrapolation are included.

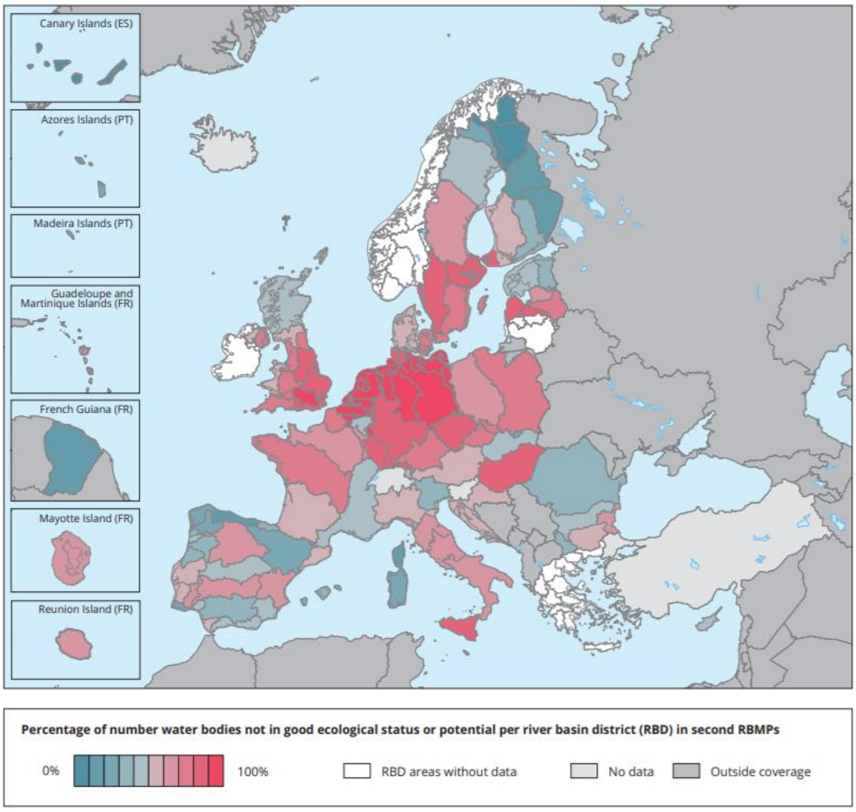
There are several iconic examples of river water quality improvements in Europe, one of them being that of the River Rhine. Owing to decades of organic rich domestic and industrial discharges, the Rhine was one of the most polluted rivers in Europe, with some of its downstream reaches being completely oxygen depleted and devoid of life. During the 1970s, industrial discharges had started to be regulated and more efficient treatment technologies started to emerge and be utilised by industries along its banks. The advent of the UWWTD also led to a marked decrease in the organic and nutrient pollutant load reaching the river, with further improvements having been achieved under the WFD. Therefore, the river is now able to sustain highly sensitive fish and aquatic invertebrates which can thrive only in relatively unpolluted waters (ICPR, 2018).

Another example of river water quality restoration is that of the River Seine, downstream of Paris. Historically, water quality in this stretch has been influenced by both nutrient rich agricultural run-off as well as organic rich industrial and domestic discharges from the Paris conurbation. Marked improvements in water quality have been achieved after the introduction of the UWWTD, due to technological upgrades implemented at UWWTPs as well as regulatory measures for industrial and commercial establishments. Nitrogen pollution linked to agricultural run-off remains a challenge, however the implementation of efficient crop management techniques may help to reduce nitrogen inputs in the future (Estela et al, 2016).

Results from the first RBMP (2009) shown that 38 % of surface water bodies were at Good Ecological Status/Potential, this increasing to 40 % in the second RBMP (2015). On the other hand, the proportion of water bodies which failed to achieve Good Ecological Status increased from 47 % to 58 % between the two RMBPs, this mainly reflecting the status of waterbodies for which data was unavailable during the first RBMP. The proportion of waterbodies which did not achieve Good Ecological Status within countries across Europe is illustrated in Figure 2-5. As seen from this figure, the river basin districts (RBD) with most failures are in highly industrialised countries, such as the UK, Netherlands, Belgium, Germany, Poland and France but also in countries with less industry such as Hungary and Estonia. Finland is the only country which has a river basin characterised by 90 % good ecological status compliance, thus demonstrating the widespread issues encountered in all other countries reporting under the WFD. However, it should be noted that status improvements for individual classification elements (biological elements as well as single pollutants) have been achieved for many waterbodies but the 'one out, all out' principle governing waterbody classification dictates that the overall status would only be 'good' if all the elements are considered 'good'.

With respect to change in chemical status, the proportion of waterbodies achieving Good Status remained unchanged between the two RBMPs (41 %). The proportion of waterbodies failing to achieve Good Chemical Status increased from 30 % to 50 %, reflecting the greater number of waterbodies for which monitoring data available was available. The second largest pressure leading to a failure to achieve good chemical status are emissions from UWWTPs. **Error! Reference source not found.**Figure 2-6 illustrates the chemical status of European RBDs; as seen from this figure, there is a stark contrast between countries like Germany, Sweden, Netherlands, Belgium and countries like Romania, Italy, Spain and the UK. This discrepancy may be largely explained by the different assessment methodologies applied by different Member States but also by the fact that there are significant differences with respect to the distribution of industrial emissions and the level of waste water treatment applied within Member States. Moreover, waterbodies within highly industrialised countries have accumulated significant levels of some priority substances as a consequence of intensive historical use. This legacy pollution may be detected in waterbodies and causing them to fail long after pollutant discharges have ceased (EEA, 2018).

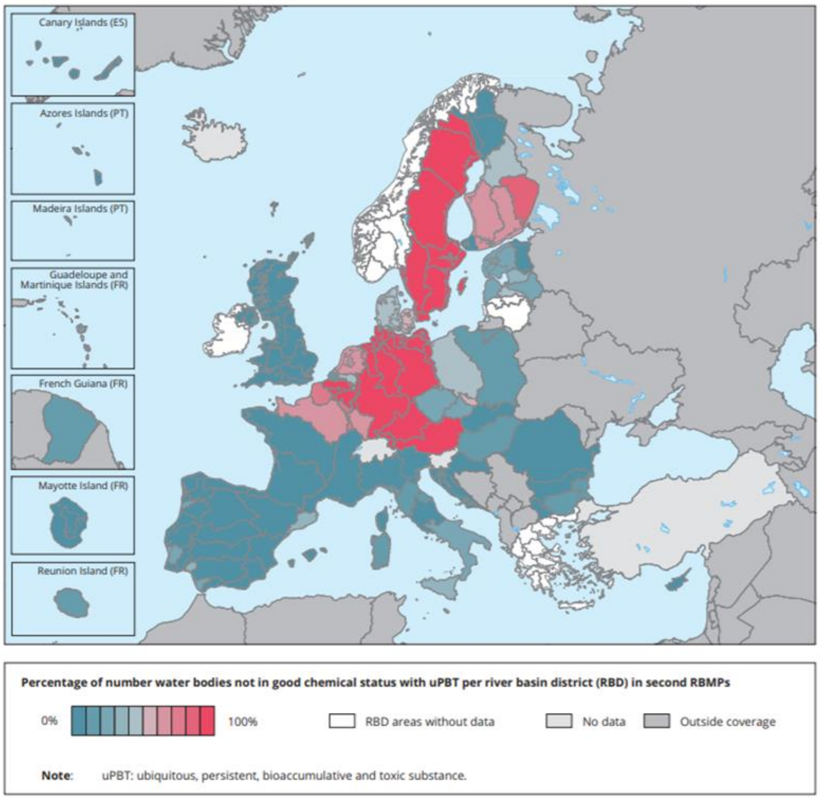
### Figure 2-5 Good Ecological Status failure overview




**Source:** Results are based on WISE-SoW database including data from 24 Member States (EU-28 except Greece, Ireland, Lithuania and Slovenia). Water bodies failing to achieve good status, by RBD; see also Surface water bodies: Ecological status or potential (group) and Surface water bodies failing to achieve good status by RBD .

Source: EEA (2018)

**Figure 2-6 Chemical status failure overview**




**Source:** Results are based on the WISE-SoW database including data from 24 Member States (EU-28 except Greece, Ireland, Lithuania and Slovenia). Surface water bodies: Chemical status with and without uPBT maps, by RBD.

Source: EEA (2018)

Pollutants are emitted to waters from a wide variety of point and diffuse sources, including industry, agriculture, transport, mining and waste disposal and waste water discharges (currently representing a pressure for 12 % of waterbodies across EU Member States).

The status of waterbodies is highly dependent on the pressures experienced at river basin scale (e.g. diffuse pollution) or locally (e.g. excessive abstraction of water). After hydromorphological pressures, which affect 40 % of waterbodies in Europe's RBDs, the single largest pressure is diffuse source pollution (affecting 38 % of rivers). In comparison, pressures from point sources and water abstraction affect only 18 % and 7 % of waterbodies, respectively (EEA, 2018). Diffuse pollution associated with agricultural and urban run-off and unconnected sewage discharges constitutes a leading reason for failure to achieve Good Ecological Status/Potential for many waterbodies. With respect to Chemical Status, failures are linked to diffuse pollution caused by mercury deposition and emissions of a few hazardous substances. Efforts made in curbing the emission of hazardous substances to the environment through the implementation of EU legislative measures such as the Industrial Emissions Directive (European Commission, 2010) and REACH (European Commission, 2016) as well as banning of widely used chemicals have contributed to reducing the number of pollutants casing failures for water bodies across EU Member States.

Most recently, the detection of trace amounts of 'emerging contaminants' in UWWTP effluent has been recognised as a new threat to surface waters. Emerging contaminants such as pharmaceuticals (PhACs), personal care products (PCPs) and endocrine disrupting chemicals (EDC) pose risks to the aquatic environment although the scale and significance of this risk is yet to be fully understood. Much research is currently directed at understanding the threat from emerging contaminants, as some of these substances pose serious health risks to both humans and wildlife (WHO, 2012). In light of the variety of pressures on the water environment, it is necessary to adopt an integrated approach which combines the management of diffuse pollution (especially agricultural runoff) with innovative and efficient waste water treatment technology and pollutant emission reduction, to ensure long-term improvements and compliance with WFD objectives.

# 3 Existing approaches to UWWTP in Europe

## 3.1 Overview

This Chapter describes existing operations of UWWTP in Europe based on their approaches to address some of the current challenges to UWWT related to the quantity and quality of the received waste water, climatic conditions, status of receiving water bodies and issues related to sustainability. The table below presents the criteria used to select examples of UWWTP that help to illustrate the challenges faced and how operators currently respond to them. It also lists the UWWTP featured, their geographical location (ensuring that, where relevant[6], the plants are operating in different countries and geographies) and size (with the aim of presenting existing operations in a range of plants of different size).

[6] Some current challenges, such as low ambient temperatures for most of the year, are only relevant to some, not all, European regions.

### Table 3-1 Topics of the case studies and UWWTPs and agglomerations featured

| Topic | UWWTP / agglomerations | Country | Size |
|---|---|---|---|
| | **Receiving waste water from highly industrialised areas** - These plants, located near major industrial parks or ports, must cope with high influent concentrations of pollutants declared as priority substances, priority hazardous pollutants and other specific pollutants under the WFD, such as heavy metals, nonylphenol, TCE, DDT, etc. | | |
| | Davyhulme | United Kingdom | 💧💧💧 |
| | Janowek | Poland | 💧💧💧 |
| | Rotterdam Dokhaven | Netherlands | 💧💧💧 |
| | **Using their waste water/sludge to derive added benefits for other sectors** – UWWTPs around Europe have found it beneficial and cost-effective to utilise the sludge resulting from the treatment process to produce biogas, recover phosphorus and/or use sludge in agriculture, rather than disposing it. | | |
| | Wulpen WWTP | Belgium | 💧💧 |
| | Limassol WWTP | Cyprus | 💧💧💧 |
| | Amersfoort WWTP | Netherlands | 💧💧💧 |
| | **Operating within cities/regions experiencing high seasonal tourist influx** – high variation in population size throughout the year can create challenges for UWWTP which are generally designed to serve a specific population size. These challenges are prevalent in cities and regions popular with tourists. | | |
| | Zlatni Pyasatsi WWTP | Bulgaria | 💧💧 |
| | Liepājas ūdens WWTP | Latvia | 💧💧 |
| | Rowy WWTP | Poland | 💧 |
| | **Discharging into Nutrient Sensitive Areas, Bathing Waters or watercourses with European level designations (Special Area of Conservation, Ramsar, Special Protected Area)** - these plants need to treat effluent to a very high standard in order to comply with the stringent requirements for effluent discharged to designated watercourses. | | |
| | Stavnholt Renseanlæg WWTP | Denmark | 💧💧 |
| | Dresden-Kaditz WWTP | Germany | 💧💧💧 |
| | Clonakilty WWTP | Ireland | 💧💧 |
| | Arad WWTP | Romania | 💧💧💧 |
| | **Operating within regions experiencing high annual rainfall averages (>700 mm/year)** - The collection systems and treatment plants must overcome challenges imposed by: high peak flows and diluted urban waste water and difficulty in controlling hydraulic conditions (with high in-flows at times of heavy rainfall) and biological treatment. | | |
| | Copenhagen (City) | Denmark | Capacity is not shown as case studies consider approaches to improve collection systems, not directly attributed to a WWTP. |
| | Malmö (City) | Sweden | |
| | City of Glasgow | United Kingdom | |
| | **Operating within regions experiencing low ambient temperatures for most of the year** - these plants must overcome challenges imposed by inefficiencies in biological treatment due to low water temperatures which inhibit degradation of organic matter. | | |
| | Viikinmäki WWTP | Finland | 💧💧💧 |
| | Sjölunda WWTP | Sweden | 💧💧 |
| | Lillehammer WWTP | Norway | 💧💧💧 |
| | **Operating in water scarce regions** - to allow direct or indirect water re-use, UWWTPs operating in water scarce regions must overcome challenges imposed by: higher influent concentrations due to reduced dilution of waste water streams; the need to deploy advanced treatment techniques to treat water to a higher standard and to have reduced dry weather flows to avoid gross pollution problems in receiving watercourses. | | |
| | Ta' Barkat WWTP | Malta | 💧💧💧 |
| | Baix Llobregat WWTP | Spain | 💧💧💧 |
| | Eskişehir WWTP | Turkey | 💧💧💧 |

Legend: Load/capacity: 💧 less than 10 000 p.e.; 💧💧 10 000-100 000 p.e., 💧💧💧 in excess of 100 000 p.e.

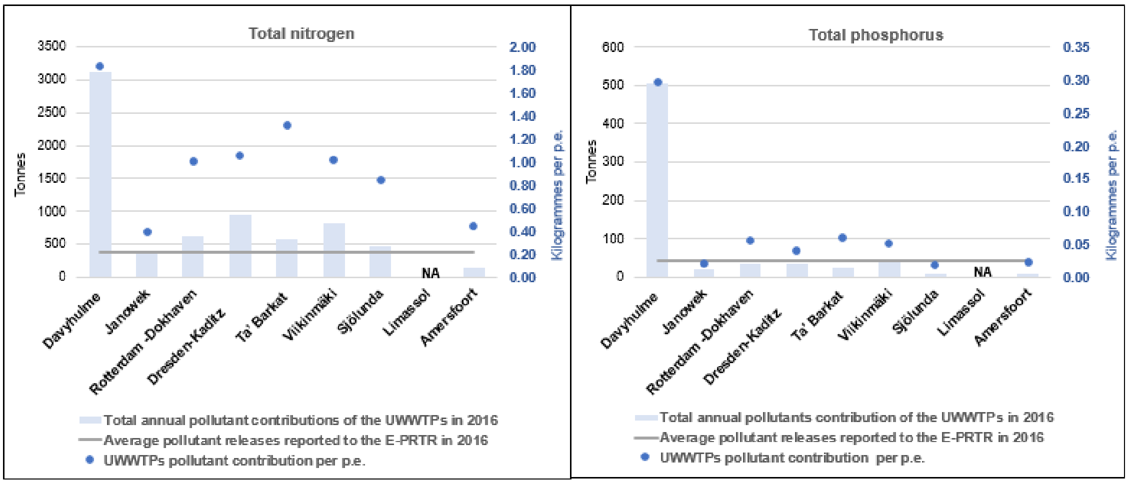
## 3.2 Environmental performance of the UWWTPs featured in the case studies

The figures below illustrate the nutrient and metals contributions of the UWWTPs considered in the case studies, where information was available. The contributions are expressed as totals and per p.e. and are presented in the context of the average contributions of all UWWTPs reporting to the E-PRTR in 2016. It is noteworthy that, due to the reporting thresholds of the E-PRTR, the presented information concerns only UWWTPs with a capacity of over 100 000 p.e.[7]

In 2016, the installation with the highest nutrient contributions, both expressed as total and per p.e. was Davyhulme WWTP in Manchester, United Kingdom. The UWWTP has the largest size in the sample, processing a load of industrial and domestic waste water of 1.7 million p.e. The installation has low or medium heavy metals contributions per p.e., with the exception of arsenic.

All other installations from the sample reported low phosphorus contributions with maximum values of 50 g/p.e., and mixed nitrogen contributions ranging from 0.3 to 1.2 kg/p.e. With regard to metals, the highest mercury, cadmium and lead values per p.e. were reported by Limassol UWWTP, Cyprus. High copper, nickel and zinc values per p.e. were reported by the Viikinmäki UWWTP, Finland.

