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Characterization of unplanned water reuse in the EU

Final Report

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Characterization of unplanned water reuse in the EU

Final Report

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Executive Summary

Background and Scope of the Study

Where municipal wastewater effluents are not being reused but discharged to the aquatic environment the water reenters the hydrological cycle. This unintentional or *de facto* water reuse scenario is likely widespread but a comprehensive documentation quantifying the degree of impact by wastewater effluent discharge on European river basins is lacking. As a consequence, where wastewater effluents account for a substantial fraction of a river the source water quality might adversely impact downstream non-potable and potable use options, aquatic life, or local groundwater qualities.

Many downstream users and regulatory bodies have not made any explicit notion of this conditions and common water resource management refers to ‘surface’ or ‘river’ water assuming an appropriate quality for various downstream uses. Thus, assessments are urgently needed to identify situations where acceptable risk levels using effluent-impacted surface water are exceeded and proper mitigation strategies are warranted. In order to establish safer practices, these strategies might involve additional treatment barriers or the use of alternative supplies including direct use of treated wastewater effluents (reclaimed water) providing it meets approved standards and is applied appropriately.

The main intent of developing regulations and guidance for water reuse applications is to properly manage any non-acceptable risk to human and environmental health associated with the potential presence of microbiological and chemical contaminants (NRC, 2012). These regulatory initiatives might involve management options and integration of advanced technical barriers in existing wastewater treatment facilities to reduce any remaining risk to acceptable levels before reclaimed water is being used for a particular water reuse application.

Criteria for reuse of reclaimed water have been developed by several EU Member States (i.e., Cyprus, France, Greece, Italy, Portugal and Spain). In general, there is little harmony among existing water reuse standards of Member States and there is concern that this can create some trade barriers across Europe for agricultural goods irrigated with reclaimed water and a perception among end users that there are different levels of safety for similar irrigation practices. To overcome this issue and to foster water reuse as a core element of the EU action plan for the Circular Economy, the European Commission presented the concept of the circular economy on December 2, 2015, which included a number of actions to further promote water reuse across the EU (EU Commission, 2015). One of these actions is to table a legislative proposal of minimum quality requirements for water reuse for agricultural irrigation and groundwater recharge in 2017. In support of this initiative, the Joint Research Centre (JRC) was asked by the European Commission to develop a technical proposal for minimum quality requirements for water reuse in agricultural irrigation and groundwater recharge. This most recent draft of this proposal was presented in June 2017 (JRC, 2017).

In order to assess policy options regarding requirements for water reuse via agricultural irrigation and groundwater recharge, the European Commission requested an additional source of information. Thus, the aim of this study was to benchmark the current degree of unplanned water reuse in Europe, in particular in areas that are practicing agriculture irrigation and artificial groundwater recharge using surface water. This assessment included a characterization of qualities of water sources currently used in agricultural irrigation in the EU, including direct and indirect reuse of treated wastewater. In addition, the extent of unplanned reuse and the impact of the development of planned (and direct) water reuse has been assessed for case studies in selected EU river basins in Spain, Italy, France and Germany.

Characterization of qualities of water sources currently used in agricultural irrigation in the EU

More than half of the water used in agriculture is from groundwater abstraction in Austria, Denmark, Hungary, Germany, the Netherlands, and Slovakia. For over 40% of farms in Italy, Greece, Slovenia and Cyprus, irrigation water comes from off-farm water supply sources, which are usually fed by surface water sources like rivers or lakes, surface run-off, groundwater, and reclaimed water. Consumption is markedly higher in southern and southeastern Europe than elsewhere across the continent, accounting for more than 60% of total freshwater abstraction.

According to the Food and Agriculture Organization of the United Nations (FAO), the main water quality issues of surface water or groundwater use in irrigated agriculture are associated with salinity, specific ion toxicity, excessive nutrients, and a change of the water infiltration rate. These issues are being addressed in the FAO water quality guidelines for irrigation considering surface or groundwater (Ayers and Westcot, 1994). The source of irrigation water can be impaired by the presence of pathogens resulting in potentially adverse effects for farm workers and consumers of fresh produce. In addition, the occurrence of trace organic chemicals (e.g., pesticides, antibiotics) could be an additional concern if they have the potential to accumulate in produce. However, these water quality issues are not further specified in the FAO guidelines.

To date, no databases on microbial quality of irrigation water have been compiled. The degree of microbial contamination of natural sources of water (like lake or river water, shallow groundwater or rainwater) and sources partially impaired by wastewater discharges can vary significantly and is dependent upon several factors. There is a substantial database available on microbial water quality parameters of surface waters based on indicator organisms or human-specific pathogens including bacteria, viruses and protozoa. However, this information is of limited value for estimating risk for produce contamination associated with agriculture due to deficiencies in location, timing and/or frequency of sampling, and incomplete coverage of the entire transmission and exposure path.

In 2017, the EU Commission has proposed a *'Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene'* to address the public health risks posed by pathogens in food of non-animal origin, addressing in particular the risk factors and the mitigation options including possible microbiological criteria. This guidance document suggests a risk assessment considering the source and the intended use of agricultural water defining the suitability for agricultural purposes, the recommended microbiological threshold values of a fecal indicator (i.e. *Escherichia coli*), and the frequency of monitoring. It also recommends that microbial analyses of the potential water sources should be performed to determine the suitability of the water source for its use as agricultural water.

Extent of unplanned reuse in select EU river basins

Since many surface waters in the majority of EU regions that practice agriculture irrigation are also receiving discharge from municipal wastewater effluents, the quality of these streams can be impaired due to the introduction of pathogens, organic chemicals or elevated levels of nutrients and other salts. While previous studies have quantified the degree of wastewater discharge to a stream mainly based on flow data, assessing the degree of impact on water quality is more difficult since site-specific conditions (i.e., local degree of mixing and dilution; upstream load prior to discharge; in-stream attenuation processes like biodegradation or photolysis; etc.) need to be considered. In addition, specific studies that have investigated impacts on river water quality are available, but frequently these are limited to certain river stretches, specific water quality parameters, or did not quantify the degree of upstream wastewater discharge.

Thus, for the purpose of providing a relative risk assessment of unplanned water reuse using impaired surface water for agriculture irrigation, the following assumptions were made for a risk exemplar. A hypothetical pristine stream is impacted to different degrees by discharge of a secondary treated wastewater effluent (i.e., representing impacts of 5, 10, 20 and 50% discharge of wastewater). It is assumed that the secondary effluent meets the requirements of the EU Urban Waste Water Treatment (UWWT) Directive. It is further assumed that pathogens being discharged to the river will survive for a few days, potentially a few weeks. Where the degree of discharge of non-disinfected wastewater to a receiving stream is exceeding a certain value and this impaired source water is used downstream for agriculture irrigation, it is likely that elevated levels of pathogens might be present in the irrigation water.

The results of this risk exemplar suggest that even high dilution ratios (10% and less wastewater effluents in the receiving streams) will result in a downstream water quality that will likely exceed the fecal indicator values of *E. coli* as specified in the EU Commission guidance document for good produce hygiene as well as the values proposed in the JRC report on minimum quality requirements for irrigation of crops eaten raw (Class A and Class B). While the survival of these pathogens will depend on local environmental conditions (i.e., biomass present; in-stream photolysis, etc.), it is very likely that any surface water that is being abstracted within a few hours to days downstream of this discharge point will be compromised and exceed background levels of pathogens my several orders of magnitude.

To estimate the degree of unplanned agricultural water reuse in EU river basins, various case studies were selected in three EU Member States (namely Spain, Italy and France) representing areas with a high degree of agriculture irrigation using surface water sources. The dilution ratio was used to assess the degree of *de facto* water reuse, representing the ratio between treated wastewater effluent flows to stream flow for a particular location or flow measurement section.

Within the Ebro river basin in northeastern Spain, the results obtained from this effort suggest that the degree of impact from wastewater discharge to the Segre river basin can vary between 3 and 11% depending on flow conditions in the stream. In particular, river stretches of the Segre river from Balaguer to Lleida were characterized by 5 and 11% wastewater impact and are located in areas that widely use surface water for irrigation in agriculture. For the Llobregat river district, the degree of impact from wastewater effluents was estimated to vary between 8 and 82% on average, in particular in river stretches that are dominated by agricultural irrigation. In Italy, watersheds in the Lombardy region, which has major agricultural production areas, were selected and both the Adda and the Oglio rivers exhibited degrees of impact varying between 7-27% and 4-15%, respectively. During times of high flow in these streams, the degree of impact doesn't seem to be significant, but during times of low flow conditions which usually occur during periods of high irrigation demand, the degree of impact can vary between 14 and 68%. In France, river basins of the Loir and Montpellier rivers were selected. The degree of impact from wastewater effluents along the Loir river only varied between 0.3 and 2.6% on average, which is not of concern. However, during low flow conditions the degree of impact from wastewater effluents can increase up to 24%. For the Montpellier river basin, the degree of impact varied between 1.5 and 51% on average.

The case studies presented in this study clearly illustrated that surface water qualities in different regions of Europe where agricultural irrigation is practiced are impacted by wastewater effluents to a significant degree. These irrigation water qualities in particular during times of low-flow conditions are - very likely - currently not meeting the EU Commission guidance document for good produce hygiene, the values proposed in the JRC minimum quality requirements report for irrigation of crops eaten raw, or existing national water reuse guidelines of individual Member States. These findings should be confirmed by targeted water quality monitoring campaigns in the specific watersheds.