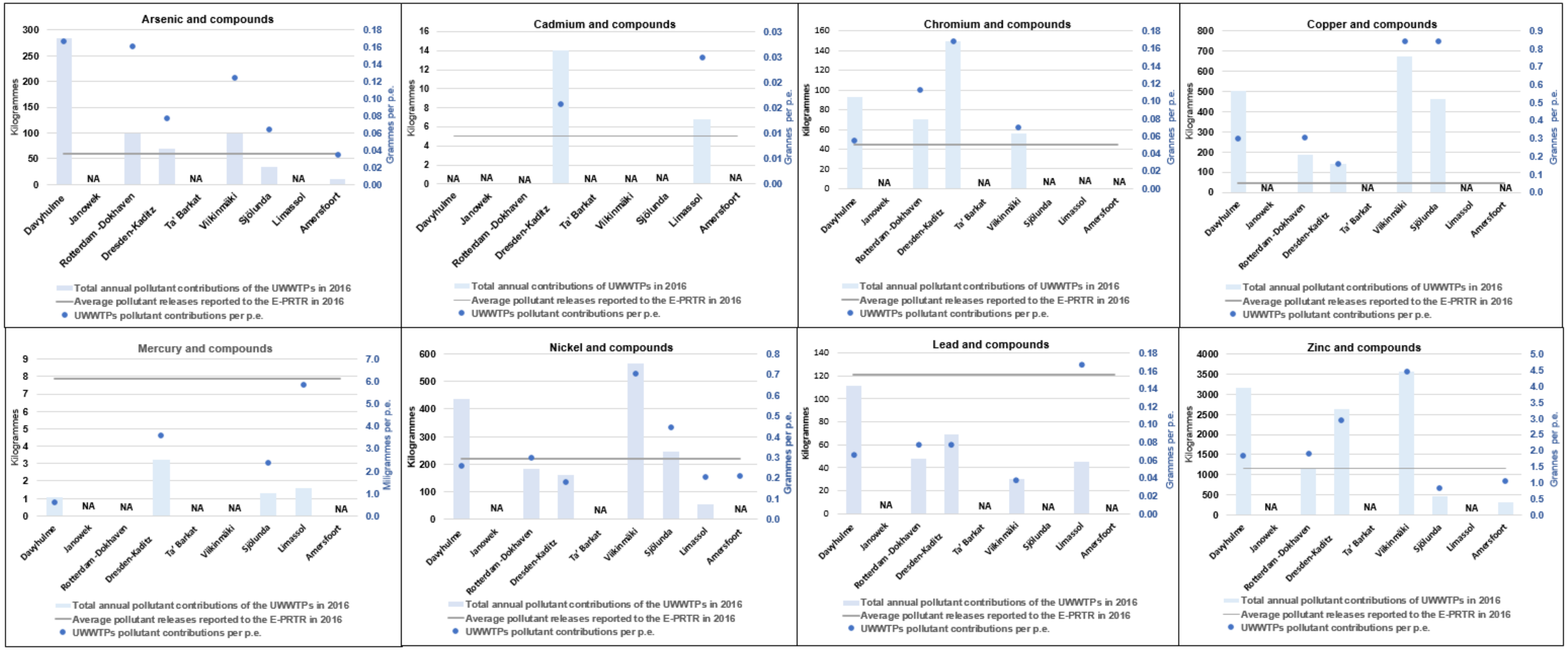
**Figure 3-1 Nutrient releases by UWWTPs featured in the case studies and average nutrient releases reported in the sector, 2016**




Source: EPRTR, 2016

[7] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:033:0001:0017:EN:PDF#page=8

## Figure 3-2 Metal releases by UWWTPs featured in the case studies to average heavy metals releases reported in the sector, 2016




*Note: NA has been used to indicate where an installation did not report pollutant releases to the E-PRTR in 2016.*

Source: EPRTR, 2016

## 3.3 Examples of UWWTPs addressing different challenges

# WWTPs receiving effluent from highly industrialised areas

| | |
|---|---|
| **Overview** | In recent decades, urban sprawl throughout Europe has led to further industrialisation both within historical industrial regions as well as cities, this often being evidenced by the emergence of business and technology parks aimed at small to medium businesses (SMEs). Waste water loads generated from these business parks and industrial areas can be substantial and although some industries have their own treatment facilities, most businesses rely on local UWWTPs for treatment of their waste waters. This can often lead to a change in the chemical signature of effluent received by these UWWTPs as the waste water generated within industrialised areas can contain not only high organic matter content, but also hazardous chemicals derived from the various industries present in the WWTP's catchment area. Therefore, UWWTPs are faced with the challenge of treating large quantities of effluent with different chemical characteristics to an acceptable standard to avoid compromising the water environment |
| **Geographies affected** | Industrial areas and business parks are found across all large cities in Europe, and these mostly comprise of 'light industry' and SMEs, such as consumer goods manufacturing, small chemical manufacturing facilities, research centres, laboratories, etc. On the other hand, some regions in Europe host areas which present a concentration of 'heavy industry' such as large oil and chemical refineries, steel mills, power plants, vehicle manufacturing, etc. Although a mix of heavy and light industry can be found in every European country, some countries such as the UK, Netherlands, Germany, Poland, France and Italy have significant agglomeration of light and heavy industry in certain areas (e.g. Rhine-Ruhr area of Germany, Rotterdam, North-West England, Lower Silesia area in Poland, etc.) |

## Selected examples of UWWTP

**Davyhulme (United Kingdom)**

Davyhulme WWTP is located in Manchester, UK and has a treatment capacity of 1.7 million p.e. The WWTP receives a mix of domestic and industrial effluent, due to being located within Europe's second largest industrial park (Trafford Park). Trafford Park hosts over 1 300 businesses and it is zoned to include a range of light and heavy industries. A large proportion of the park is dedicated to the manufacturing of food, plastics, chemical products as well as coke and refined petroleum products. There are also a multitude of SMEs such as major IT and media companies as well as shopping centres and other tourist attractions. Therefore, the park attracts a significant number of visitors, in addition to its 35 000 employees. The UWWTP discharges treated water to an artificial water body – the Manchester Ship Canal. Discharges from UWWTP combined with legacy pollution due to the long-term presence of the light and heavy industry in the area contribute to water quality issues further downstream in the River Mersey Estuary and Irish Sea.

In order to comply with the UWWTD and WFD, Davyhulme WWTP has recently undergone a major upgrade to extend its primary and secondary treatment process (more primary settlement tanks, aeration and a new activated sludge plant). The plant also applies tertiary treatment (biological aerated flooded filter for nitrification, tertiary ammonia removal plant and a final polishing step to remove carbon and suspended sediments) (Sutton et al, 2016). Information on the treatment removal efficiency at Davyhulme is not available. The cost of the upgrade was around EUR 228 million and was funded by United Utilities, with contributions from the UK government.

In 2016 (E-PRTR, 2016), the plant released 3 120 tonnes of total nitrogen and 505 tonnes of total phosphorus, and also reported emissions of heavy metals (arsenic, chromium, copper, mercury, nickel, lead and zinc). The overall contribution of the UWWTP was high when compared to other installations reporting to the E-PRTR the same year (**Figure 3-2**, **Figure 3-2**) which can be explained by the high load processed. The contributions per p.e. were distinctively high only for nutrients and arsenic.

Furthermore, the plant reported emissions of nolyphenols and one pesticide -diuron. In 2016, the plant released 319 kg of nolyphenols which compares to 123 kg average for all installations reporting to the E-PRTR in 2016. Regarding pesticides, the installation released 9.25 kg of diuron compared to the average of 3 kg.

The sewage sludge generated by the plant is treated via thermal hydrolysis[8] (Lissett et al, 2016) to improve the efficiency of its subsequent digestion. Produced biogas is sufficient to meet the plant's own energy demand, with the excess being exported to the gas grid (Lissett et al, 2016). This has led to a reduction in the plant's operating costs.

**Janowek (Poland)**

Janowek WWTP is located in the Polish city of Wroclaw (Silesia industrial region) and has a treatment capacity of 1 million p.e. The UWWTP receives mixed domestic and industrial effluent, the latter being derived from Wroclaw Industrial Park which features 250 businesses representing a mix of light and heavy industry ranging from construction, electrical engineering and IT, to metallurgy and transport. Besides the fact that this park is experiencing continuous growth, a new Technology Park is currently being developed within the city. Therefore, Janowek WWTP is now being challenged to adapt and accommodate varied effluent loads with different chemical signatures. The plant is discharging to the Odra River which experiences pollution issues and exports excessive nutrient loads to the Baltic Sea.

In 2012, the Janowek WWTP has undergone extension and redesign of its treatment process. The plant now benefits from primary and secondary treatment in the form of activated sludge process and more stringent treatment for removal of phosphorus and nitrogen, as well as a facility for sludge digestion (MPWIK, n.d). Janowek WWTP's upgrade was part of a wider water and waste water management investment programme, costing approximately €50.3 million and being co-financed by the European Union.

Based on the 2016 data, the treatment processes deployed at Janowek WWTP removed around 90 % of total nitrogen, 97 % of total phosphorus, 99 % of BOD and 96 % of COD from the incoming waste water. Removal efficiency of the TSS is close to 100 % (Wody Polskie, 2016). The WWTPs have managed to reduce their nutrient inputs into the receiving waters, this being a major driver of the treatment upgrades. In 2016, the plant released 21 tonnes of total phosphorus and 390 tonnes of total nitrogen (EPRTR), but did not report releases of other substances[9]. The amounts of phosphorus and nitrogen released are low when compared to other installations, both in terms of totals and per p.e. (**Figure 3-1**).

The upgrade at Janowek WWTP has had beneficial impacts relating to the reduction of nutrient inputs to the Odra River as well as the Baltic Sea. Moreover, the plant reuses a proportion of its treated effluent as process water for technological and operation purposes and produces enough biogas to meet 70 % of the plant's energy needs (MPWIK, 2018). In 2015 the plant used 21 GWh of electricity and produced 12.6 GWh, and both produced and used 10 GWh of heat (Maciejewski , 2016). On average, plants of this size in Europe use 35 GWh/y **(Ganora et al., Upcoming)**.

[8] A two-stage process combining high-pressure boiling of waste or sludge followed by a rapid decompression. This combined action sterilizes the sludge and makes it more biodegradable, which improves digestion performance.
[9] This may be because direct releases of these substances did not exceed pollutant reporting thresholds in the E-PRTR

**Rotterdam -Dokhaven (Netherlands)**

Dokhaven WWTP has a treatment capacity of 620 000 p.e and is situated in the city of Rotterdam in the Netherlands. This city hosts Europe's largest port, which is home to many heavy industries such as oil and chemical refineries, biofuel processing, minerals and coal processing as well as freight operations. Although most of these heavy industries have their own treatment facilities, Dokhaven still receives industrial effluents from small and medium enterprises as well as biomedical waste from several hospitals which are located in close proximity. The plant discharges to River Rhine (Nieuwe Maas branch) which is a heavily modified waterbody with legacy pollution issues.

The treatment process at Dokhaven WWTP utilises a modified activated sludge process (two stage process involving adsorption and bio-oxidation) to remove organic contents as well as phosphorus. As the plant is constructed underground, aeration capacity is limited therefore nitrate and ammonia load in final effluent are reduced in proportion of approximately 88 %, using the annamox treatment technique [10] (PAQUES, 2018).

Information related to the removal efficiencies Rotterdam-Dokhaven WWTP are capable of removing 70 % of heavy metals and up to 30 % of organochloride pesticides and pharmaceuticals (CEMAGREF, 2009). In 2016, Dokhaven released 620 tonnes of nitrogen and 34 tonnes of phosphorus. It also reported releases of heavy metals such as arsenic, chromium, copper, nickel, lead and zinc. It is evident from **Figure 3-1** and **Figure 3-2** that Dokhaven's total pollutant emissions are below average when compared to typical emissions from this sector, except for arsenic, and nitrogen which are above average. Contributions per p.e. are medium to high in most cases with the exception to arsenic where the second highest values were reported.

Dokhaven WWTP is constrained by its size and therefore does not operate an on-site sludge treatment facility. Around 20 000 tonnes of sludge the plant produces every year are digested off-site at the Sluisjesdijk facility. The biogas produced here allows the plant to meet a third of its total energy need (7 million kWh/year). To reduce its energy consumption in the future, Dokhaven WWTP is trialling to operate the nitrogen removal process at lower temperatures (10-20°C compared to 30-35°C).

## Summary

- The plants presented are examples of large UWWTPs (>100 000 p.e) which receive a mix of domestic and industrial effluent. In addition to organic matter, suspended solids and phosphorus commonly found in exclusively domestic effluents, these treatment plants receive industrial waste water which, depending on the nature of the industry, may be rich in heavy metals, chlorinated organic substances and other organic substances.
- To minimise the impacts on quality of receiving water bodies, all three UWWTPs utilise tertiary treatment techniques aimed at reducing phosphorus and nitrogen concentrations in final effluent. This has led to an improvement in the water quality of receiving watercourses (**Figure 3-2**). The Janowek and Dokhaven UWWTPs have overall good environmental performance compared to other UWWTPs reporting to the E-PRTR. By contrast, Davyhulme reported significantly higher emissions compared to other E-PRTR UWWTPs. However, this could be explained by its comparatively large size and the fact that it receives waste water from several light and heavy industries.
- All three plants have processes in place to produce biogas as part of the sludge digestion process. Some of the sludge generated at these treatment plants is used as fertiliser, with the remainder being incinerated and disposed to landfill.
- The biogas produced at the three treatment plants enable them to meet a good proportion of the plants' energy demands, with Davyhulme WWTP being completely self-sufficient. In addition, the clean energy produced by the plants allow them to reduce their carbon footprint and reduce their operational costs.

[10] The Sharon Annamox process is a biological waste water treatment step during which ammonia and organic nitrogen are converted to nitrogen gas.

# WWTPs discharging effluent into sensitive areas

**Overview**

Some European rivers, lakes and coastal waters are often afforded special protection under European and national level legislation, due to being designated as:

- Drinking Water Protected Areas (Drinking Water Directive) - designated for the protection of drinking water sources
- Sensitive Area (Urban Waste Water Treatment Directive) - designated for the protection of waters which are sensitive to nutrient pollution
- Bathing Water (Bathing Water Directive) - designated for the protection of water bathing waters
- Special Protected Area (SPA) (Bird Directive) – designated for the protection of bird habitats
- Special Area of Conservation (SAC) (Habitats Directive) – designated for the protection of flora and fauna as well as habitats

Therefore, effluent discharged to designated waters must meet superior quality criteria to maintain their integrity.

**Geographies affected**

Designated waters are found throughout Europe and most European coastal waters benefit from some level of designation, being associated with either Bathing Waters, Shellfish Waters, SPAs and SACs or nationally important designations. On the other hand, rivers and lakes are most often designated as SACs and SPAs, Drinking Water Protected Areas or Nutrient Sensitive Areas.

## Selected examples of UWWTP

**Arad (Romania)**

Arad WWTP is located in the city of Arad, Romania and has a treatment capacity of 225 000 p.e. The city of Arad hosts a wide array of commercial enterprises as well as light industries and therefore, the effluents reaching the WWTP have a high content of organic matter and nutrients as well as smaller amounts of other contaminants. The WWTP discharges its effluent into a highly sensitive stretch of the Mures River, which is designated as a SPA (Lower Mures Valley SPA) and Nutrient Sensitive Area. The river is affected by widespread diffuse nutrient pollution, linked to agricultural activities along its course. In addition, there are a multitude of WWTP and other point-source discharges which affect water quality in the river

In order to minimise nutrient inputs from the city of Arad as well as surrounding villages, Arad WWTP has undergone extensive upgrades in 2010. This was part of a larger investment, co-financed by the EU Cohesion Fund, which aimed to rehabilitate water treatment plants, reservoirs and water transmission pipes, rehabilitate the sewage network, construct and upgrade seven WWTPs in the wider region of western Romania. The cost of the WWTP upgrade was EUR 18 million (CAARAD, 2018).

The upgraded WWTP uses primary treatment together with activated sludge process (to remove phosphorus, nitrate and organic pollutants from waste water effluent. This type of treatment can usually achieve removal efficiencies of 98 % for BOD and phosphorus and 95 % for nitrogen (EEA, 2014)**, however treatment performance will vary between UWWTPs**. The upgrading of the Arad WWTP and subsequent extension of sewerage network have resulted in an increase in the collection and treatment of waste water (93 %) resulting in a significant reduction in organic and nutrient pollution load entering the River Mures.

In 2013, the plant released 58 tonnes of total nitrogen and 5.7 tonnes of total phosphorus, a significant reduction in releases compared to pre-upgrade figures from 2007 where the plant released 268 tonnes of nitrogen and 23.9 tonnes of phosphorus (EPRTR). No other pollutant releases have been reported via E-PRTR after the 2010 upgrade.

The resulting sludge from Arad WWTP is dehydrated and stored in a purpose-built facility, with a very small percentage of the total volume produced being used in agriculture. Arad WWTP does not have the necessary infrastructure in place to produce biogas.

**Dresden-Kaditz (Germany)**

The Dresden-Kaditz UWWTP is situated in the city of Dresden in Germany and has a capacity of 890 000 p.e. The plant receives effluent from the city as well as surrounding localities and this is characterised by high concentrations of nutrients and organic matter as well as other chemicals emitted by light industry, including a nearby pharmaceutical manufacturing facility (Born and Ermel, 2002). The plant discharges its effluent to the River Elbe, which at this point is designated as a Natura 2000 site for its ecological importance (Elbe Valley between Schöna and Mühlberg SPA and SAC). Historically, River Elbe has been affected by both diffuse and point source pollution issues from a variety of sources and much effort has been dedicated to restoring the river's water quality during the past few decades.

Dresden-Kaditz WWTP uses primary treatment and activated sludge process to remove phosphorus, nitrate and organic pollutants from waste water. During 2013-2018, the plant has undergone an upgrade involving the aeration basins and activated sludge tanks, this being prompted by the need to increase the WWTP's capacity and comply with more stringent discharge permit limits to the River Elbe. The upgrade cost 110 million euros and was funded by Stadtentwässerung Dresden GmbH.

After the upgrade, the efficiency of the treatment process has improved, with removal efficiencies of 91 % for phosphate and 69 % for nitrogen (EEA, 2014). In 2016, the plant released 36.7 tonnes of phosphorus and 943 tonnes of nitrogen. In comparison to average releases in the sector, phosphorus contributions were below average and nitrogen ones were above average which was also reflected in the contributions per p.e. (**Figure 3-1**). The reported data is in line with the removal efficiencies of the technologies implemented on site. Besides information on nutrients, the plant has also reported heavy metals with cadmium and chromium emissions per p.e. higher than the other installations from the sample. Information on the technologies installed to target heavy metals could not be identified.

The sludge digested here is dried and transformed in compost which is used for landscaping and land restoration at old mining sites. The digestion process generates enough biogas to cover 50 % of the plant's electricity needs and 100 % of its heating needs (Pullen, 2015).

**Clonakilty WWTP (Ireland)**

Clonakilty WWTP is located in the coastal town of Clonakilty, Ireland and has a capacity of 20 500 p.e, receiving organic and nutrient rich effluent from the domestic, commercial and industrial sectors. Until 2014, the plant failed to meet its pollutant limits in the effluent discharged to Clonakilty Harbour. This happened because the plant was treating effluent via outdated infrastructure, using the traditional activated sludge process. This led to water quality issues in the harbour, which is designated as a Nutrient Sensitive Area, SPA and SAC.

In 2015, the plant was upgraded due to the need to achieve compliance with the UWWTD and protect water quality in Clonakilty Harbour. The treatment technology was upgraded to use a more cost-effective biological waste water treatment technology which uses less energy. Moreover, the plant's capacity was also increased (from 5 000 p.e to 20 500 p.e) in order to accommodate summer tourist influx. The plant is built mostly underground to minimise the visual impact. The upgrade was entirely funded by Irish Water, as part of a wider ~6 million Euro investment which comprised other WWTPs in County Cork (Royal Haskoning DHV, 2018).

Data on the removal efficiencies of the new treatment technology is currently not available. However, the technology typically achieves >90 % removal of BOD, COD, nutrients and suspended sediments in final effluent. As a result of this project, the final effluent discharged to Clonakilty Bay, achieves compliance with EU and Irish environmental requirements (UWWTD), this prompting an amelioration in water quality the bay. The upgrade allows greater flexibility in accommodating increasing flows due to population growth and seasonal tourist influx. No information on pollutant emissions is available from EPRTR.

The Clonakilty WWTP upgrade has already prompted a 35 % reduction in operational costs, as the new treatment technology is more energy efficient and does not require chemicals (Royal Haskoning DHV, 2018). The plant produced approximately 176 tonnes of sludge/year, however does not have any infrastructure to produce biogas. Instead, part of the sludge (102 tonnes) is transferred to a commercial facility that produces biogas and injects it into the gas network. The rest of the sludge (75 tonnes) is commercialised as compost.

**Stavnsholt Renseanlæg WWTP (Denmark)**

Stavnsholt Renseanlæg WWTP (Denmark) is situated in the town of Farum in Denmark and has a capacity of 30 000 p.e. The WWTP receives effluent from domestic and commercial sectors as well as light industry. The plant discharges to the Farum Lake which is part of a wider SAC, thus causing water quality issues which can impact on the ecology of the SAC.

Stavnsholt WWTP also uses the activated sludge process as well as tertiary treatment for the removal of phosphorus and nitrogen. Following a major upgrade in 2000, the plant was able to achieve removal efficiencies of 100 % for phosphorus and BOD and 98 % for nitrate (EEA, 2014). The upgrade was driven by the need to comply with stricter limits of nutrients in final effluent entering Lake Fure. This high standard of treatment is key to ensuring the success of restoration efforts which have been primarily targeted at reducing phosphorus concentrations and improving the lake's ecology.

The plant produces 270 $Nm^3$ biogas every year and this allows the plant to cover 29 % of its total electricity needs (421 000 kWh) and around 50 % of its heating needs. The resulting 350 tonnes of sludge are incinerated and disposed to landfill (NOVAFORS, 2018). No information on pollutant emissions is available from EPRTR.

## Summary

- The plants presented are examples of medium (>10 000 p.e to 100 000) and large UWWTPs (>100 000 p.e) which receive a mix of domestic and industrial effluent. These treatment plants receive effluents rich in organic matter, suspended solids, nitrogen and phosphorus as well as heavy metals and chlorinated organic substances.
- To minimise the impacts on quality of receiving water bodies, one of the UWWTPs utilises tertiary treatment techniques while the other two rely on the activated sludge process. Pollutant emission data was unavailable for two of the plants; however, data for the Arad and Dresden-Kaditz plants shows a decrease in emissions after the plants have been upgraded. The emissions of the Dresden-Kaditz plant are lower for phosphorus and higher for nitrogen when compared to typical emissions from the sector, as reported to EPRTR.
- Two of the plants produce biogas, however the remainder two plants do not have any infrastructure in place to capture biogas as part of the sludge digestion process. Some of the sludge generated at these treatment plants is used as fertiliser, with the remainder being incinerated and disposed to landfill.
- The biogas produced at the two treatment plants enable them to meet a good proportion of the plants' energy demands. In addition, this allow them to reduce their carbon footprint and reduce their operational costs.

# WWTPs operating in water scarce regions or regions of high water stress and prone to drought

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|---|---|
| **Overview** | Water stress occurs where there is a temporary imbalance between the demand for and availability of water resources in events such as droughts. Water scarcity, on the other hand, refers to the long-term inability to satisfy average requirements. The operation of UWWTPs has crucial importance in regions prone to water stress and water scarcity as it allows the maintenance of environmental quality of the available water and provides alternative water source (UN, 2017). Waste water reuse is a common approach in such regions, but practices may vary. Some European countries such as Spain, Italy, Malta, Cyprus, Germany and the UK already have in place numerous policies and initiatives regarding water reuse (European Commission, 2018c). |
| **Geographies affected** | Southern European regions are generally more likely to experience meteorological and hydrological droughts (EEA, 2018). However, severe meteorological droughts were also observed in North Europe in 2018 (DiLiberto, 2018). Another factor that contributes to water stress is the over abstraction of water resources that is usually common to densely populated cities and agriculture-dominated areas. For the period 1990-2015, specific river basins in Poland, Germany, Belgium, Denmark, Spain and Greece had the highest water exploitation indexes in the EU ranging from 20 % to 67 %) (EEA, 2018). Over abstraction and water availability can be an issue in countries normally not associated with water scarcity, such as the United Kingdom (WRAP, 2011), where all water companies are required to put in place drought management plans (Defra, 2015).<br><br>Reuse of treated waste water can be considered a reliable water supply independent from seasonal drought and weather variability and able to cover peaks of water demand (European Commission, 2019). This can be very beneficial to farming activities that rely on reliable continuity of water supply during the irrigation period. Nutrients in treated waste water could also reduce the use of additional fertilisers resulting in savings for farmers and waste water treatment and benefits for the environment (European Commission, 2019). |

## Selected examples of UWWTP

**Baix Llobregat WWTP (Spain)**

The Baix Llobregat WWTP has capacity of 2 275 000 p.e. and is located within the Barcelona Metropolitan area which is prone to water scarcity (Acciona Agua, 2018). It discharges in the Llobregat River Delta that is required to achieve good ecological and chemical status under the WFD.

The Baix Llobregat WWTP is a tertiary treatment plant equipped with screening, biological and chemical treatment, micro- and ultra-filtration, UV disinfection and reverse osmosis (Metropolitan Area of Barcelona, 2009) (Acciona Agua, 2018). The installed technologies aim to produce high quality effluent that is suitable for reuse.

The installation provides reclaimed water for agricultural irrigation. The transportation of reclaimed water takes place through a complex infrastructure of pipelines. Depending on the purpose for which the water is going to be used, different treatment is applied. Other purposes for which the reclaimed water is used include the irrigation of urban green areas, streets washing, industry and as a barrier to saline intrusion. In particularly dry periods, the effluent is used for recharge of the Llobregat river following the highest level of treatment (Metropolitan Area of Barcelona, 2009).

The overall construction of the Baix Llobregat WWTP cost €102 million. In addition, the plant was granted €4.5 million by the Catalan Environment Agency for operation, maintenance and improvements to enable full processing of 173 000m$^3$/d and secure more reclaimed water **(Global Water Intelligence, 2018)**

**Eskişehir WWTP (Turkey)**

The Eskişehir WWTP has a capacity of 650 000 p.e. and discharges effluent in the Porsuk river. As an EU member candidate country, Turkey is in the process of implementing EU legislation, including the WFD and the UWWTD, and therefore the requirements imposed by these regulations need to be reflected by the operations of the Eskişehir WWTP.

The Eskişehir WWTP is equipped with BOD, suspended solids, nitrogen and phosphorus removal, as well as an anaerobic digestion unit for sludge disposal (PWT, n.d.).

Treated water from the Eskişehir WWTP is used for the irrigation of 50 000 ha of agricultural land. The effluent is applied “indirectly”, i.e. it is discharged to recharge the Porsuk river from which farmers extract water for irrigational purposes (Dilek et al., 2000). Previously, the plant only applied BOD and suspended solids treatment and the quality of the effluent released by the plant did not comply with EU standards (PWT, n.d.). The application of the treated waste water in agriculture led to the highest rate of gastrointestinal diseases in Turkey (Dilek et al., 2000). However, in a recent project, the plant was expanded, and further levels of treatment were installed to remove phosphorus and nitrogen and secure performance on the levels required by the EU UWWTD (PWT, n.d.).

In addition to providing reclaimed water for agricultural irrigation, the anaerobic sludge treatment unit at the Eskişehir WWT provides 100 % of the energy used in the plant reducing the associated carbon footprint (PWT, n.d.)

No information was identified regarding the costs of the Eskişehir WWTP upgrade.

**Ta’ Barkat WWTP (Malta)**

The Ta’Bakrat WWTP serves 433,634 p.e. (EEA, n.d.) (approximately 80 % of all waste water in Malta) and is subject to particular pressures during the tourist season. It discharges into the Mediterranean Sea in an area that has been assigned. In addition, all coastal areas in Malta have been assigned ‘sensitive area’ status under the UWWTD (European Commission, 2017) which imposes further requirements on treatment type.

Ta’Bakrat WWTP is equipped with biological aerated filter, sand filtration and UV disinfection (Ais Environment, 2008) and has been extended with new polishing plants in 2018 (The Independent Malta, 2018). Information on removal rates of the installed technologies was not available.

In 2016 (EPRTR), the plant reported releasing 573 tonnes of nitrogen and 25.7 tonnes of phosphorus. Comparison to the average environmental performance of other installations reporting to the E-PRTR is presented in Chapter 3.2. The total nitrogen contributions are slightly above the average for installations of this size and below average for phosphorus. In terms of emissions per p.e., the plant has the second highest nitrogen contributions and low phosphorus contributions.

To address the issue of water scarcity, the installation aims to provide 7 billion litres reclaimed water for agricultural irrigation and aquifer recharge each year.

The newly constructed polishing plants in the Ta’Bakrat WWTP cost €20 million capital investment. In addition, a further €20 million was spent for the development of infrastructure to convey treated effluent to agricultural areas for irrigation (The Independent Malta, 2018).

## Summary

- The plants presented are examples of large (>100.000 p.e) and medium (>10.000 p.e. and <100.000 p.e.) UWWTPs operating in regions of water scarcity and water stress. In all examples, the WWTPs apply intensive treatment to secure high quality reclaimed effluent that is used for agricultural irrigation or water bodies recharge.
- In the case of the Baix Llobregat plant, other purposes for which the reclaimed water is used include the irrigation of urban green areas, streets washing, and industry. In particularly dry periods, the effluent is used for recharge of the Llobregat river following the highest level of treatment.
- The Baix Llobregat has developed complex infrastructure of pipelines for transportation of reclaimed water for agricultural irrigation whereas the Eskişehir WWTP discharges directly into a river from which farmers extract water. It is unclear how the reclaimed water from the Ta' Barkat WWTP is distributed to agricultural land.
- In addition to providing reclaimed water for agricultural irrigation, the anaerobic sludge treatment unit at the Eskişehir WWT provides 100 % of the energy used in the plant reducing the associated carbon footprint.
- The costs of the projects ranged between €20 and 100 million.

# Waste water treatment in regions of high rainfall

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| **Overview** | A common issue faced by UWWTPs relates to capacity overloads during storm events due to combined sewer systems which handle sanitary, industrial and storm water flows together (Quasim, 2017). Besides the rapid increase in load quantity, the effluent entering the UWWTPs during storms has higher pollutant concentrations since storm water collects accumulated pollutants from the sewer system as it flows, and therefore needs to be diluted. This is because large quantities of pollutants accumulate in the sewer networks and could re-enter the waste water stream during storm events (Wang et al., 2011). Since UWWTPs are unable to deal with the increased load, some of the effluent could be released untreated in receiving waters despite its higher pollutant content and could lead to adverse effects. |
| **Geographies affected** | Regions in the Northern parts of Europe have significantly higher annual mean precipitation and are often likely to experience waste water treatment issues due to storm events. The severity and frequency of storm events across Europe is likely to increase due to climate change. |

## Selected examples

**Glasgow (United Kingdom)**

All WWTPs in Glasgow discharge treated effluent in the River Clyde which must comply with the requirements for good ecological and chemical status. Storm water overflows could cause problems with the attainment of good chemical status due to the high concentration of heavy metals in the released effluent. Metals such as mercury have been a key contributor to water bodies in Europe failing the chemical status requirement (EEA, 2018).

To alleviate sewer system overflows, Scottish Water developed three storage tanks in two different areas providing a total of 16 000 cubic metres of storm water storage in the sewer network. The project also included the upsizing of about 400 metres of waste water pipes in the most affected areas to ensure that the increased effluent can be accommodated by the sewage network (WWT Online, 2016). Once the water has entered the storage tanks, it is then gradually pumped out to the WWTPs where it is diluted with other effluent and gradually treated.

The cost of the project in Glasgow amounted to a total of £16 million.

**Copenhagen (Denmark)**

The WWTPs in Copenhagen discharge in coastal areas that have been assigned bathing water status and therefore need to contribute to the attainment of good water status (EEA, 2018a). Copenhagen also has an urban swimming area in the city harbour, and sewage overflows may be particularly dangerous for the health of those using the bathing facilities. The coastal areas in both countries have also been given “sensitive area” status and therefore must comply with the requirements of the UWWTD (European Commission, 2017). It is noteworthy that Denmark has committed to install tertiary treatment in 100 % of the installations across the country (European Commission, 2017). This is due to the fact that Denmark implemented the UWWTD with all its territory as sensitive.

In Copenhagen (HOFOR, 2018), underground reservoirs were installed to minimise the possibility of sewer overflows and make the development of a Harbour Bath possible. The sewer structure was equipped with transmitters to indicate the risk of overflow effects. The transmitters continuously send information to a central computer in the Waste Management Department at Copenhagen Energy, and every fifteen minutes data of overflow volumes are transmitted to Copenhagen Environmental Protection Agency and Danish Hydraulic Institute. If an overflow is spotted, a text message is sent automatically to all water officials. Calculations are then made in a model that uses online data and if the E-coli count exceeds 500 per 100 ml of water, a public warning is issued. Data on the quality of swimming facilities can be monitored by the public at any time during the swimming season online.

In Copenhagen, annual investments in the sewer systems of Copenhagen are approximately 200 million DKK (approx. €26 million). Investments in the sewer system do not solely relate to swimming water quality but also to rehabilitation and flooding. It is not clear what were the capital investments for the development of storage tanks and the installment of monitoring system.

**Malmö (Sweden)**

The WWTPs in Malmö discharge in coastal areas that have been assigned bathing water status and are therefore required to contribute to the attainment of good bathing water status (EEA, 2018b).

In Malmö, an open storm water system was designed to accommodate a 15-year rainfall event as the baseline. It includes a total of 6km of canals and water channels, 10 retention ponds, at least 30 green roofs and a Botanical Roof Garden, which covers 9,500 square meters of an old industrial roof. Rainfall is collected in natural ditches and reservoirs before directing it into a conventional sewer system. The system is integrated within green spaces that can be temporarily flooded to help manage water by slowing its entry into the conventional storm water system. Following the implementation of the storm management project, no floods have been observed in the area and the performance of the combined sewer system has improved since only a negligible amount of storm water enters the sewer system (Climate-ADAPT, 2014).

The open water system in Malmö leads to significant energy savings by diverting storm water away from entering the collection systems and WWTPs, leading to reduced carbon footprint (Climate-ADAPT, 2014).

## Summary

- All examples presented related to solutions implemented by cities located in regions of high rainfall to reduce the possibility of sewer overflows during storm events.
- Two of the examples related to installing storage tanks. In the example of Copenhagen, these tanks were equipped with advanced monitoring technology, allowing timely response and announcements to the public with regard to bathing water quality.
- The open water system in Malmö represents an alternative cost-efficient solution that reduces the need for treatment of storm water and therefore enables energy savings.
- The example projects in the three cities limited sewer overflows, floods and ensured that more effluent is treated prior to entering the receiving water body in storm events by introducing storm water storage. They contributed to protection of the aquatic environment and public health.

# WWTPs operating in regions with seasonal changes in population

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| **Overview** | High seasonal tourist influx can put pressure on UWWTPs through the sudden and significant increase of incoming effluent. Studies show that tourists are likely to use more water compared to permanent residents. For instance, a study by the EEA showed tourists use approximately 3-4 times more water than residents (EEA, 2009). Therefore, as well as producing more effluent, tourism also contributes to water stress issues across Europe. |
| **Geographies affected** | All countries in Europe have regions or cities experiencing periodic increases in local population, due for example to tourism. |

## Selected examples of UWWTP

### Rowy WWTP (Poland)

The Rowy WWTP receives 1 000 $m^3$ of waste water per day in the winter, and three times as much in the summer (Zacharzewska, 2014). It discharges directly into the Łupawy river and is therefore subject to the requirements of good chemical and ecological status of surface water bodies imposed by the WFD. In addition, it must meet the requirements of the UWWTD.

The Rowy WWTP is a secondary treatment plant equipped with advanced aeration system and membrane bioreactor which combine ultrafiltration with activated sludge treatment (Zacharzewska, 2014). No information was available on the direct releases and quality of the effluent from this plant.

To respond to the growing pressures of high tourist influx, the Rowy WWTP underwent renovation works, increasing the capacity of the installations and implementing new and more efficient technologies. The plant has been rebuilt to operate in two modes – "winter" mode when there is less waste water to process and thus only part of the plant is operating, and the "summer" mode when all equipment at the plant is switched on to cope with the higher quantities of water to treat. The renovation of the Rowy WWTP costed PLN 32.5 million (approximately €7.5 million) (Zacharzewska, 2014). The ability of the plant to operate in two modes allowed energy savings in the winter.

### Zlatni Pyasatsi WWTP (Bulgaria)

The Zlatni Pyasatsi WWTP receives water from 18 000 p.e. in the winter and from up to 72 000 p.e. in the summer (Petrov, 2017). The Zlatni Pyasatsi WWTP discharges in bathing waters in the Black Sea and is therefore required to contribute to the attainment of the BWD goals. In addition, the Black Sea has been given a "sensitive area" status under the UWWTD by Bulgaria, and therefore all coastal WWTPs need to comply with the additional requirements of the UWWTD. There is limited information on the technologies currently applied in Zlatni Pyasatsi WWTP, however plans for renovation include the building of tertiary treatment sites (Petrov, 2017).

In 2016 (EPRTR), the installation reported releases of 267t nitrogen and 23.4t phosphorus. These contributions are slightly below the average reported nutrient releases of UWWTPs of similar size (**Figure 3-1**). Zlatni Pyasatsi WWTP also reported heavy metal releases. In the case of Zinc, Nickel, Cadmium and Lead, these were significantly higher than the average of installations reporting to the E-PRTR (**Figure 3-2**).

To respond to the growing pressures of high tourist influx, the Zlatni Pyasatsi WWTP started renovation works, increasing the capacity of the installations and implementing new and more efficient technologies. This also involved implementing nitrogen and phosphorus removal in line with the requirements of the

UWWTD. The project is to be completed in 2019 at a cost of LV 37 million (equivalent of approximately €18 million) (Petrov, 2017).