Characterization of EU surface water qualities receiving wastewater effluents currently used for artificial groundwater recharge

Surface water that receives upstream discharge from wastewater effluents might also be used for artificial groundwater recharge. The majority of MAR applications are based on induced bank filtration and surface spreading methods and are utilizing surface water from lakes or rivers. Many MAR sites are located within major European river basins like Danube, Rhine, Elbe, Inn, Guadalquivir, Llobregat, Seine or Garonne.

Similar to agriculture irrigation, the degree of impact on groundwater quality will also depend on attenuation processes for microbial and chemical contaminants in the river prior to use (i.e., local degree of mixing and dilution; upstream load prior to discharge; in-stream attenuation processes like biodegradation or photolysis; etc.). In addition, attenuation processes in the subsurface (i.e., biodegradation, adsorption, filtration) as well as blending with native groundwater need to be considered to properly assess any remaining risk to public health. Due to the fact that factors impacting the final groundwater quality are highly site-specific, this study attempted to identify sites in river basins that practice managed aquifer recharge. To estimate the degree of unplanned water reuse via groundwater recharge in EU river basins, three case studies were selected in two EU Member States (namely Germany and France). For the city of Berlin, raw water supplies from surface water can contain between 17 and 35% wastewater effluents. Up to now, no adverse risks from human pathogens have been associated with the current practice of *de facto* potable water reuse in Berlin. However, especially persistent and polar chemicals have been detected in extracted groundwater at elevated concentrations. These findings suggest that surface water qualities in different regions of Europe where artificial groundwater recharge is practiced can be impacted by wastewater effluents to a significant degree.

Potential benefits and drawbacks to the environment by engaging more broadly in planned non-potable water reuse

Engaging more broadly in planned non-potable water reuse requires that the reclaimed water quality used for various non-potable reuse practices is safe for the users and not compromising local groundwater, surface water or soil qualities. Multiple planned reuse applications in Europe and around the world have demonstrated that the use of reclaimed water for such an application does represent a safe practice. It should be noted that re-directing flows towards reuse instead of receiving streams might also negatively affect ecological conditions of the stream in particular during low-flow conditions where wastewater effluents have maintained a steady stream flow in the past. Thus, not the entire volume of wastewater effluents in areas of high reuse demand might be available where environmental base flows also need to be maintained. Many non-potable reuse applications (e.g., agricultural irrigation; cooling water) exhibit high seasonal dependencies which requires either storage options or alternative reuse practices during off-season. While storing reclaimed water or alternative reuse options might not be feasible in every locations, reclaimed water is commonly discharged to streams during off-season periods, which might result in highly dynamic flow and water quality variations in the receiving water body.

The volume of irrigation water from surface and groundwater is only measured where water is supplied by public networks or in well managed irrigation districts. However, a substantial portion of irrigation water in Southern Europe is abstracted illegally for example from groundwater wells on site, unless metering and reporting are enforced by law (Weirdt et al., 2008). Addressing this short-sighted and not sustainable abstraction practice, likely motivated by economic considerations, is important where planned water reuse programs are being proposed. Multiple studies have been performed in the past to demonstrate long-term environmental and economic benefits of planned water reuse.

Planned water reuse does challenge the traditional framework of water allocation, funding structures, deriving water quality standards, regulatory compliance, and institutional mandates (FAO, 2010). These issues need to be addressed and properly managed. The concern regarding unacceptable risks to public health from an increasing use of reclaimed water is a serious obstacle to a wider acceptance of this practice. However, unplanned water reuse is also associated with a risk that might not be properly managed in all cases, as illustrated in this study for case studies representing examples for agriculture irrigation and also managed aquifer recharge. This consequence of assuming “pristine” surface water conditions for current irrigation practices should be considered in overall water resource planning. Thus, well planned and executed water reuse programs and applying consistent risk-based standards for agricultural irrigation and groundwater recharge have the potential to reduce the overall risk to workers, the public and the environment while offering an alternative and sustainable water supply.

This Report

The Chair of Urban Water Systems Engineering at the Technical University of Munich (TUM) has been contracted by the European Commission to undertake a study on the characterization of unplanned water reuse for agricultural irrigation and groundwater recharge in the European Union in support of the current development of EU-level instruments on water reuse (specific contract No. 070201/2017/758172/SER/EMV.C.1). This report presents the results of this effort and is intended to support the overall assessment of the policy options on minimum quality requirements for water reuse identified by the European Commission.

The content of this report could be used as one source of information by the European Commission to assess policy options regarding requirements for water reuse via agricultural irrigation and groundwater recharge. However, additional work is needed in order to update the assessment of unplanned water reuse within selected river basins of the EU since data availability of the degree of impact and the scope of this study has been limited.

The views set out and analysis presented are those of the authors and do not necessarily represent the views of the Commission in general or of DG Environment.