**Liepājas ūdens WWTP (Latvia)**

Liepājas ūdens WWTP treats loads of 63,900 p.e. outside tourist season but has physical capacity to treat 105,416 p.e. (UWWTD-SIIF, 2014). It discharges in coastal areas assigned with bathing water status and is therefore required to contribute to the bathing water quality in the area. In addition, the Baltic sea had been given a "sensitive area" status under the UWWTD by Latvia, and therefore all coastal WWTPs need to comply with the additional requirements of the UWWTD.

The Liepājas ūdens WWTP is a tertiary treatment plant, with the main treatment technology being anaerobic sludge digestion (SIA Liepājas ūdens , n.d.)

A series of projects were run by the operators to expand the sewer network and improve the connectivity to waste water treatment facilities in the area. The projects began in 2015 and followed 6 stages that enabled 99.8 % of the population to be connected to waste water treatment. It is unclear whether this figure takes account of seasonal population numbers. The costs of the different project stages differed significantly, ranging from €1 to €25 million. The more expensive stages include the renovation and expansion of WWTPs.

## Summary

- The plants presented are examples of small (<10.000 p.e.) and medium (>10.000 p.e. and <100.000 p.e.) UWWTPs operating in regions of high seasonal tourist influx. Three different approaches were taken by the three installations.
- The Rowy WWTP increased its capacity and implemented new technologies. The installation works in two modes – "winter" mode where only part of the plant operates, and a "summer" when the installation is operating at full capacity.
- The Zlatni Pyasatsi WWTP implemented nitrogen and phosphorus removal.
- In Liepājas ūdens WWTP, the projects aimed at improving the connectivity of the population to the waste water facilities. The projects enabled 99.8 % of the population to be connected to waste water treatment. It is unclear whether this figure takes account of seasonal population numbers.

# WWTPs operating in regions of low ambient temperatures

| | |
|---|---|
| **Description** | The performance of secondary (biological) treatment techniques is lower in countries with colder climates since low ambient temperatures limit the activity and growth of the enzymes used in the biological processes (Reddy et al., 2017). This means that the treated effluent may be richer in dissolved and suspended organic compounds. The most commonly affected processes include nitrification and denitrification. |
| **Geographies affected** | On average, regions in the North of Europe experience lower ambient temperature throughout the year. In some Southern regions, large seasonal drops in temperature are also possible. |

## Selected examples of UWWTP

**Viikinmäki WWTP (Finland)**

The Viikinmäki WWTP is located in Helsinki and receives water from 800 000 p.e. and industry. Of the total flow into the plant, approximately 85 % is domestic waste water and 15 % is industrial waste water. The treated waste water is fed through a 16km discharge tunnel into the Baltic Sea (Helsinki Region Environmental Services Authority, 2017).

The Viikinmäki WWTP has screening, primary and secondary sedimentation, activated sludge treatment with a denitrification filter and chemical treatment. The produced sludge is used at the plant's own production unit for biogas and for soil additive in agriculture (Helsinki Region Environmental Services Authority, 2017).

To address the issue of denitrification in low ambient temperatures, the Viikinmäki WWTP implemented an extensive process aiming at removing N. The process includes effluent treatment with activated sludge process with denitrification and additional chemical processes to reduce the nitrogen. The temperature of denitrification processes can be as low as 9 °.

In Viikinmäki WWTP, 95 % of solid and oxygen-consuming matter and phosphorus are removed from the waste water as well as 90 % of nitrogen (Helsinki Region Environmental Services Authority, 2017).

In 2016 (EPRTR), the installation reported 815t of nitrogen and 42t of phosphorus. The installation also reported releases of metals. Comparison to the average environmental performance of other installations reporting to the E-PRTR is presented in Chapter 3.2. The figures show that the plant has overall low nutrient contributions, expressed both as total pollutant load and per p.e. Regarding metals, the plant has very high copper, nickel and zinc contributions per p.e.

**Lillehammer WWTP (Norway)**

The Lillehammer WWTP receives water from 70 000 p.e. It discharges in Lake Mjosa which is regulated by the WFD as a surface water body and is required to comply with the good economical and chemical status requirements. Prior to installation of denitrification technologies in the WWTP in the 1990s, Lake Mjosa experienced high levels of eutrophication (AnoxCaldnes, n.d.).

The Lillehammer WWTP has installed screening, primary sedimentation, moving bed biofilm reactor and chemical treatment (AnoxCaldnes, n.d.).

To respond to the issue of low ambient temperatures, the installation opted for the secondary treatment technology Moving Bed Biofilm Reactor (MBBR) that is an alternative to the activated sludge treatment but has better performance in cold climates. MBBR was developed in Norway specifically to achieve nitrogen removal at cold temperatures. The process is more compact than activated sludge, requires less chemicals and is easily adjusted to different volume of the incoming load (Dale at al., 2015).

**Sjölunda WWTP (Sweden)**

The Sjölunda WWTP that receives water from 550 000 p.e., releases the treated effluent in the Baltic Sea through a 3km discharge tunnel (CTCN, n.d.). The WWTP is required to contribute to the attainment of the BWD goals and secure good quality of bathing waters. In addition, since Sweden has classified the Baltic sea as “sensitive area” under the UWWTD (European Commission, 2017), the WWTPs must comply with the additional requirements.

The Sjölunda WWTP is equipped with equalisation, screening, grit removal, activated sludge, nitrifying trickling filters, denitrification and flotation (VASYD, 2016). Similarly to Viikinmäki, the Sjölunda unit also produces biogas on site through the anaerobic sludge digestion process.

The Sjölunda WWTP attempted nitrogen removal through post-denitrification using methanol as an external carbon source. However, the results achieved were not satisfactory and therefore the plant has been planning to replace the process with anaerobic ammonium oxidation in MBBRs to ensure that it is not affected by temperature drops. The process will be operated through an online control system that will allow high efficiency operation and lead to energy savings (CTCN, n.d.). The achieved nitrogen removal efficiency was 93 % of the incoming load (Bårdskär, 2016)

In 2016 (EPRTR), the installation reported releases of 466t nitrogen and 10.2t phosphorus. The UWWTP also reported releases of metals. Comparison to the average environmental performance of other installations reporting to the E-PRTR is presented in Chapter 3.2 where it is illustrated that the plant has overall low total and per p.e. contributions when compared to other plants in the sample.

## Summary

- The plants presented are examples of large (>100.000 p.e.) and medium (>10.000 p.e. and <100.000 p.e.) UWWTPs operating in regions of low ambient temperatures where the operation of traditional biological treatment technologies is limited.
- The Viikinmäki WWTP and the Lillehammer WWTP adopted different approaches, whereas the **Sjölunda WWTP** initially used similar approach to Viikinmäki WWTP and later adopted the approach of Lillehammer WWTP seeking better results.
- The Viikinmäki WWTP implemented an extensive number of secondary treatment technologies and accelerated the **denitrification rates by introducing methanol.**
- The Lillehammer WWTP **implemented MBBR**, a technology specifically designed to address the issue of denitrification in low ambient temperatures.
- **The Sjölunda WWTP** attempted post-denitrification using methanol as an external carbon source. However, the results achieved were not satisfactory and therefore the plant replaced the process with anaerobic ammonium oxidation in MBBRs to ensure that it is not affected by temperature drops.
- The Viikinmäki WWTP and the Sjölunda WWTP produce **biogas on site** through the anaerobic sludge digestion process.

# WWTPs utilising their waste water/sludge to derive added benefits

| | |
|---|---|
| Overview | Waste water and sludge are among the largest untapped waste categories and their reuse can greatly benefit society. The shift towards circular economy will see more waste water and sludge being processed, recycled and reused. Sludge is already widely processed for the extraction of biofuel and manufacturing of fertiliser/compost. However, sludge can also be used for phosphorus recovery and there is currently much research directed to optimising this process. On the other hand, waste water is sometimes re-used for the irrigation of crops and sometimes in industrial processes. However, this practice was limited due to the absence of European level measures to ensure treated waste water is safe for re-use in agriculture. However, water reuse is a top priority area in the Strategic Implementation Plan of the European Innovation Partnership on Water, and maximisation of water reuse is a specific objective in the Communication ""Blueprint to safeguard Europe's water resources"(European Commission, 2012), and objective of the proposed Regulation on minimum requirements for water reuse. |
| Geographies affected | Waste water re-use is important in water-scarce regions across Europe such as the Mediterranean, but it is becoming popular in other regions which are less water-stressed, such as Belgium, Germany, UK and Sweden, where it may help address long-term imbalances between water demand and supply. The use of digested sludge as fertiliser as well as production of biogas are commonplace in most European countries, while phosphorus recovery from sludge is spearheaded by certain countries such as Austria, Germany, Netherlands, Sweden, Switzerland and Finland. |

## Selected examples of UWWTP

**Limassol WWTP (Cyprus)**

Limassol WWTP serves the city of Limassol and has a capacity of 272 000 p.e. The plant receives effluents which are characteristic of large municipal areas comprising a mix of domestic and light industrial emissions and therefore, the effluent is rich in nutrients and organic matter. The Limassol WWTP does not discharge its effluent to any waterbody; instead, 100 % of treated effluent is used for irrigation purposes, with some discharges being directed into the Mediterranean Sea during winter months.

The treatment process at Limassol comprises primary treatment (including the removal of oil and fats), secondary treatment (activated sludge process) and tertiary treatment for the removal of nitrogen. Additional polishing steps such as disinfection and sand filtration are also employed to ensure a high-quality effluent for irrigation. Therefore, the plant achieves a removal efficiency of 83 % for nitrogen, 87 % for phosphorus and 99 % for BOD. However, no information was available about the removal efficiencies for heavy metals.

The Limassol plant has been extended to increase its capacity, however details surrounding the cost of the upgrade are not available. In 2016 (EPRTR), the plant emitted 55.9 kg of nickel, 45.3 kg of lead, 6.8 kg of cadmium and 1.59 kg of mercury. The metals releases were comparatively low compared to similarly-sized installations from the sector (**Figure 3-2**), however the contributions per p.e. were very high for mercury, lead and cadmium. No information on recent phosphorus or nitrogen emissions is available.

Limassol WWTP represents a prime example of a plant which contributes to the alleviation of fresh water availability issues in this semi-arid region, by recycling almost all of its waste water. Moreover, the plant contributes zero waste to landfill, since all its sludge is re-used as fertilizer, with some quantities being used by cement factories as an alternative to oil (CARTIF, n.d).

**Amersfoort WWTP (Netherlands)**

Amersfoort WWTP is situated in the city of Amersfoort in Netherlands and has a capacity of 315 000 p.e, receiving domestic and light industrial effluent. At Amersfoort WWTP, the treatment process comprises primary, secondary and tertiary treatment for the removal of nitrate and phosphorus and the final effluent is discharged to River Eem.

Information on the treatment efficiencies achieved by this plant is not available. In 2016 (EPRTR), the plant released 198 tonnes of total organic carbon, 7.5 tonnes of total phosphorus and 138 tonnes of nitrogen. The plant also released heavy metals such as zinc (329 kg), nickel (65.9 kg), and arsenic (11 kg) The overall pollutant contributions of Amersfoort WWTP are significantly lower compared to the average contributions of UWWTPs reporting to the E-PRTR in 2016 (**Figure 3-1**, **Figure 3-2**).

In 2016, Amersfoort was transformed into a regional sludge processing hub for several WWTPs in the area. The investment was supported by the EU LIFE subsidy programme at a cost of €10.5 million. This hub is Europe's first commercial nutrient recovery facility and utilises innovative technologies to recover phosphorous and nitrogen from sludge. This process results in a superior fertiliser product which improves crop yields and significantly reduces leaching and runoff, thus protecting local waterways from nutrient pollution.

The plant also produces biogas, being 100 % self-sufficient and exporting enough energy to power 600 city dwellings.

**Wulpen WWTP (Belgium)**

Wulpen WWTP serves the town of Koksijde in Belgium and has a capacity of 74 700 p.e, receiving mainly domestic and commercial effluents rich in organic matter and nutrients. Wulpen WWTP injects its waste water into the dune aquifer of St-André and subsequently use this as an indirect potable water source (DEMOWARE, n.d).

The plant includes primary, secondary and tertiary treatment (chemical removal of phosphorus) as well as advanced techniques such as reverse osmosis, ultrafiltration and UV treatment for disinfection. This ensures that the treated water is free of micropollutants and pathogens and of a superior quality, similar to drinking water. The advanced treatment lines have been installed as part of the plant’s upgrade in 2002, in a separate plant named Torreele. The upgrade of the Wulpen WWTP was prompted by the need to protect the aquifer of St-André from saline intrusion as a result of over abstraction. This project was financed by the European Union’s Seventh Framework Programme for research, technological development and demonstration, at a cost of €6 million (IWVA, n.d).

The artificial aquifer recharge initiative at Wupen WWTP has reduced pressures on drinking water sources, with approximately 45 % of the total water demand in the area being fulfilled through the reuse of effluent. Moreover, the natural groundwater extraction in the 2 existing dune water catchments, St-André and Westhoek, has been reduced by 30 % or 1 million m3/year. The increased groundwater levels contributed to the preservation of the ecological importance of the dunes (IWVA, n.d).

No information on the pollutant removal efficiencies or pollutant emissions was available for this plant.

## Summary

- The plants presented are examples of medium WWTPs (>10 000 p.e to 100 000) large UWWTPs (>100.000 p.e) which re-use their waste-water or sludge in different ways. These treatment plants receive effluents rich in organic matter, suspended solids, nitrogen and phosphorus as well as heavy metals and chlorinated organic substances.
- All plants apply various tertiary treatment techniques, the most advanced treatment being used at Wulpen WWTP, which re-uses its effluent as an indirect potable resource. Pollutant emission data was unavailable for two of the plants, showing
- Only one of the plants produce biogas, while the remainder two plants do not have any infrastructure in place to capture biogas as part of the sludge digestion process. The sludge generated at Amersfoort WWTP is used to produce a high-quality fertiliser.
- The biogas produced at Amersfoort WWTP enable the plant to achieve energy self-sufficiency. All three plants manage to reduce their carbon footprint and reduce their operational costs, with the largest benefits being achieved at Amersfoort WWTP, which produces both biogas and commercial fertiliser.

# 4 Challenges and opportunities for urban waste water treatment in the 21st century

## 4.1 Overview of challenges and opportunities

The examples provided in Chapter 3.3. showcase a wide range of operational challenges that the UWWTP currently faces. The information presented in this chapter draws on both literature review as well as the outputs of interviews conducted with waste water experts from industry, academia and national authorities. As seen from the case studies presented in this report, significant investment is still needed to maintain existing and develop new waste water networks and treatment assets, especially for countries in southern and eastern Europe. Figure 4-1 below illustrates the challenges and opportunities identified as the highest priority for UWWTPs in the medium to long term which are described further in this chapter.

**Figure 4-1 Challenges and opportunities for urban waste water treatment**


Source: Own compilation

### 4.1.1 *Compliance with UWWTD and WFD*

The results of the second RBMP indicate that most Member States are struggling to achieve their targets with respect to restoring waterbodies to 'Good Status' by 2027. Some of these issues stem from the inability to 100 % comply with the UWWTD, as some Member States face difficulties in ensuring waste water is collected from most dwellings and treated to an acceptable standard before being discharged back to the water environment. Achieving compliance with WFD is particularly challenging for waterbodies affected by diffuse agricultural pollution and legacy contamination, as meeting EQS can be translated to achieving higher removal efficiencies at UWWTPs. This challenge is poised to become more pressing as the level of ambition related to improving the status of surface waters as well as expectations for UWWT may potentially increase in the future following on from the ongoing evaluations of EU water policy. This would translate into a higher level of effort needed from the Member States who are currently struggling the most.

### 4.1.2 *Storm water management and adaptation to climate change*

Another important challenge within the waste water sector is the management of storm water entering UWWTPs, both in terms of quantity and quality. Urban areas feature large impervious areas which convey runoff to the combined sewer network almost instantly. Overloading of combined sewer networks and UWWTPs results in overflows which can pollute the water environment. Since the frequency of storm events is expected to increase in the next few decades owing to climate change, storm water overflows may become more prevalent especially if these are not correctly sized to accommodate these flows. Current practices in storm water management can lead to adverse impacts on the water environment, increased flood risk from rivers and sewers as well as increased waste water treatment costs. The increased treatment costs stem from the fact that treating large volumes of diluted waste water requires more energy. This challenge is universal across urban areas, however it is more pressing in countries which receive significant rainfall amounts, such as northern and western Europe, compared to the Mediterranean states. This issue is expected to become more pressing in the next few decades, as climate change impacts become more evident and urbanisation trends continue to grow.

This challenge provides an opportunity and driver to implement sustainable urban drainage systems (SUDS) on a large scale. SUDS are designed to manage runoff in a sustainable way, by harvesting rainfall, capturing and infiltrating runoff to the ground or capturing and releasing runoff to a water body at a rate which closely mimics the runoff signature expected from undeveloped land. Some forms of SUDS are designed to manage runoff only (e.g. storage tanks and rainwater harvesting) while others are also designed to treat runoff to deliver water quality benefits (e.g. constructed wetlands and swales). Therefore, the implementation of SUDS on a large scale can result in the capture of much of the runoff generated from impervious surfaces and reduce flows reaching both UWWTPs and combined sewer networks. In turn, the incidence of combined sewer overflows would decrease, and this would prompt improvements in the water quality within receiving waterbodies while reducing treatment costs. Moreover, SUDS would also reduce flood risk and provide added benefits within urban areas, particularly with regards to biodiversity and recreation.

### 4.1.3 *Urban and rural waste water treatment provision*

UWWTP operators are often confronted with decisions regarding the provision of suitable waste water treatment in both urban and rural areas, and this can be challenging due to certain issues affecting the options available to them. Within urban areas, the main challenges are centred around securing the space necessary to upgrade UWWTPs and other assets. This issue is particularly important in very large cities such as London, where UWWTPs are increasingly at risk of being encroached by residential urban development. In other countries such as France, there is strong public opposition to further UWWTP development near residential areas owing to noise and odour issues.

Conversely, decisions surrounding the provision of waste water treatment in rural areas is often compounded by population densities, which is a key factor in determining the type of collection and treatment system needed. Investment in small scale sewers and treatment is generally costly and may impact heavily on a few polluters. Moreover, within rural areas and smaller towns it is often difficult to find suitably qualified personnel which can operate UWWTP assets. This decision-making process is expected to become more difficult in the future, due to regional and local changes in populations (e.g. steady trends in emigration from eastern to western Europe, population shifts from the west to the east of Scotland).