Objectives of this Study

On December 2, 2015, the European Commission presented the concept of the circular economy, which included a number of actions to further promote water reuse across the EU (EU Commission, 2015). One of these actions is to table a legislative proposal of minimum quality requirements for water reuse for agricultural irrigation and groundwater recharge in 2017. The development of this proposal has been subject to an impact assessment to evaluate the most suitable EU-level instruments to foster water reuse, while ensuring the health and environmental safety of water reuse practices and the free trade of food products.

As part of this impact assessment, the European Commission is looking for additional scientific evidence regarding:

- the quality of water sources presently used in agricultural irrigation in the EU, including direct and indirect reuse of treated wastewater;
- the extent of unplanned reuse in EU river basins, and
- the impact of the development of planned (and direct) water reuse.

In order to address these issues, the objectives of this study are twofold. First, the study will benchmark current qualities of water sources used in agricultural irrigation in the EU today, including direct and indirect reuse of treated wastewater. In addition, the extent of unplanned reuse in select EU river basins for agricultural irrigation and groundwater recharge and the impact of the development of planned (and direct) water reuse will be assessed.

Benchmarking Irrigation Water Qualities

Initially, current requirements in EU member states for irrigation water qualities using surface water or groundwater were compiled, also considering recommendations by international agencies (e.g., FAO, WHO) regarding microbiological and chemical parameters. Surface water quality requirements used for agricultural irrigation were benchmarked against the quality of a.) treated urban effluents discharged to the environment, b.) treated urban effluents reused for irrigation purposes as currently regulated by individual member states, and c.) treated urban effluents (reclaimed water) reused for irrigation purposes as proposed in the technical report by the Joint Research Council (JRC, 2017). This comparison did provide the foundation for a relative risk assessment considering these different qualities of sources for agricultural irrigation.

Estimating the Degree of Impact from Unplanned Water Reuse

For selected case studies of representative river basins in selected EU Member States, irrigation and groundwater recharge practices were evaluated regarding the quantitative extent of unplanned reuse in select EU river basins. This investigation provided an assessment of the impact on water resources today and the potential development of planned water reuse. Additionally, building upon these case studies, estimates regarding the degree of impact from wastewater discharge or unplanned water reuse in selected EU river basins were derived for representative flow conditions and irrigation seasons.

These assessments assisted in illustrating potential benefits and drawbacks to the environment as the EU is more broadly engaging in non-potable water reuse to augment future water supplies with an unconventional water resource in comparison to current irrigation practices.

1. Introduction

1.1 Motivation for the study

The main intent of developing regulations and guidance for water reuse applications is to properly manage any non-acceptable risk to human and environmental health associated with the potential presence of microbiological and chemical contaminants (NRC, 2012). These regulatory initiatives might involve advanced management options and integration of technical barriers in existing wastewater treatment facilities to reduce any remaining risk to acceptable levels before reclaimed water is being used for a particular water reuse application. This remaining risk level associated with reclaimed water use should be equivalent to a water quality that is similar or better than the use of conventional freshwater supplies including surface water or groundwater (Asano et al., 2007).

Where municipal wastewater effluents are not being reused but discharged to the aquatic environment the water reenters the hydrological cycle. As a consequence, in an effluent-impacted surface water the effluent from a municipal wastewater treatment plant, except where discharge occurs in coastal water bodies, will be available for reuse by downstream users. This unintentional or *de facto* water reuse scenario occurs quite commonly but is frequently not acknowledged (Figure 1.1). Conditions of unplanned reuse are usually of no concern where pristine surface provides a high degree of dilution. However, where wastewater effluents account for a substantial fraction of a river the quality of the source water might adversely impact non-potable and potable use options, aquatic life, or local groundwater qualities (NRC, 2012; Ebele et al., 2017; Thebo et al., 2017). In regions where freshwater supplies are already scarce or might become more stressed in the future due to climate change impacts, the degree of effluent discharge to a receiving stream can become even more relevant.

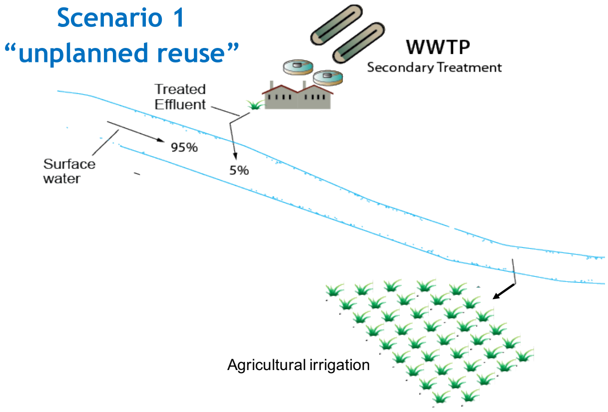

Figure 1.1 Illustration of an unplanned or *de facto* water reuse scenario for agricultural irrigation using surface water that receives discharge from an upstream wastewater treatment plant effluent