### 4.1.4 *Funding the provision and maintenance of waste water treatment assets*

The implementation of the WFD is proving expensive for many EU Member States. This issue is especially prominent for eastern and southern European countries, some of which are yet to fully implement the basic measures under the UWWTD. More affluent Member States also have difficulties in funding the upgrade of their treatment assets and maintain sewer and surface drainage networks. This is due to the burden of maintaining old combined sewer assets within European cities as well as building newer surface water and foul networks. Moreover, UWWTP operators also invest heavily in detecting and tackling any misconnections between the foul and surface networks, this being a widespread problem. Where the foul network is erroneously discharging into the surface network, this can cause significant pollution to receiving waterbodies. Conversely, where the surface water network discharges into the foul sewer, the waste water load entering UWWTPs is greatly increased. Moreover, funding is also needed to upgrade many UWWTPs which are overloaded or have outdated, inefficient treatment technologies that prevents them from achieving their compliance targets.

Another challenge relates to the level of understanding and awareness customers have regarding the need for and benefits of waste water treatment provision, as well as how their behaviour can impact service costs. For example, UWWTP operators have started running educational campaigns to show customers that disposing of cooking oils and wet wipes via household drains can lead to the formation of 'fatbergs', which block the sewer network and are expensive to remove. A related issue is that while in some countries (e.g. UK) customers receive water and waste water bills which clearly illustrate water use and associated costs, in others the cost is charged as part of municipal taxes, leading to a lack of transparency. Hence, there are opportunities to educate customers (e.g. via advertisement campaigns, school visits, etc.) and improve their understanding of the services they pay for, how this money is invested and how the price of the service may change in the future along with the associated benefits.

### 4.1.5 *Improving energy and resource efficiency*

During the past two decades, the waste-water sector has been under pressure from consumer protection bodies, non-governmental and governmental economic regulators, to become more energy efficient and tap into the potential to re-use sewage sludge and waste water as well as capitalising on treatment process by-products. In recent years, many UWWTPs have invested in technologies which enable them to capture the biogas resulting from sewage sludge digestion, which is used to support the plants' energy needs. Other examples of energy efficiency measures include the recovery of heat from waste water processes and smart utilisation of space to accommodate wind turbines and solar panels, thus providing renewable energy (e.g. UWWTPs in Helsinki and Vienna). Approximately half of all sewage sludge produced by EU Member States is currently re-used in agriculture as a substitute for fertiliser. These represent positive steps towards the realisation of circular economy within this sector. Nevertheless, these practices are not uniform across the EU, being widely implemented in northern and western Europe and less prevalent in southern and eastern Europe. This is owing to the considerable cost of implementing the necessary upgrades to allow UWWTPs to produce biogas and treat sludge to ensure it is sufficiently free of contaminants to allow its reuse.

There is also a recognition that UWWTPs should become more resource-efficient. This requires a shift in how society views water and sludge, from harmful waste streams to valuable sources from which energy and other materials (such as nutrients) can be recovered. Currently, however, this is not always economically viable, as the cost of recovery far exceeds that of using raw materials (e.g. phosphorus recovery costs far exceed those of raw phosphorus). Hence, there is an opportunity to implement measures which can drive the circular economy agenda within the sector and create markets for waste water by-products.

### 4.1.6 *Emerging contaminants and antimicrobial resistance*

In recent years, there has been an increasing degree of awareness regarding the presence of emerging contaminants and mixtures of contaminants (e.g. pharmaceuticals, nanosilver and microplastics) within the water environment. Comparatively, there has been little research with regards to their hazard properties such as environmental persistency, bioaccumulation, and endocrine effects. The absence of evidence represents an obstacle in establishing environmental quality standards and devising effective treatment techniques to remove them from the water environment (Heiss & Kuster, 2015). Nevertheless, some of these substances may become regulated in the near future (and classed as WFD priority substances) as new evidence on their hazard properties emerges (NORMAN, 2013). This will increase the compliance challenges faced by UWWTPs, as operators may have to trial and implement more advanced treatment techniques to remove these substances from the final effluent, in order to comply with EQSs.

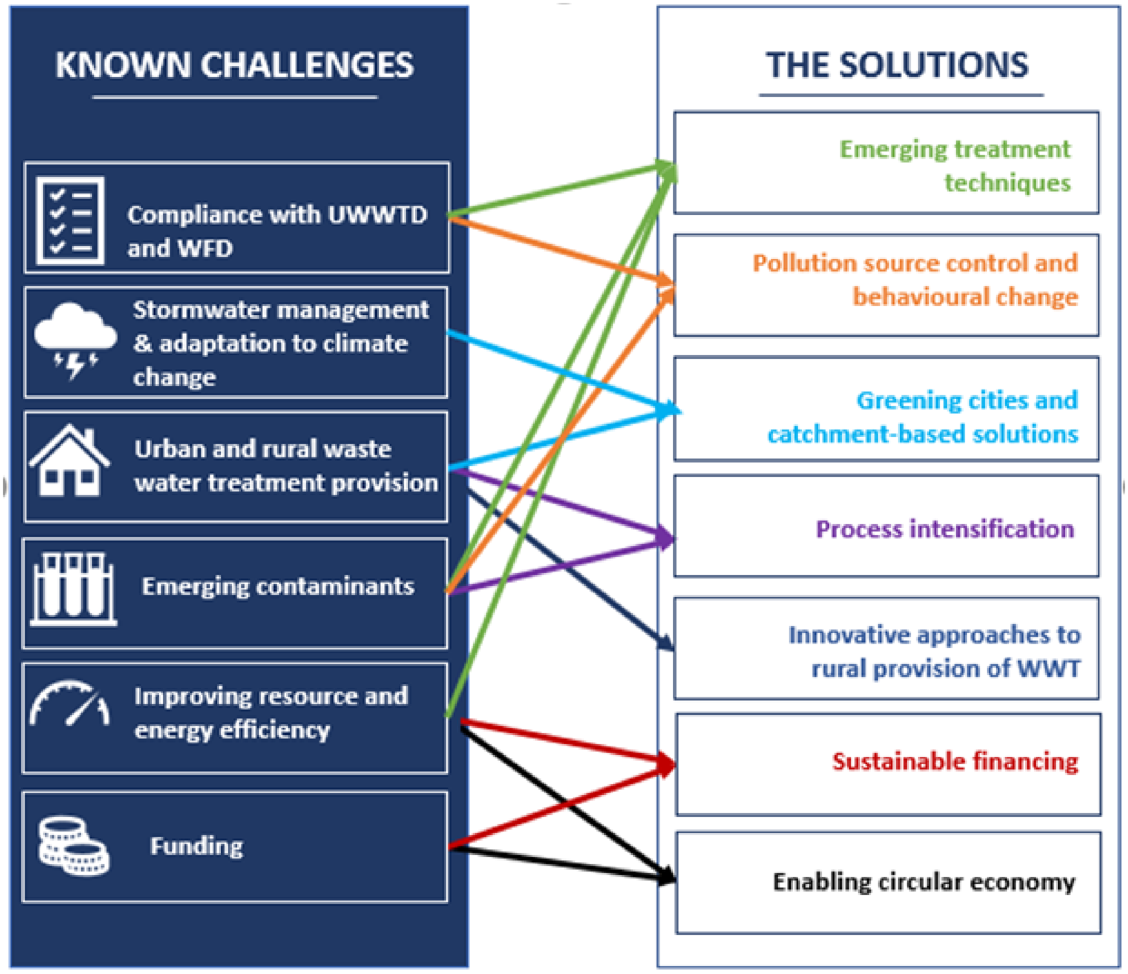
An emerging issue is the antimicrobial resistance (AMR) arising from the use of antimicrobials, such as antibiotics, in human and veterinary medicine. Use and excretion of antimicrobial agents has resulted in the evolution of resistant bacteria, viruses and microbes which can cause disease and now resist medicinal treatment. As a consequence, it has become increasingly difficult to tackle certain infections (WHO, 2014). Pathways to the environment through urban waste water treatment largely arise from people themselves excreting bacteria with AMR, or taking medicine and excreting some of the active ingredient, which may allow bacteria in the environment to develop AMR. As UWWTPs act as a point source from where pollutants can enter rivers, lakes and coastal waters, they may be transferring AMR genes to receiving water bodies. However, currently there is limited information on the pathways for and significance of AMR in the environment to reach humans (EEA, 2019).

The challenge posed by emerging contaminants and antimicrobial agents gives rise to the opportunity to act early to ban or restrict the use of certain substances and/or to encourage less harmful alternative products, as this approach has proved effective in other instances (e.g. EU restrictions on triclosan use). Moreover, given the consumers' increasing awareness on the topic of emerging contaminants and microplastics, there is also opportunity to engage them in devising solutions to tackling the use and spread of such contaminants in the environment.

## 4.2 Solutions

This Chapter presents a set of solutions which are aimed at addressing the challenges presented in Chapter 4.1. As illustrated in Figure 4-2 some of the solutions address multiple challenges faced by UWWT sector. These are described in turn.

Figure 4-2 Solutions to the challenges for UWWTPs




Source: Own compilation

### 4.2.1 *Emerging treatment techniques*

The implementation of novel treatment techniques may help address the aforementioned challenges related to WFD compliance, emerging contaminants and the improvement of resource and energy efficiency. At a European level, the Entrepreneurship and Innovation Programme (EIP) (part of the Competitiveness and Innovation Framework Programme (CIP)) has supported innovation activities related to technologies which can reduce environmental impacts, prevent pollution or achieve a more efficient use of natural resources. This support was delivered by providing better access to finance and encouraging competitiveness and innovation especially for small to medium enterprises (European Comission , 2014).

Currently, there are a series of treatment techniques which have been trialled and tested to ascertain their potential for treating emerging contaminants such as pharmaceuticals. These treatment techniques include ozonation, advanced oxidation, biologically active filtration, hybrid ceramic membrane filtration, activated carbon and nanofiltration (further described in Annex 1). These treatments have been trialled at full scale across plants in several countries and some are already using them successfully (Stein et al, 2016). Results suggest that such techniques can be integrated into existing treatment processes and that they can achieve >80 % removal rates for a broad range of micropollutants. Although these advanced treatment technologies are more energy intensive, they can greatly improve the quality of surface water.

However, implementing such techniques more broadly can be cost prohibitive for many EU Member States.

One of the countries outside of the EU which has taken steps to tackle micropollutants is Switzerland. The initiative to provide advanced treatment steps at 100 UWWTPs across the country has been complementary to measures previously introduced to manage some micropollutants at source via restrictions in their use. In the case of Switzerland, a nationwide financing solution was devised in order to enable the implementation of such techniques at some of its UWWTPs, as part of the adaptation of its Water Protection Law. This process has been subject to public consultation as well as consultation with numerous stakeholders. Hence, by 2040, all the selected UWWTPs are required to implement an additional treatment technique capable of reducing micropollutant loads from waste water by >50 %. The total investment necessary to realise this was estimated at €1 billion, with the majority of these costs being financed through a waste water tax, according to the 'polluter pays principle'. When compared to existing treatment processes at those plants, the cost of upgrading and operating these additional treatment technologies would increase by 5–10 % (for larger plants) and 15–25 % (for smaller UWWTPs) (Müller, n.d).

As seen from this example, significant effort must be dedicated to integrating new technologies into existing treatment processes and this necessitates cooperation between a number of stakeholders as well as public acceptance, especially where this has implications for the costs paid by consumers. The implementation of a sustainable financing solution to fund improvements across a number of plants was also essential in Switzerland. Nevertheless, a number of experts consulted in this study support the view that tackling emerging contaminants cannot be an 'end of pipe' solution alone and must be supported by other initiatives such as the management of pollutants at source and the implementation of environmental taxes and/or extended producer responsibility, which are described in the following Chapters.

### 4.2.2 *Pollution source control and behavioural change*

The implementation of more pollution source controls and instigation of behavioural change could help address some of the challenges linked to WFD compliance and emerging contaminants. Pollutant source controls (e.g. discharge permits, banning/restricting the use of certain substances) have been implemented throughout EU Member States for some decades, as required by EU legislative measures (e.g. REACH, Industrial Emissions Directive, WFD). These measures have led to dramatic improvements in the water environment already and could continue to help tackle the spread of emerging contaminants. The implementation of advanced treatment technologies (e.g. ultrafiltration or reverse osmosis) that can remove emerging contaminants should be considered as a measure of last resort, as this would be cost prohibitive for many UWWTPs.

Alternatively, in addition to regulating more priority substances through the WFD, it may be useful to place controls on trade effluents, to limit their spread closer to the source. For example, effluents from hospitals and care home facilities could be required to have prior treatment before entering UWWTPs, although this may not be feasible on a large scale. In addition, more compounds could be restricted under REACH or even banned. This would both lessen the pressure on UWWTPs (i.e. in terms of financing expensive upgrades to provide more advanced treatment steps) and greatly reduce the spread of these substances in the water environment.

Some experts consulted also indicated that the implementation of source controls could take the form of extending the responsibility for managing emerging contaminants to producers. This could include responsibilities for researching the ecotoxicology of various substances and the development of 'water-friendly substances' which can degrade rapidly upon entering the water environment. This principle could also be applied to the formulation of antimicrobial agents. Measures to reduce the use of antibiotics could be implemented (e.g. tighter controls on antibiotic prescriptions) although there are limitations to the reduction levels that may be achieved. Moreover, discharges of trade effluent containing antimicrobial products to UWWTPs could be minimised, in order to reduce their spread into the water environment. Nevertheless, there are still many significant knowledge gaps around AMR in the environment that need to be addressed.

To ensure the adoption of source control measures at the European level, it may be useful to integrate a set of overriding principles detailing how to implement such pollutant source controls within EU legislation such as, for example, the UWWTD. Currently, UWWTP monitoring data suggests these substances are widespread and generally present in very small concentrations in final effluent. Nevertheless, many emerging substances are not routinely monitored in all EU Member States, leading to difficulties in selecting new substances which should be prioritised under the WFD. Hence, the scale of chemical contamination in some water bodies may be underrepresented, as evidenced by major discrepancies between reported pollutant emissions to water from E-PRTR and the respective number of river basin–specific pollutants. To this end, reporting data from UWWTPs <100 000 p.e could be included in the scope of E-PRTR reporting in an effort to account for pollutant emissions from smaller UWWTPs. Improvements to the quality assurance checks on the UWWTD reporting data is also necessary, to ensure key data are reported for more priority substances across EU Member States. There is also a need for consistency in the approach taken to determine compliance with the required ecological and chemical status of surface water bodies across Member States (EEA, 2019).

Similarly, tackling diffuse pollution could be more effective if management responsibilities would be extended to the larger polluters (e.g. agricultural sector). This would require significant investment to support the implementation of on-farm pollution control measures and educating farmers to manage their land in a more holistic way (e.g. measures to retain polluted runoff, reducing the frequency and rate of fertiliser and pesticide applications). Nevertheless, this may prove difficult to implement if farmers do not readily accept responsibility for causing diffuse nutrient pollution. Therefore, it would be necessary to enforce the ‘polluter pays principle’ more effectively to instigate a substantial reduction in diffuse pollution across EU Member States.

The solutions already discussed could benefit from being supplemented by behavioural changes from the customer’s side (e.g. safe disposal of unused medication, pesticides, paint, etc), as some contaminants enter the water environment if not disposed of safely. Most EU Member States encourage consumers to return unused medication to pharmacies and caution them against disposing of hazardous chemicals via surface drains. Customers should also be shown how their behaviour can affect the price they pay for the provision of waste water services, as this is a reflection of the level of treatment required to tackle the substances reaching UWWTPs. Some UWWTP operators have already taken steps to clearly highlight the link between high sewer network maintenance costs incurred as a consequence of unsafe disposal of ‘unflushable’ products (e.g. wet wipes, oil and fats) and customer’s bills by running information campaigns e.g. South West Water’s ‘Think Sink’ campaign) (South West Water, n.d).

### 4.2.3 *Greening cities and catchment-based solutions*

The concept of ‘greening the cities’ refers to creating green spaces and adopting nature-based solutions as a means of adaptation to climate change and its effects (e.g. increases in temperature and incidence of storm events, increasing flood risk etc). Implementing sustainable urban drainage systems (SUDS) is one of the most effective ways to manage the excessive runoff loads generated from impervious surfaces in cities throughout Europe. This is a significant issue especially in cities where old combined sewer systems are dominant. These sewer systems carry both surface runoff and raw sewage to UWWTPs. However, during storm events, they are designed to spill much of this mixed effluent directly to watercourses, in order to avoid overwhelming the UWWTPs capacity. This input of pollutants, although intermittent, greatly affects the ability of water bodies to achieve Good Status.

SUDS could be targeted to new developments since retrofitting existing impervious surface on a large scale is very expensive. Depending on site conditions and specific requirements, different types of SUDS may be implemented, from those which can store and treat urban runoff effectively (e.g. reedbeds and wetlands) to runoff storage only solutions, which can help mitigate flood risk and promote water-reuse (e.g. storage tanks, rainwater harvesting systems). Reducing runoff entering UWWTPs would reduce treatment costs, wear and tear to the sewer network, the incidence of overflows to rivers as well as surface and fluvial flood risk. This could lead to an increase in asset life, improvements in water quality as well as recreational and amenity value. Additionally, this reduction in inflows to UWWTPs would improve headroom, increasing the UWWTPs flexibility in accommodating variations in flows linked to population growth, tourism or process intensification. In Wales, the implementation of legislation which renders the adoption of SUDS mandatory for new developments (Welsh Government, 2018) has already reduced the runoff burden on UWWTPs (Harrington, 2019). Within western and northern Europe, waste water operators invest heavily into resilience measures to manage flows entering the UWWTPs, and some have started to implement catchment-based solutions to reduce runoff before it reaches the network. However, most EU Member States still struggle to embed SUDS into their planning legislation because it is still unclear who should bear the responsibility of managing these assets and how to finance their maintenance in the future.

Another related aspect is the need for integration of catchment-based solutions within urban planning as well as long-term drainage and waste water management planning. Catchment-based solutions represent collaborative measures involving multiple stakeholders (waste water operators, environmental regulators, academia, businesses and customers) designed to deliver multiple benefits (e.g. improvements to water quality, enhanced biodiversity, reduced flood risk, resilience to climate change). These may include the implementation of measures to mitigate diffuse pollution from individual farms to a catchment scale or initiatives to create habitats to improve a local water course. Such solutions have proven successful (e.g. Catchment Partnerships in the UK) and represent an effective means of sharing the responsibility for managing the water environment, thus lessening the burden on waste water operators. This approach, coupled with a requirement to implement a long-term management approach to waste water, would provide a better framework for designing resilient assets.

### 4.2.4 *Process intensification and approaches to rural provision*

The intensification of treatment processes represents a solution to the challenge brought by emerging contaminants and may also help streamline the provision of waste water treatment in rural and urban areas to provide further capacity resilience. Rather than investing in building new UWWTPs, process intensification is aimed at concentrating treatment provision at fewer, larger plants which already benefit from more energy efficient treatment technologies. This may involve building of UWWTPs on multiple levels to address space constraints in cities, although this may increase GHG emissions due to additional pumping requirements and additional treatment steps required; therefore, any trade-offs should be considered carefully. Some larger plants may also need to upgrade to more sophisticated treatment technologies (see to tackle emerging contaminants which cannot be easily removed by conventional methods (e.g. implementing moving bed bio reactor instead of activated sludge process, see Annex 1 Current and emerging treatment techniques in WWTPs).

The implementation of smart networks benefiting from real-time monitoring systems (i.e. flow meters and other sensors within networks) could further improve UWWTP processes. These sensors would alert waste water operators when the network is at risk of becoming overloaded, enabling them to redirect flows to plants which have the capacity to accommodate them. Such sensors are already used by some waste water operators; however they are expensive to implement and not always economically feasible for less affluent ones. Nevertheless, more sophisticated technologies require more energy and therefore innovation is needed in order to find more energy efficient treatment solutions. In addition, advanced treatment methods require more labour and financial resources to operate, maintain and manage the waste loads with a larger proportion of hazardous substances.

With respect to rural service provision, waste water treatment operators need to evaluate which solutions are fit for purpose based on local factors such as population density, availability of space and availability of labour force to operate assets. In instances where there are no assets already in place, rural waste water treatment provision may be addressed via nature-based solutions, such as reed beds and constructed wetlands. Nevertheless, such solutions would only be suitable to treat effluent from very small populations (<100 p.e) and will be subject to the availability of space and ability to deliver compliance with regulatory requirements. Where collection systems already exist, these may be connected to a larger nearby UWWTP or to a local independent system.

### 4.2.5 *Sustainable financing of WWT infrastructure investments*

Sustainable finance has been attracting ever-increasing attention and is now a cornerstone of EU policies and is reflected in the 2018 EU Action Plan on Sustainable Finance. Within this context, the financing of UWWT infrastructure also needs to consider these key principles and private investments should take into account environmental, social and governance considerations and showcase transparency.

The interviews conducted with industry representatives have identified two mechanisms by which funds for necessary upgrades can be secured. The first principle revolves around setting waste water treatment tariffs which ensure cost recovery and in return educate customers about the real cost of waste water treatment provision and how customer behaviour influences this cost but with allowances being made to ensure these are affordable to struggling customers. When setting tariffs there are benefits of including customers in consultations and ensuring the process is transparent. For instance, in the UK water tariffs are flat. However, allowances for struggling households which would benefit from reduced rates and longer payment terms are included. A similar approach could be implemented across other EU Member States and once a tariff is agreed, relevant public and private funding bodies could provide waste water operators with long-term loans that have low interest rates, to enable the spread of investment costs over several generations. This funding solution would mimic the one provided by the European Investment Bank which supports the development and maintenance of waste water assets in many EU Member States.

An alternative financing mechanism is focussed on moving away from end user tariffs and devising a fairer system based on the ‘polluter pays’ principle. This system would be particularly suited to countries which have never had a tariff approach before and/or those where there is considerable public opposition for tariffs (e.g. in the case of Ireland there are no water tariffs and fees are merged into general council taxes). Given that, in general, point sources of pollution are relatively easier to control by implementation of environmental permits and fines for any pollution incidents, the system would mainly be designed to spread the cost of diffuse pollution across society, with a higher charge placed on larger polluters (e.g. agricultural sector) and new residential and mixed-use developments.

Interviewed stakeholders also highlighted the importance of environmental taxes and charges which are increasingly used in EU Member States (EUROSTAT, 2019) and offer a potential to reuse collected funds to support environmental protection objectives. The highlighted financing mechanisms, and in particular the targeting of large polluters could work well in association with compulsory or voluntary charges on certain products and resource taxes (such as pesticide or fertiliser taxes).

### 4.2.6 *Enabling circular economy*

Waste water treatment can play an important role in contributing to the attainment of the EU circular economy objectives.

Several resource-efficient approaches are already implemented in some WWTPs across Europe. For instance, the case studies presented in Chapter 3 showcased several examples where treated waste water has been reused for numerous applications such as in countries experiencing water stress or scarcity. In addition, the recent proposal for a Regulation on minimum requirements for water reuse (European Commission, 2018a) (see Chapter 1.1.4) aims to further encourage water reuse for agricultural irrigation while ensuring a high level of public health and environmental protection.

Another existing example of circular economy practices in the context of waste water treatment is the production of biogas from sewage sludge, and its further application as an on-site source of heat and electricity (see Chapter 2.1.3). The case studies presented in Chapter 3 provided examples of UWWTPs that produce enough biogas to meet their own electricity and heat demands, with the excess being exported to the gas grid (e.g. the Davyhulme UWWTP, UK), and other examples where the produced biogas was sufficient to meet the WWTPs demands only partially.

A more recent development in this area has been the recovery of phosphorus from sewage sludge ash through mono-incineration or thermal hydrolysis. The process, together with challenges and recent developments, is described in Chapter 2.1.3 and Annex 2 Sewage sludge management.

Innovation in the area of circular economy is spearheaded by several countries such as Germany, Switzerland and Netherlands, the latter already having laid out its vision for implementing product recovery at a wide scale (Association of Regional Water Authorities, 2013). According to the vision, opportunities which are currently under research in the Netherlands include: the recovery of bioplastics, sulphur, nitrogen, algae and alginate[11] from waste water, the recovery of P from manure as struvite, a phosphate mineral that could be used in a slow-release fertiliser (joint initiative with the agricultural sector), $CO_2$ and syngas[12] recovery and the recycling of toilet paper. The vision includes examples of already implemented practices in heat recovery from sewage treatment and UWWTPs exporting energy to national grid. Further opportunities that are envisaged for 2030 include the installation of wind turbines in the proximity of UWWTPs and solar panels on treatment tanks. The Netherland's strategy also details how waste water treated to a lower standard could be re-used for landscaping and recreational use as well as irrigation (Association of Regional Water Authorities, 2013). A novel approach is the production of ultra-pure water to be sold to pharmaceutical companies as well as demineralised water to be used by chemical companies (Association of Regional Water Authorities, 2013). It should be noted that while the vision outlines the development of technologies to recover the listed materials,

[11] Alginate is a by-product of the treatment of (granular) sludge. Alginate can be used for emulsifying and stabilizing liquids, i.e. as a thickening agent for ink, sauces, dairy products, pharmaceuticals and paper.
[12] Syngas is composed mainly of hydrogen and carbon monoxide and is produced in the process of sludge gasification. It is a component used for the production of chemicals like methanol but can also be used in plastic, glue, paint and cosmetics.

further research and development is required to produce technologies that could generate products of sufficient quality, the wide implementation of which is economically feasible.

To date, achieving product recovery has been hampered by political and economic barriers. Currently it is much cheaper to use raw materials than invest in their recovery (e.g. phosphorus rock) unless synergies with other industrial processes are created (Egle et al, 2016). Moreover, European legislation which regulates material recovery and provides standards for any derived by-products is currently lacking and only a few Member States have national regulations addressing this. For instance, in Germany all plants with a capacity of >50 000 p.e. must implement measures to recover >80 % of phosphorus from sewage sludge by 2023 (NEBRA, 2018 ). Similarly, Switzerland has also implemented legislation to promote phosphorus recovery and this specifies quality standards with respect to recovered fertilisers, to ensure any heavy metal accumulation in soils does not compromise safety for at least 500 years, whilst remaining technically feasible (European Sustainable Phosphorus Platform, 2017).

However, the EU Fertiliser Regulation is currently under review with the aim to harmonise standards for fertilisers produced from secondary raw materials in the EU and set standards for pollutant content. The reviewed regulation will encourage the implementation of circular economy practices in the waste water treatment industry relating to P recovery at a larger scale.

According to some experts consulted, funding circular economy initiatives is often problematic. From their experience, there is scope for the provision of tax incentives to address this issue. It is noteworthy however, that while circular economy initiatives often require high capital investment costs, they also provide savings or revenues as a result of the recovered products. Furthermore, the EU provides extensive support for research and development projects and circular economy investments.

## 4.3 Outlooks for water quality status

The UWWTD aims to protect the environment from the adverse impacts of waste water discharges and is one of the enablers to achieve the objectives of the WFD on the Good Status of water bodies. Yet 18 % of surface water bodies in the EU remain under pressure from point emission sources including discharges from UWWTP and storm overflows. While some countries such as Austria or Germany apply the highest level of treatment in all UWWTPs in their territories, some Member States, particularly the newer EU-13 Member States, are not yet compliant with the requirements of the UWWTD concerning waste water collection, secondary and more stringent treatment requirements. Full compliance with UWWTD would lead to better protection of the quality of the water environment, however new connections to the sewage collection systems and modernisations of UWWTPs are expensive and take time. Due to these issues, achieving compliance with the WFD remains a key challenge for the sector in the short to medium term according to the experts interviewed in this study

The treatment technologies currently deployed at UWWTPs vary widely, from traditional secondary treatment solutions such as activated sludge, to tertiary treatment designed to strip nutrients and more advanced processes designed to remove persistent micropollutants. As evidenced in some of the case studies presented in Chapter 3, the pollutant removal efficiencies for both conventional and novel treatment techniques are generally high. Many UWWTPs across Europe have already been upgraded or being targeted for upgrades in the near future to achieve compliance with UWWTD and WFD requirements. Upgrading technologies at UWWTPs is set to further improve water quality and maintain the positive trend in water quality observed since the introduction of UWWTD and other regulatory measures.

The impacts of the attainment of full compliance with UWWTD has been modelled by the JRC as part of a separate study for the European Commission, as part of the evaluation of the Urban Waste Water Treatment Directive which is on-going at the time of writing.

# 5 Conclusions and recommendations

## 5.1 Existing approaches to UWWT in Europe

UWWTPs deliver multiple benefits to society and the environment through collection and treatment of waste water: eliminating health hazards, safeguarding drinking water supplies, bathing waters and fisheries. In delivery of this service, UWWTPs need to cope with a range of different conditions which determine their technology choices and operations. These concern variations in the quality of effluent received, seasonal changes to the population served, climatic conditions such as hot and cold temperatures, heavy rainfalls or water scarcity. Some of these drivers will continue to increase in significance over the next 50 years.

Implementing basic waste water collection and treatment measures under the UWWTD is a prerequisite for compliance with the requirements of the WFD. Some Member States have adopted advanced treatment techniques across most or all of their UWWTPs (e.g. Austria, Germany and Denmark) while countries which have more recently joined the EU still struggle to comply with the UWWTD. In general, WFD compliance is greatly hampered by diffuse pollution, this being one of the leading causes of failure to achieve 'Good Status for many waterbodies.

## 5.2 Practical solutions which could lead to significant improvements in the quality of waste water effluents

Addressing the challenges discussed in this report may require a shift from traditional 'end of pipe' solutions, since these are expensive and do not address the root cause of these issues. A more effective approach would be the integration of various pollutant source controls within European level legislation and ensuring this is applied consistently throughout the EU Member States. Such measures can be effective in reducing the quantity and improving the quality of runoff requiring treatment, reducing the frequency and magnitude of combined sewer overflows and generally improving water body status. Similarly, emerging contaminants and the spread of AMR would also require novel regulatory approaches, such as the extension of responsibility to producers and a requirement for specific discharge permits. Additionally, the 'polluter pays principle' must be thoroughly applied across the agricultural and industrial sector, as this would greatly help stimulate the wider implementation of catchment-based solutions.

Nevertheless, it is also important to recognise that implementing such measures may not be straightforward and may take considerable time, considering the European scale. Hence, in the short term, an approach which would target improvements for designated water bodies (e.g. Special Protected Areas, Bathing Waters, etc) is needed as safeguarding these from pollution is vital. Where discharges from UWWTPs are the primary cause of failure to achieve WFD compliance, treatment technologies could be upgraded to provide a better, more targeted removal of substances, including emerging contaminants (e.g. implementing ultrafiltration, granular activated carbon technology, etc). Achieving that however could come at an overall higher cost of delivering the waste water treatment service, greater energy consumption and potentially restrictions to the use of sludge as a resource (due to transition of certain pollutants such as heavy metals and microplastics from water to sludge during the treatment). Experts interviewed in this study have suggested that advanced treatment techniques will not deliver better outputs for water quality in isolation.

In summary, addressing the current and future challenges faced by UWWTP, would require the implementation of:

- **Pollution source control measures:** restricting use of products containing certain compounds, extending the responsibility for managing emerging contaminants to the producers, consistent enforcement of the 'polluter pays principle'
- **Greening of cities and implementation of catchment-based solutions**: including implementation of sustainable urban drainage systems and integration of catchment-based solutions within urban planning as well as long-term drainage and waste water management planning
- **Intensification of the waste water treatment processes:** concentrating treatment provision at fewer, larger plants, at a potentially higher energy use
- **Techniques and management options enabling shift to circular economy:** product recovery from waste water and sludge
- **Sustainable financing of infrastructure investments:** setting waste water treatment tariffs which ensure cost recovery or devising a system based on the 'polluter pays' principle

Applying these solutions in combination result in significant improvements and support the achievement of water body objectives by 2027, at least for a proportion of water bodies which are currently non-compliant. These solutions facilitate the shifting of the burden from management of negative impacts of waste water away from UWWTP alone and onto the polluter; this is in line with the key principles of EU policy making: the polluter pays principle and the precautionary principle.

## 5.3 Expectations of UWWT in the next 25-50 years

In the medium to long term, challenges faced by UWWTPs will be exacerbated by a changing climate and greater frequency and intensity of severe weather events, the need to balance urban and rural water provision, treating water with new contaminants while achieving greater energy and resource efficiency. Finance to deliver the necessary solutions to better cope with these challenges will be required.

The above challenges provide opportunities for UWWTPs to transition to more sustainable operations and enable a greater contribution to circular economy and climate change mitigation objectives. The shift to achieving compliance with UWWTD could therefore go hand-in-hand with realising the opportunities posed by the long-term challenges; these include maximising water re-use potential, resource efficiency and renewable energy generation.

| Circular economy | Climate change mitigation | Water re-use |
|---|---|---|
| Recovery of **phosphate** from sludge for use in fertiliser production or use of biophosphate from waste water as fertiliser<br><br>Recovery of **nitrogen** for production of ammonia compounds<br><br>**Use of by-products of the waste water and sewage sludge treatment processes** in other industrial processes: carbon dioxide, syngas, sulphur and alginate<br><br>**Harvesting of algae** growing on waste water residuals for production of animal feed | Avoidance / reduction of sewage sludge volumes reaching landfills to minimise methane emissions<br><br>Recovery of **heat** from sludge incineration for UWWTP and industrial-process heating (directly or through heat exchanger and storage solutions)<br><br>Producing **biogas** from gasification of sewage for use in heat and/or power production<br><br>**Optimisation of the treatment process** to minimise own use of energy<br><br>Producing **renewable energy from wind turbines and solar panels** installed at UWWTPs | Re-use treated waste water **as urban, park and recreational waters**<br><br>Re-use treated waste water in **agriculture and greenhouses** |

In the context of the future challenges and opportunities for the sector, a new monitoring framework for the UWWT sector could be established to measure the progress Europe is making towards more sustainable UWWTP operations. This could be integrated into the Eurostat platform for tracking progress to sustainable development goals (Eurostat, n.a) and could draw on both existing UWWTD reporting data (under the Directive and in EPRTR) as well as new / revised datasets generated from potentially new reporting requirements implemented under a revised UWWTD. The indicators included in such a monitoring framework could include:

- Renewable energy generated per p.e. – this could consider renewable energy generated from all potential sources, including from anaerobic digestion or gasification of sewage sludge, as well as wind turbines and solar panels. Expressing the indicator relative to the population it serves would allow tracking progress in UWWTPs of different sizes, recognizing that larger plants, with more land available have greater potential to realise opportunities related to wind and solar power.
- Indicators concerning the mass of recovered materials per p.e. – this could consider specific materials considered as critical in Europe (i.e. designated as critical raw materials (CRMs)[13]). Materials included in the current list of CRMs most relevant for the UWWT sector include phosphate rock and phosphorus.

[13] CRMs combine raw materials of high importance to the EU economy and of high risk associated with their supply.

## 5.4 Current gaps in knowledge and recommendations for further work

Review of literature and interviews with experts have highlighted some gaps in current knowledge. These mainly relate to:

- The impact of emerging contaminants and antimicrobial agents on aquatic environments
- Innovation related to energy-efficient treatment technologies
- Enabling the cost-effective recovery of waste water treatment by-products

With regards to the challenge posed by emerging contaminants and antimicrobial agents, more research should be conducted in order to infer hazard properties (e.g. bioaccumulation and persistence), effects on aquatic organisms and prevalence in the environment. This would facilitate the prioritisation of substances to be regulated under WFD and the development of appropriate environmental quality standards. This would assist waste water treatment operators in decision-making processes related to the level of treatment required at different UWWTPs, according to the chemical signature of waste water inflows. This would mean that rather than upgrading all UWWTPs, a more targeted approach could be implemented in which advanced treatment techniques are implemented where they can deliver most impact (e.g. UWWTPs discharging into sensitive water bodies, UWWTPs processing industrial effluents).

Devising legislative measures which regulate the collection and treatment of hazardous substances before they reach UWWTPs and the possibility of restricting more substances should also be given consideration. Furthermore, there is also a need to quantify the benefits of running campaigns which raise customer awareness and provide information on the environmental fate of hazardous substances and implications for the aquatic environment. The benefits of improving sludge management processes at UWWTPs to reduce potential transmission routes for hazardous substances and antimicrobial agents should be considered, in light of the final use of the sludge (e.g. agriculture versus product recovery).

More broadly, further research is required into policies which would encourage value generation from UWWTP operations while incentivising a more integrated approach with regards to waste water management. This should cover provisions for the management of storm water run-off and pollution at source as well as waste water treatment by-product recovery. This could cover how sustainable markets for such products could be created, and how product recovery could be done in a cost-effective manner. For example, phosphorus recovery from sewage sludge could be encouraged through a system of incentives (either direct for the recovery of phosphorus or for use of products using recovered phosphorus) and/or taxes discouraging the use of raw materials (e.g. applied on products manufactured with the use of phosphorus rock).