Multiple studies in the recent past have attempted to quantify the degree of wastewater contained in receiving streams using various methodologies to assess this impact. An evaluation of the spatial and temporal variations of *de facto* potable reuse across the USA has been published by Rice and Westerhoff (2015). The study covered 2,056 surface water intakes operated by 1,210 drinking water facilities, each serving more than 10,000 people, representing approximately 82% of the nation's population. This study revealed a high frequency of *de facto* reuse with 50% of the drinking water facilities being potentially impacted by upstream municipal wastewater effluent discharges. Abegglen and Siegrist (2012) quantified the degree of wastewater impact on streams in Switzerland (Figure 1.2). These findings suggest that the densely populated area of northern Switzerland is characterized by many streams that contain more than 20% wastewater effluent. A similar study for the River Ouse in the Cambridge area (United Kingdom) by Johnson and Williams has resulted in a hydrological model that estimates the fraction of wastewater effluent in different surface water bodies under base-flow conditions (NRC, 2012). Findings of this study are illustrated in Figure 1.3 and suggest that many river stretches and tributaries of the River Ouse are characterized by more than 25% wastewater effluent while this watershed is also being used for public drinking water supply.

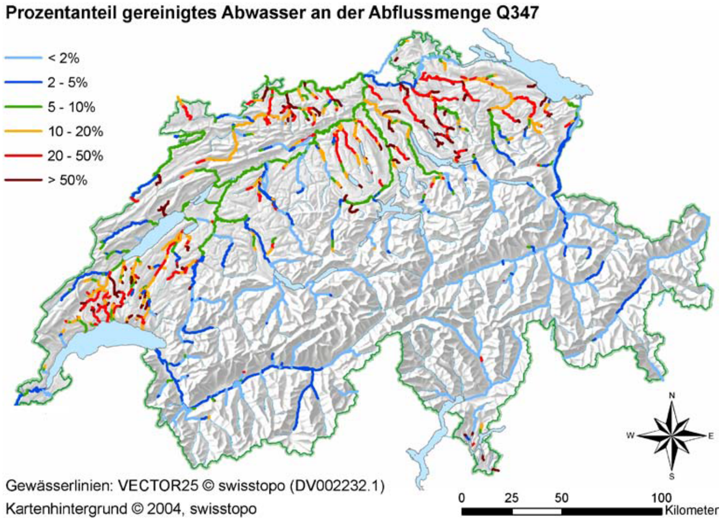

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Figure 1.2 Degree of wastewater content in Swiss streams (based on dry weather flow, Q347) (Abegglen and Siegrist, 2012)

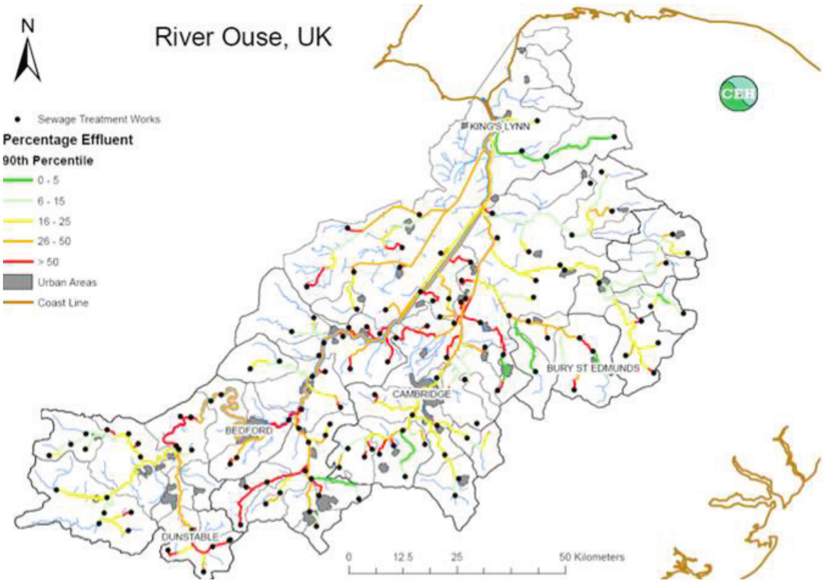


Figure 1.3 Degree of wastewater content in the River Ouse, UK (based on dry weather flow) (NRC, 2012)

Despite this widespread practice of unintentional or *de facto* reuse, many downstream users and regulatory bodies have not made any explicit notion of these conditions and common water resource management refers to 'surface' or 'river' water assuming an appropriate quality for various non-potable and potable uses. Thus, assessments are needed to identify situations where acceptable risk levels using effluent-impacted surface water are exceeded or the use of additional treatment barriers or alternative supplies including use of reclaimed water meeting approved standards might be warranted in order to establish safer practices.

The number of studies in the peer-reviewed literature that have attempted to quantify the degree of *de facto* reuse for agricultural irrigation with sound data is scarce. A recent study by Thebo et al. (2017) provided a global, spatially-explicit assessment of irrigated croplands influenced by impaired surface water with a focus on developing countries. While the study reported a much higher percentage of unplanned water reuse for agricultural irrigation compared to previous, highly uncertain estimates, the assumptions made and the national and large-regional scale of this study are not directly applicable to the conditions in Europe.

1.2 Agricultural irrigation practices in Europe

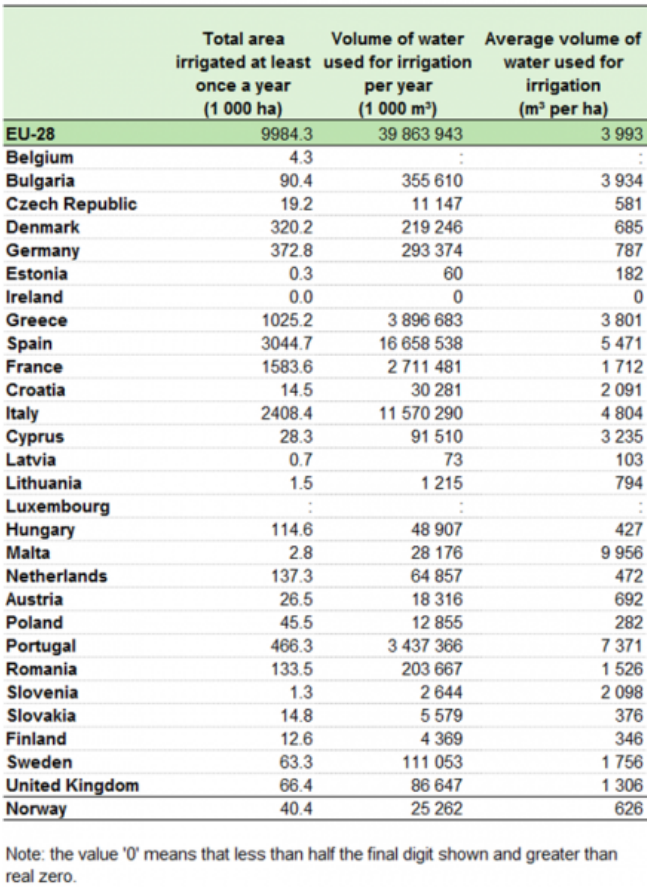
Of all human activities utilizing water in Europe, agriculture irrigation is the most important category accounting for 36% of the total annual water use of 182 billion m^3 (182 km^3) per year of total freshwater abstracted (excluding Turkey), followed by public water supply (32%) (European Environment Agency, 2012; JRC 2016). Given that precipitation across the region is subject to high annual and seasonal variability (Correia et al., 2009), irrigation is an essential component of production for many farmers as it supports crop diversification, assures yield and quality of crops, and helps to stabilize food supplies (Hanjra and Qureshi, 2010). In 2013, the total irrigable area in the EU was 18.7 million ha with 10.2 million ha actually irrigated (EuroStat, 2016).

The abstraction of water for irrigation varies by Member State and according to location and season, water use for agriculture can increase to 60% during the summer. Consumption is markedly higher in southern and southeastern Europe than elsewhere across the continent (Table 1.1), accounting for more than 60% of total freshwater abstraction, although this figure can be as high as 80% in certain river basin districts (e.g., Spain 64%, Greece 88%, Portugal 80%) (Wriedt et al., 2008).

In large parts of southern France, Spain, Portugal, Italy, Greece and Cyprus, irrigation enables crop production where water would otherwise be the limiting factor (European Environment Agency, 2014). In more humid and temperate regions of central and northern Europe, irrigation helps in balancing the seasonal variability in water availability to better match the agricultural needs. In central and northern European countries agricultural water abstractions account for less than 1% of total abstractions (e.g., Belgium 0.1%, Germany 0.5%, The Netherlands 0.8%) (Wriedt et al., 2008). In these regions, temporary irrigation is generally used to improve production in dry summers, especially when the dry period occurs at a sensitive crop growth stage. By the total volume of water used for irrigation per year, Spain, Italy, Greece, Portugal and France are the biggest users followed by Bulgaria, Germany, Denmark and Romania.