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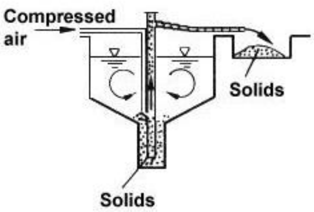
# Annex 1 Current and emerging treatment techniques in WWTPs

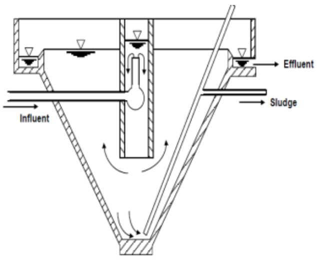
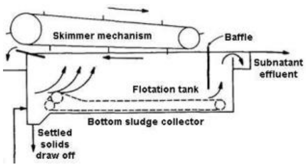
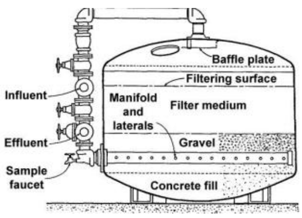
**Current treatment techniques in WWTPs**

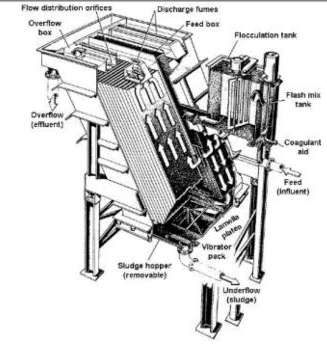
***Pre-treatment***

| Technique | Figure | Description |
|---|---|---|
| Screening |  | Screening is the most common pre-treatment technique. It removes objects such as rags, paper, plastics and metals to prevent damage and clogging of downstream equipment. Some modern waste water treatment plants use both coarse screens and fine screens. Manual cleaning screens require frequent cleaning and increase the operational costs for human labour whereas mechanical cleaning screens have high associated maintenance cost. |
| Grit removal |  | Removal of grit (sand, gravel, cinder, or other heavy solid materials heavier than the organic biodegradable solids) provides downstream protection of processes, as well as preventing excessive wear of equipment. It also averts the build-up of grit in digesters which would otherwise result in reduction of the process capacity of the digester. Grit removal is usually performed after the waste water has been screened. |

Source: BREF series

***Primary techniques***

| Technique | Figure | Description |
|---|---|---|
| **Sedimentation** |  | Separation of suspended solids and floating material by gravitational settling. The settled solids are removed as sludge from the bottom, whereas floated material is skimmed from the water surface. When the particles cannot be separated by simple gravitational means, special chemicals are added to cause the solids to settle. |
| **Neutralisation** |  | Adjustment of the pH of waste water to a neutral level (approximately 7) by the addition of chemicals. It aims to prepare the waste water treatment for subsequent biological and chemical treatment (i.e. secondary and tertiary treatment). Sodium hydroxide or calcium hydroxide is generally used to increase the pH; whereas, sulphuric acid, hydrochloric acid or carbon dioxide to decrease the pH. The inorganic acids used for neutralisation might result in the formation of potentially insoluble salts |
| **Flotation** |  | Separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers. Drawback include possibility of clogging of valves and higher operational costs than in the case of sedimentation |
| **Filtration** |  | Separation of solids from waste water by passing them through a porous medium. Drawback include possibility of clogging and fouling processes when semi-continuous sand filters are used, as well as possibility of additional pollution caused by breakthroughs. In addition, sand filtration, microfiltration and ultrafiltration are not suitable for large scale plants. |

| | | |
|---|---|---|
| **Coagulation and flocculation** |  | Used to separate suspended solids from waste water and carried out in successive steps. Coagulation requires adding coagulants with charges opposite to those of the suspended solids. Flocculation is carried out by adding polymers, so that collisions of micro floc particles cause them to bond to produce larger flocs. |

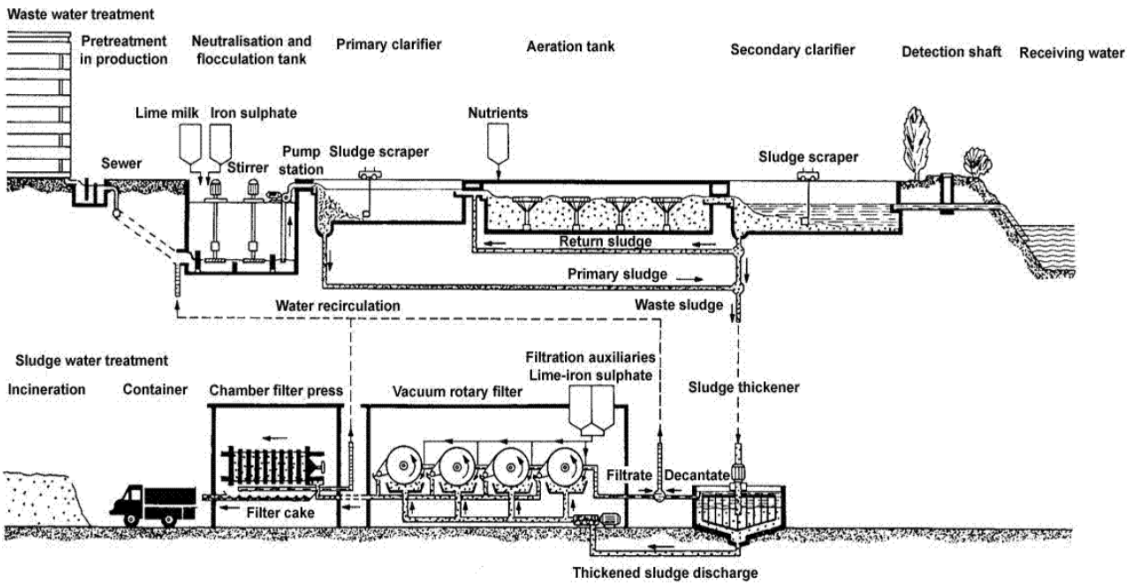
Source: BREF series

***Secondary treatment***

| ***Technique*** | **Description** |
|---|---|
| ***Activated sludge treatment*** | This process targets biodegradable organic compounds through the biological oxidation of dissolved organic substances with oxygen using the metabolism of microorganisms. In the presence of dissolved oxygen, the organic components are mineralised into carbon dioxide and water or are transformed into other metabolites and the activated sludge. The microorganisms are maintained in suspension in the waste water and the whole mixture is mechanically aerated. The activated sludge mixture is sent to a separation facility from which the sludge is recycled to the aeration tank. This method may include high operational costs, sensitivity of biological processes to contaminants or temperatures that are too high (> 37 °) or too low (< 5 °C), high operational costs, and high amounts of excess sludge that requires disposal. |
| **Membrane bioreactor** | This technique targets biodegradable organic compounds through a combination of activated sludge treatment and membrane filtration. Two variants are used: a) an external recirculation loop between the activated sludge tank and the membrane module; and b) immersion of the membrane module into the aerated activated sludge tank, where the effluent is filtered through a hollow fibre membrane, the biomass remaining in the tank (this variant is less energy-consuming and results in more compact plants). Drawback is membrane fouling (especially in the presence of silicones in the influent), high capital and operational costs and low flux of the membrane (Ozgun et al., 2013). |

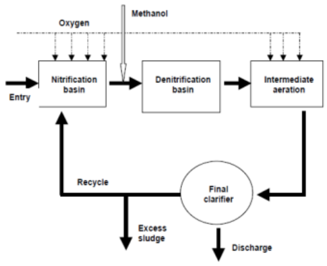
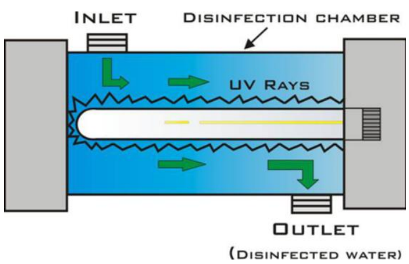
| | |
|---|---|
| **Biological trickling filters** | This technique enables organic material in the waste water to be adsorbed by a population of microorganisms (aerobic, anaerobic, and facultative bacteria; fungi; algae) attached to the medium as a biological film or slime layer (0.1-0.2 mm thick). As the waste water flows over the medium, microorganisms already in the water gradually attach themselves to the rock, slag, or plastic surface and form a film. The organic material is then degraded by the aerobic microorganisms in the outer part of the slime layer. As the layer thickens through microbial growth, oxygen cannot penetrate the medium face, and anaerobic organisms develop. As the biological film continues to grow, the microorganisms near the surface lose their ability to cling to the medium, and a portion of the slime layer falls off the filter. The solids are then picked up by the underdrain system and transported to a clarifier for removal from the waste water. |

**Example of a WWTP using activated sludge treatment**




Source: (JRC, 2016)

***Tertiary treatment***

<table>
<tr><th>Technique</th><th>Figures</th><th>Description</th></tr>
<tr><td>Nitrification /Denitrification</td><td>
</td><td>A two-step process targeting general nitrates and ammonia that is typically incorporated into biological waste water treatment plants. The first step is the aerobic nitrification where microorganisms oxidise ammonium to the intermediate nitrite, which is then further oxidised to nitrate. In the subsequent anoxic denitrification step, microorganisms chemically reduce nitrate to nitrogen gas.</td></tr>
<tr><td>Chemical precipitation</td><td colspan="2">This technique is used to remove phosphorus or phosphate compounds, fats, oils, greases and some other organic compounds from waste waters through the conversion of dissolved pollutants into an insoluble compound by adding chemical precipitants. The solid precipitates formed are subsequently separated by sedimentation, air flotation, or filtration. If necessary, this may be followed by microfiltration or ultrafiltration. Multivalent metal ions (e.g. calcium, aluminium, iron) are used for phosphorus precipitation. Complex chemical dosages is a drawback.</td></tr>
<tr><td>UV disinfection</td><td>
</td><td>UV provides rapid, effective inactivation of microorganisms through a physical process. When bacteria, viruses and protozoa are exposed to the germicidal wavelengths of UV light, they are rendered incapable of reproducing and infecting. UV light has demonstrated efficacy against pathogenic organisms. UV radiation is not suitable for water with high levels of suspended solids, turbidity, colour, or soluble organic matter as these materials can react with UV radiation and reduce disinfection performance (National Drinking Water Clearinghouse, 2000).</td></tr>
</table>

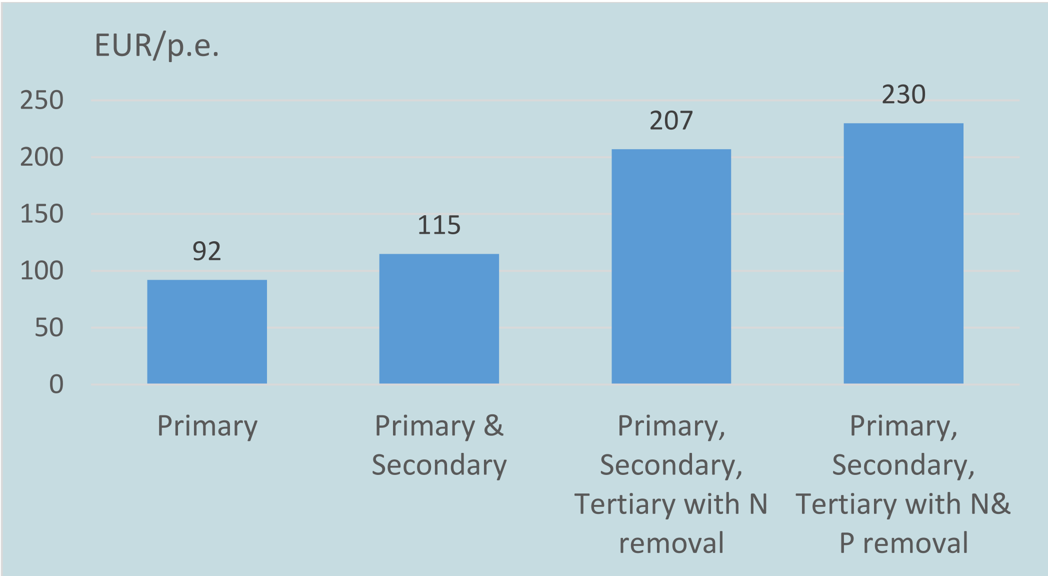
***Sludge disposal***

Sludge disposal processes concern the sludge residue from various waste water treatment techniques, and include sludge stabilisation and conditioning, thickening and dewatering. Stabilisation is chemical or biological process that stops the natural fermentation of the sludge whereas thermal and chemical conditioning aims to improve the conditions for thickening and dewatering. Sludge thickening and sludge dewatering are operations to increase the solid content of sludge and remove part of the water fraction. Their benefit is a manifold decrease in volume to facilitate subsequent treatment operations as well as decrease the necessary size and capacity of treatment equipment.

***Cost and market trends of waste water treatment technologies***

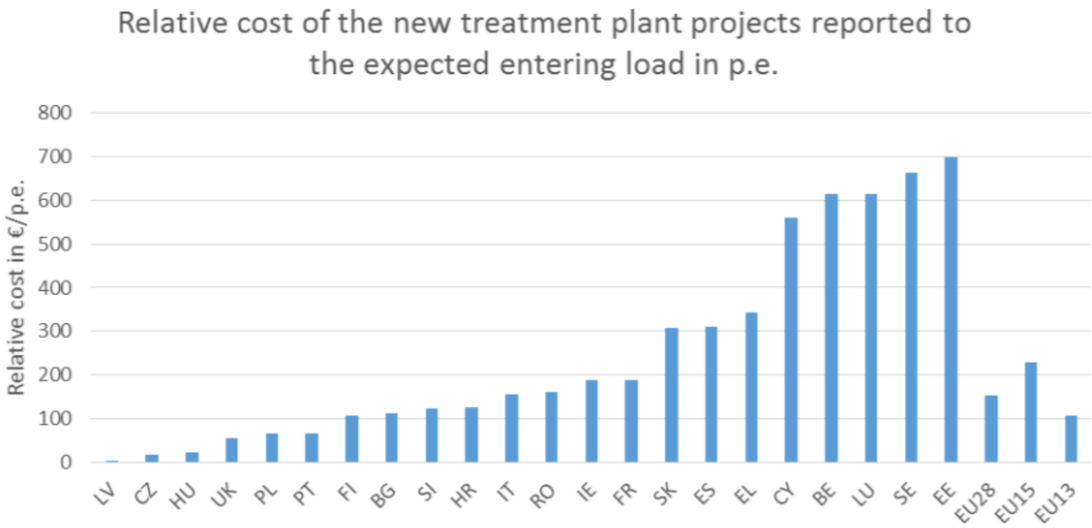
Investment cost increases with treatment plant complexity. Figure below shows how WWTP with primary and secondary stages have lower investment cost since they are based on common techniques. More complex arrangements with tertiary measures (such as Nitrogen or Phosphorous removal) would increase significantly the capital investment cost. The figures show investment expressed in euro per p.e. for plants beyond 100 000 p.e. (European Commission, 2010), as well as the reported investment costs per p.e. by Member States in 2017 (European Commission, 2017).

**WWTP Investment cost in 2008 for installations over 100 000 p.e.**




Source: (European Commission, 2010)

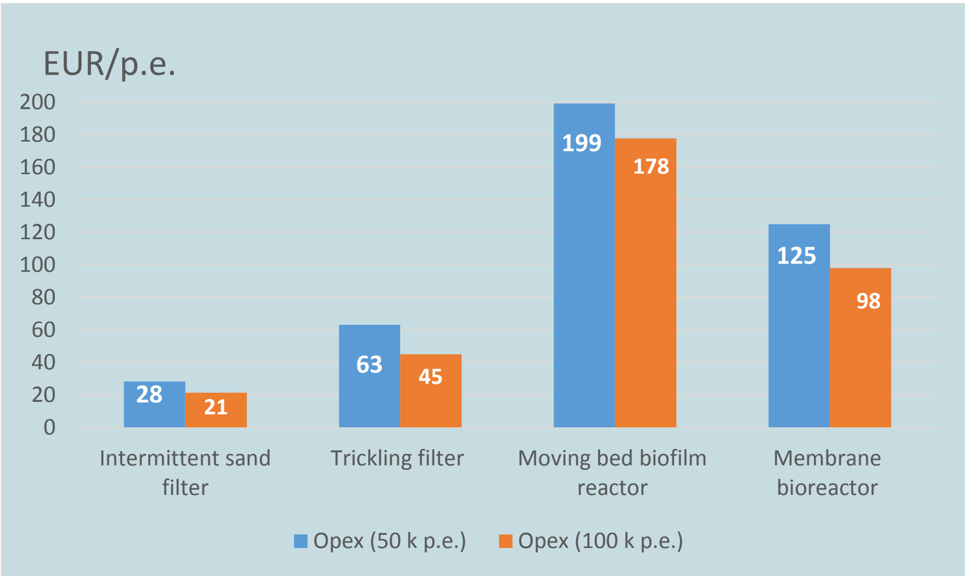
**Investment costs of new WWTPs relative to the expected entering load in p.e.**




Source: (European Commission, 2017)

Annual operating costs of WWTP will also change depending on the technology required for emission abatement. The core operating cost relies on the secondary stage. Figure below provides information on the cost of some of these techniques (Molinos-Senante et al., 2012). The cost per population equivalent decreases with WWTP size for all techniques.

**Annual operating cost for some secondary techniques**




Source: (Molinos-Senante et al., 2012)

**Novel and emerging techniques in waste water treatment plants**

The focus in this Chapter is on emerging techniques and eco-innovation developments that could help to address the challenges associated with industrial off-site transfers and releases of waste water. Within the waste water industry, it generally takes between 10 and 15 years from research and development to commercial implementation (WBL, 2012). As such, the main area of interest is emerging techniques which are close to commercial implementation.

For this review, emerging techniques are classified according to the phase of the treatment: preliminary, primary, secondary and tertiary – and sludge processing. Process management systems are also considered – as horizontal aspects relevant across all phases of waste water treatment. Case studies from across Europe are also included.

**Overview of emerging techniques**

| Pre-treatment | Primary | Secondary | Tertiary |
|---|---|---|---|
| *Screening (removal of large particles)* | *Sedimentation (removal of small particles)* | *Aeration (biological processes)* | *Advanced removal/ disinfection (advanced oxidation and chemical processes)* |
| • **Floating matrasses** for **wave attenuation** | • **Filtration** (e.g. sand filtration or rotating belt screens) | • **Biological processes** (cultured microorganisms; enzymes; electroactive bacteria)<br>• **Granular Activated sludge**<br>• **Membranes** (ceramic/ anaerobic)<br>• **Constructed wetlands** (use of aeration techniques; enhanced filtration)<br>• **Circular processes** | • **Advanced oxidation techniques**<br>• **Advanced photocatalysis**<br>• **Alternative disinfectants** (e.g. two-step chlorination)<br>• **Electro de-nitrification** |
| **Process management** (e.g. automated control systems, modular plant design, solar powered systems, monitoring) | | | |
| **Sludge processing** (e.g. aerobic technology, natural drying processes) | | | |

Source: Own compilation

***Pre-treatment***

Pre-treatment are typically industry specific in relation to targeted challenges. For instance, the emerging challenge of active pharmaceutical substances in waste waters has led to the employment of different types of oxidation and filtration techniques as pre-treatment techniques. In most cases, however, emerging techniques are difficult to isolate in such cases owing to the integrated approaches taken by industry.