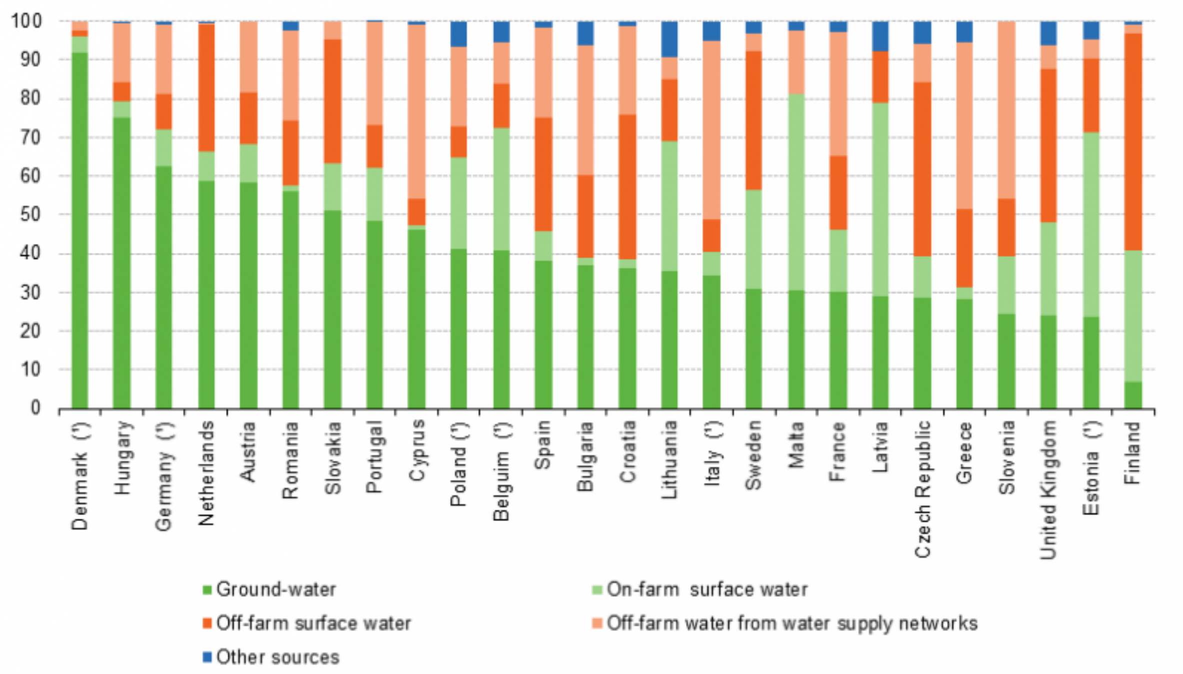
The origin of water resources used for irrigation in European countries has been determined in a 2010 survey on agricultural production methods (Eurostat, 2016). These findings suggest that more than half of the water used in agriculture is from groundwater abstraction in Austria, Denmark, Hungary, Germany, the Netherlands, and Slovakia (Figure 1.4). For over 40% of farms in Italy, Greece, Slovenia and Cyprus, irrigation water comes from water supply sources outside farm boundaries (off-farm water supply), which are usually fed by surface water sources like rivers or lakes, surface run-off, groundwater and reclaimed water. However, at a local scale these percentages can differ significantly.

Table 1.1 Volume of water used for irrigation, 2010 (Source: Eurostat, 2016)



	Total area irrigated at least once a year (1 000 ha)	Volume of water used for irrigation per year (1 000 m³)	Average volume of water used for irrigation (m³ per ha)
EU-28	9984.3	39 863 943	3 993
Belgium	4.3	:	:
Bulgaria	90.4	355 610	3 934
Czech Republic	19.2	11 147	581
Denmark	320.2	219 246	685
Germany	372.8	293 374	787
Estonia	0.3	60	182
Ireland	0.0	0	0
Greece	1025.2	3 896 683	3 801
Spain	3044.7	16 658 538	5 471
France	1583.6	2 711 481	1 712
Croatia	14.5	30 281	2 091
Italy	2408.4	11 570 290	4 804
Cyprus	28.3	91 510	3 235
Latvia	0.7	73	103
Lithuania	1.5	1 215	794
Luxembourg	:	:	:
Hungary	114.6	48 907	427
Malta	2.8	28 176	9 956
Netherlands	137.3	64 857	472
Austria	26.5	18 316	692
Poland	45.5	12 855	282
Portugal	466.3	3 437 366	7 371
Romania	133.5	203 667	1 526
Slovenia	1.3	2 644	2 098
Slovakia	14.8	5 579	376
Finland	12.6	4 369	346
Sweden	63.3	111 053	1 756
United Kingdom	66.4	86 647	1 306
Norway	40.4	25 262	626

Note: the value '0' means that less than half the final digit shown and greater than real zero.



Note: Ireland:data considered not existing or non-significant; Luxembourg: data not available.
(¹) Only main water source for irrigation used on farms was reported.