***Primary treatment***

Similarly, there are few emerging techniques relating to primary treatments. Although the technological concepts in **micro-flocculation and sand filtration** have been around for years, the recent technological developments such as improved settling velocity and smaller system footprint indicate that they may be subject to increased popularity in future. In China, **micro-flocculation and sand filtration** has been commonly retrofitted to complement the existing secondary treatment anaerobic-anoxic-oxic (AAO) to improve denitrification (Li et al, 2014).

***Secondary treatment***

Emerging secondary techniques are described below. A distinction is made between biological processes and the use of membranes.

***Biological processes***

The use of microorganisms is a well-established secondary waste water treatment. Emerging techniques to enhance these natural processes have been developed. Such techniques are particularly useful when accidental sewage overspills occur and there is a need for a rapid response. Examples of enhanced biological processes include:

- **Application of enzymes to the filter:** enzyme-carrying filtration system able to remove a large range of organic pollutants.

- **Microbial communities:** Development of cultured microorganisms as microbial communities for injection into biological treatment processes to speed up the natural processes. In the US, microbial communities are also split by process to target the different biological processes (Multi-Stage Activated Biological Process) (USEPA, 2013).

- **Biofilters**: combining electroactive bacteria with electroconductive material.

- **Constructed wetlands** are a well-established low cost (with low maintenance needs) and low energy technique commonly used for primary treatment relying on biological processes to convert substances in waste water. Emerging techniques concern the design and maintenance of the wetland so that it can be used for secondary treatment. For example:

- **I**n Denmark with the use of reactive materials and aeration devices to increase treatment capacity and hybrid hydrolytic anaerobic systems to decrease the surface area required (improving effectiveness) (GEMMA-UPC et al, 2017).

- In Portugal the use of constructed wetlands together with oxidation and membrane technologies are also being trialed to specifically target the removal of pharmaceutical products, toiletries and personal care compounds (GEMMA-UPC et al, 2017).

- In Spain, cork waste is being used within a constructed wetland to absorb recalcitrant organic compounds (LIFE ECORKWASTE, 2015-2018)

Similar to constructed wetlands, **managed aquifer recharge (MAR)** is also low-cost waste water treatment option using low levels of energy, involving the management of natural aquifer treatment processes, including mechanical filtration, sorption and biodegradation (Stein et al, 2016)(GEMMA-UPC et al, 2017). Treated water can be used for potable water, process water for industry, irrigation and groundwater ecosystems. This technique can be used together with advanced oxidation processes to improve its removal of organic micropollutants. MAR has also been successfully trialled for treatment of the emerging pollutant Bisphenol-A (Syranidou et al., 2017).

Options for enhancing biological treatment processes are being tested although are still some way from commercialisation. Examples of such techniques with promising results include the **integration of electrolysis within a constructed wetland system** (E-HFCWs) to enhance the removal of nitrogen and phosphorus (Gao et al., 2017)the **use of biocatalysts** for targeted removal of pharmaceutical products (Martins et al, 2017); **Gravity-driven membrane** (GDM) filtration (whereby a thin layer of adsorbent was pre-deposited on the membrane surface prior to filtration) (Shao et al, 2017).

Alternative process management techniques to **improve oxidation in biological processes** have also been developed to improve energy efficiencies in secondary treatments, including (USEPA, 2013):

- **Critical Oxygen Point Control** whereby the optimum oxygen point for waste water under aeration is identified and then used for biological processes
- **Ultra-fine Bubble Diffusers** whereby bubble diffusers are used to enhance aerobic biological treatment processes

***Membranes***

Emerging techniques concerning the use of membrane technology are designed to enhance existing approaches. Examples include:

- **Hybrid Ceramic Membrane Filtration (HCMF):** To remove pathogens, particles and organics. The technique is being developed further to improve cost-efficiency and durability) (Stein et al, 2016). E.g. the eco-friendly ceramic membrane bioreactor (2015-2018) Horizon 2020 project which applies the technique to the treatment of agricultural and industrial waste waters. Clay membranes have successfully also been trialed for the removal of emerging pharmaceutical pollutants (Dordio et al., 2017).
- **Vacuum Rotation Membrane** (VRM®) System: An ultrafiltration system to remove biomass. The technique is developed in the US as an alternative to reduce membrane fouling (USEPA, 2013).
- Another example involves the use of **ammonium adsorption into zeolites** combined with membrane contactors (LIFE ENRICH, 2017-2021)
- **Anaerobic Membrane Bioreactor:** hallow-fibre membrane technology (AnMBR, 2017 – a European Innovation Partnership project). This technique is also referred to a Membrane Biofilm Reactor (MBfR).
- In China, **ammonium adsorption** using DEnitrifying AMmonium Oxidation (DEAMOX) integrated with partial-denitrification and anammox is being researched as an alternative technique for nitrogen removal (Du et al, 2017). In the US, this technique is more developed and is referred to as ‘deammonification and mainstream nitrite shunt’ (i.e. the oxidation of ammonia to nitrite (nitritation) in an aerobic environment without proceeding to nitratation) (USEPA, 2013).

Alternative process management techniques to **reduce membrane fouling** have also been developed to improve energy efficiencies in secondary treatments (USEPA, 2013).

***Tertiary treatment***

Emerging tertiary techniques are described below. A distinction is made between oxidation and photocatalysis processes, and the use of alternative disinfectants.

Note that tertiary treatment with the use of **UV-based photochemical processes/ AOPs** is a growing area of emerging research to treat emerging pollutants although the techniques described are not close to commercialisation and therefore are not reviewed below (e.g.(Calza et al, 2017) (Duan et al, 2017) (Li et al, 2017a))).

Alternative process management techniques to existing UV techniques have been developed to **improve energy efficiencies** in tertiary treatments, using **automated systems** and UV LEDs to minimise harmful chemicals used in conventional UV systems (USEPA, 2013) ( (Aquasense , 2019)

***Advanced oxidation***

Advanced oxidation builds on existing oxidation techniques used for disinfecting potable water and waste water, e.g. **combining oxidation with sand filtration or biological activated carbon filtration** to remove emerging pollutants Stein et al, 2016). As described in relation to a trademark advanced oxidation technique in the US (Blue CAT™), the technique removes slowly biodegradable or nonbiodegradable micro-constituents, which disinfects without producing chlorine by-products (USEPA, 2013).

Advanced oxidation can also c**ombine oxidation processes with light pulses, photocatalysis and photosensitisers** to degrade pollutants and pathogens. E.g. LIFE CLEAN UP (2017-2020) . This technology may also be combined with other techniques to further enhance treatment. E.g. LIFE-EMPORE (2016-2019) which combines filtration/adsorption by columns, filtration by membrane technology, Electrochemical Advanced Oxidation Processes (EAOPs) and AOPs.

The effect of **dissolved oxygen concentration (DO)** on simultaneous nitrification and denitrification has recently been studied in relation to a moving bed sequencing batch reactor and was found to effectively remove total inorganic nitrogen (Cao et al., 2017) . While this technique is still being researched, it could be retrofitted to existing techniques indicating that the lag time for commercialisation may be reduced compared to other treatment techniques (Cao et al., 2017)

***Advanced photocatalysis***

Solar powered photocatalytic processes were established as prototypes in 2010 and ready for small scale implementation (ObservatoryNANO, 2010).

**Titanium dioxide ($TiO_2$)-based photocatalysis** has also been researched extensively in the EU as an inexpensive viable alternative or complementary method for waste water treatment plants since 2010. Research into this technique is in varying stages of market readiness, where it is being applied to emerging pollutants (such as hexavalent chromium), compared to its use for transforming inorganic ions into less toxic forms.

***Alternative disinfectants***

Emerging techniques relating to disinfection processes include the use of **alternative disinfectants**, for example in the US, peracetic acid (PAA) or Dimethylhydantoin (BCDMH) have been approved as alternatives (USEPA, 2013). More recently, research has demonstrated the benefits of a **two-step chlorination** process to disinfect primary sewage effluent, using the same chlorine dosage (Li et al., 2017b).

***Sludge processing***

Another phase in waste water is sludge processing. Two emerging techniques include:

- Solar drying of waste water sludge (Bennamoun, 2012).
- **Sludge drying reed beds**: Sustainable technology (not requiring any chemical additives; low operating and maintenance costs; low energy) to treat accumulated treated sludge (Monte Negro) (GEMMA-UPC et al, 2017) .

***Process management***

In addition to emerging techniques relating to the treatment of waste water, advances are reported relating to the management of treatment processes to enhance the effectiveness of existing techniques and better accommodate emerging techniques, as follows:

- **Automated Neural Net Control Systems (ANCS):** A computer-based system used across the waste water treatment industry to optimise treatment, requiring regular maintenance. Most typically used by large scale plants in the potable water industry in addition to polymeric membranes  (Stein et al, 2016). E.g. the LIFE EFFIDRAIN project demonstrated an integrated real-time control strategy for UDNs and WWTPs to minimise the discharge of pollutants into receiving waters (LIFE EFFIDRAIN, 2015-2019)

  **Modular sustainable sewage treatment plant**: A patented modular approach to plant design. Whereas conventional plants are maintained in the same location, same capacity, waste load and layout for ~30 years; a modular approach provides flexibility in how these features can be managed overtime to better adapt to emerging techniques. Relates to the supply (comprising booster systems, grids/ filters and sand collection) and treatment (including the biological treatment processes and a rainwater buffer) (WBL, 2012).

  **Solar powered systems**:

  - Solar-powered algal treatment of waste water from fruit and vegetable processing (LIFE ALGAECAN, 2017-2020)
  - Solar drying system and a thermochemical gasification process to dry the sludge (LIFE-DRY4GAS, 2017-2020)
  - Solar evaporation/condensation and forward osmosis process for leachate treatment (LIFE LEACHLESS, 2016-2019)

- **Monitoring:** There are several emerging techniques to improve the identification of substances in waste water. A summary of techniques includes (USEPA, 2013):

- System to detect changes in the microbial activities that are caused by a shock load or toxicity
- System to identify specific microorganisms in waste water. Allows real-time feedback for microbial detection
- Real-time detection of pathogens in water and waste water
- System to identify presence of toxins in waste water
- Process to determine Chemical Oxygen Demand (COD)

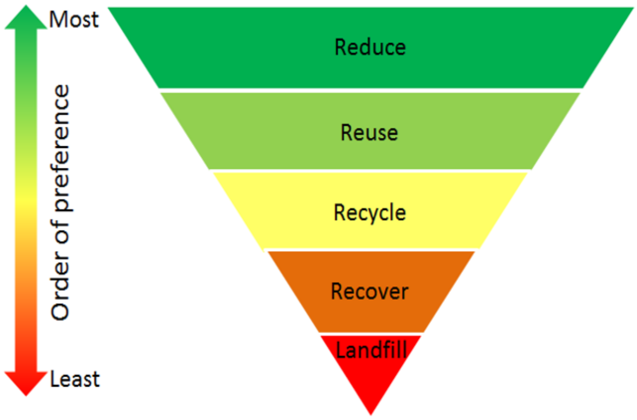
# Annex 2 Sewage sludge management

The most common methods of sludge disposal are landfilling, incineration, nutrient recovery through application in agriculture and production of biogas. These are associated with different levels of environmental protection.

The Waste Framework Directive 2008/98/EC governs approaches to waste disposal and reuse in the EU and sets out the Waste Hierarchy which defines the most desirable methods of waste disposal (summarised in the figure below). However, it also makes clear that Member States shall take measures to encourage the options that deliver the best overall environmental outcome, thus allowing departing from the hierarchy. Furthermore, Member States are required to follow the Directive implementing the precautionary principle.

Considering these observations, UWWTP operators should not support landfilling or incineration of sewage sludge where possible. With regards to reuse of sewage sludge in agriculture, it is noteworthy that the sewage sludge often contains heavy metals, pathogens and hazardous chemicals which raises concerns over the risk of contamination from sewage sludge reuse. The Sewage Sludge Directive (86/278/EEC) requires sludge is treated before used for agricultural purposes to reduce the health hazard, targeting heavy metals and pathogens. Nevertheless, the Directive is more than 20 years old and there are concerns that the limits imposed by it are outdated, and that more pollutants need to be included in its scope. Therefore, this route of sewage sludge disposal should be applied with precaution.

**The waste hierarchy**




Source: Own compilation

### *Sludge pre-treatment*

Pre-treatment usually consists of dehydration of the sludge through various methods and has the following benefits (Ontario, n.d.):

- Reduction in digester sizing requirements to achieve the same solids retention time;
- Reduction in heat exchange capacity requirements for anaerobic digestion;
- Reduction in sludge pumpage and transportation costs;
- Decrease in ultimate disposal costs;

- Reduction of handling problems and leachate production during sludge landfilling operations.

The dehydration process typically goes through the following stages. In some cases, chemical or physical conditioning are applied to improve the dewatering characteristics of the sludge. Thickening is the first step for reducing the sludge volume and increase the solids concentration. The most commonly used thickening processes include gravity thickening, dissolved air flotation, rotary drum thickening and centrifuge thickening. Finally, sludge dewatering is applied. This can be done through mechanical processes, centrifuges, vacuum filters, filter presses and others.

Where the sludge is intended for biogas production, several additional treatment steps can be applied to increase its anaerobic degradability. The methods vary and include biological (largely thermal phased anaerobic), thermal hydrolysis, mechanical (such as ultrasound, high pressure and lysis), chemical with oxidation (mainly ozonation), and alkali treatments (Carrere et al., 2010).

*Landfill*

Sewage sludge can be disposed of in landfill. Landfilling requires additional resources for the operation of the landfill site, such as fuel for vehicles, electricity, and additional materials when leachate is treated on-site. Outputs consist of leachate, landfill gas and energy production when the gas is recovered. Landfill operation therefore generates emissions to air, soil and water. The operation of a landfill also generates other impacts in terms of noise and dust from the delivery vehicles, as well as odours, land use, disturbance of vegetation and the landscape (European Commission, 2002). Therefore, this is the most unsustainable disposal option. It should be noticed that in most countries, disposal to landfill of sludge had been progressively reduced or phased out, as part of application of the Directive on the landfill of waste (1999/31/EEC) which recommends reducing the quantities of biodegradable waste going to landfills, and prohibits the landfilling of both liquid wastes and untreated wastes (European Commission, 2001).

*Incineration*

One alternative to landfilling of sludge is incineration. There are three main types of incinerations – mono-incineration, when sludge is incinerated in dedicated incineration plants, incineration with other wastes, or co-incineration when sludge is used as fuel in energy or material production (Kelessidis and Stasinakis, 2012) Incineration can be used to produce energy; however, the generated emissions to air require the application of abatement technologies such as flue gas treatment. Energy production generally counterbalances the energy needs for sludge drying (Kelessidis and Stasinakis, 2012). Operation of an incineration plant may also produce noise, dust, odour and visual pollution (European Commission, 2002).

*Uses in agriculture*

Organic sludge can be rich in nutrients such as nitrogen and phosphorous and contains valuable organic matter that is useful when soils are depleted or subject to erosion. The organic matter and nutrients are the two main elements that make the spreading of this kind of waste on land as a fertiliser or an organic soil improver suitable. For instance, the availability of sludge nitrogen to crops is broadly in the range of 15-85 % compared with the availability of nitrogen in inorganic fertiliser. Dewatered sludge has logistical advantages over liquid sludge and is the sludge product most widely used in agriculture (European Commission, 2010).

The sludge, however, often contains pollutants such as heavy metals, pathogens and hazardous chemicals that are often not monitored. Therefore, the Sewage Sludge Directive (86/278/EEC) requires it is treated before used for agricultural purposes to reduce the health hazard. The types of treatment required may include biological, chemical or heat treatment, long-term storage or any other appropriate process.

As discussed earlier, there are concerns related to the usage of sewage sludge in agriculture due to the content of chemicals that may not be regulated, or the outdated limits on pollutants such as heavy metals. It is also noteworthy that the extensive treatment of the sludge is associated with high energy consumption and corresponding GHG emissions. These concerns require further investigation.

### *Phosphorus recovery from sewage sludge ash*

Apart from recovering phosphorus through the direct application of sludge on agricultural land, phosphorus could also be recovered from sewage slush ash through thermal hydrolysis or mono-incineration (Herzel et al., 2016). Sewage sludge ash from co-incineration could not be used due to the low content of phosphorus. Depending on the nature of the phosphate precipitation and the origin of the sludge, the phosphorus content in the ash varies between 3 % and 10 % which is lower compared to the direct application of sewage sludge. The benefit of this method is that the thermal treatment secures safe destruction of organic pollutants. However, heavy metals are not removed, and further treatment should be pursued to secure the safe application of the sewage sludge ash as a fertiliser (Herzel et al., 2016).

It should be noted that the EU Fertiliser Regulation is currently under review with the aim for the updated regulation to harmonise standards for fertilisers produced from organic or secondary raw materials in the EU, opening new possibilities for their production on a large scale (European Council, 2018). In addition, the regulation will set harmonised limits for a range of contaminants contained in mineral fertilisers.

### *Biogas production*

Sewage sludge can be used to produce biogas through the application of anaerobic digestion (Bachmann, 2015). The process takes place at temperatures of 35 – 39 ° and has a retention time of around 20 days. In this time microorganisms break down part of the organic matter that is contained in the sludge and produce biogas. Following drying and cleaning of the biogas, it could be upgraded to biomethane or it can be combusted in a combined heat and power plant to generate electricity and heat simultaneously. The remaining sludge can be further treated and spread on land for agricultural purposes. The pros and cons of the method are summarised in the table below

**Advantages and disadvantages of biogas production from sewage sludge**

| Advantages | Disadvantages |
|---|---|
| Reduction of organic content of approximately 50 %. | Anaerobic digestion is a sensitive process that could be inhibited by several factors such as change in temperature, pH, presence of salts and presence of toxic materials. |
| Production of renewable energy and the possibility of independent supply of energy to the sewage treatment plant. | The treatment of the sludge resulting from the process is not easy |
| Reduction of waste, in line with the principles of circular economy | Anaerobic digestion does not destroy heavy metals and POPs. |

| Advantages | Disadvantages |
|---|---|
| Anaerobic treatment of precipitation makes a significant contribution to climate protection | High capital investment costs and operational costs. |

Source: (Stuart, 2006; Semenova, 2018)