Figure 1.4 Water source used for irrigation in 2010 (EuroStat, 2016)

1.3 Use of reclaimed water for agricultural irrigation practices in Europe

As an alternative freshwater resource, reclaimed water can be used for agricultural irrigation amounting to 32% as the largest application for water reuse globally (Global Water Intelligence 2015). The use of reclaimed water and desalination as alternative supplies for various applications including agricultural irrigation (Figure 1.5) are also becoming more spread in Europe (OECD, 2007). Unfortunately, no exact data are available on the current volume of treated wastewater being reused in the EU. A previous study estimated the current volume of reclaimed water in the EU at 1,100 million m^3/year or 0.4% of the total annual EU freshwater abstractions (BIO, 2015). In 2006, Spain and Italy jointly accounted for about 60% of the total EU reclaimed water volume (Table 1.2).

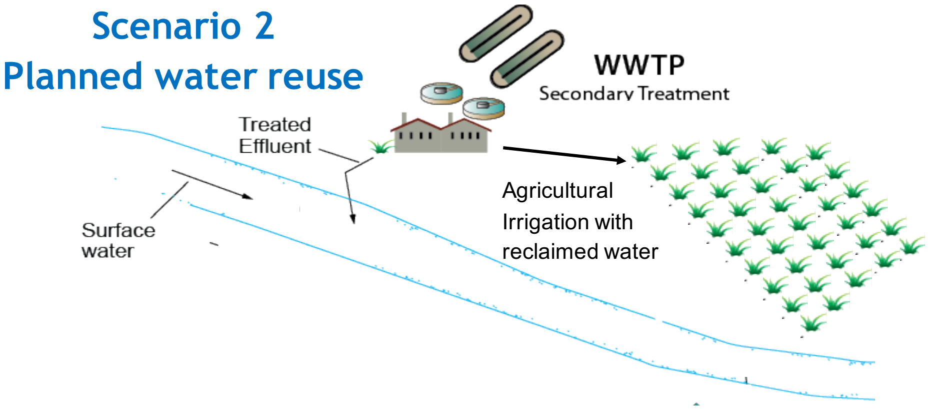


Figure 1.5 Illustration of planned water reuse for agricultural irrigation using reclaimed water

Table 1.2 Total volume of reclaimed water used in selected member states within Europe in 2006 (TYPSA, 2013)

Country	Volume of reclaimed water used (million m^3/year)
European Union	964
France	N/A
Germany	42
Italy	233
Spain	347

Some EU member states are already using reclaimed water for agricultural irrigation at a large scale. Between 2004 and 2013 in Cyprus for example, 89% of the treated wastewater was reused and in 2013 with 75% a significant part of this reclaimed water was used for agricultural irrigation (Amec Foster Wheeler, 2016).

1.4 Groundwater recharge practices in Europe

Surface water and less commonly reclaimed water is also being used in managed aquifer recharge (MAR) operations via induced bank filtration, surface spreading, well injection and point or line recharge to intentionally augment local groundwater supplies (Regnery et al., 2013). Figure 1.6 illustrates the location of current MAR facilities registered in the European MAR data base (https://ggis.un-igrac.org/). In 2013, 224 active MAR sites in 23 European countries were registered (Sprenger et al., 2017). The majority (about 190) of them are designed to augment drinking water supplies using surface water sources.

The contribution of MAR to drinking water supply in different European countries ranges from significantly less than 10% in many countries including France (3%) and Italy (6 %) to more than 50% in Hungary and Slovakia (Sprenger et al., 2017). Also many central and northern European countries like Germany (14%), The Netherlands (24%), Finland (16%), and

Switzerland (10%) rely on MAR as an important source for drinking water supply. In some locations, the contribution of MAR to potable supplies can even be higher. The city of Berlin, Germany, for example, produces about 70% of its drinking water from induced bank filtration and surface spreading using local streams and lakes (Heberer et al., 2004).

The majority of MAR applications are based on induced bank filtration and surface spreading methods and are utilizing surface water from lakes or rivers (marked as light and dark green circles in Figure 1.6). Many MAR sites are located within major European river basins like Danube, Rhine, Elbe, Inn, Guadalquivir, Llobregat, Seine or Garonne. In Europe, only very few examples exist, where reclaimed water is used to augment drinking water supply (brown circles). In Torreele, Belgium, reclaimed water after advanced treatment (i.e., ultrafiltration followed by reverse osmosis) is infiltrated in a dune area to augment local drinking water supplies. While there is no legislation in Belgium on water reuse for aquifer recharge, specific standards were set including technological requirements and extensive monitoring (van Houtte et al., 2012). The village of El Port de la Selva, Spain, has recently established a project that is infiltrating a portion of the community's treated wastewater effluent in ponds upstream of drinking water wells to augment potable supplies (Zietzschmann et al., 2017). In addition, recharge of reclaimed water during MAR is applied using non-potable aquifers (e.g., for agricultural use) and as seawater intrusion barriers in coastal regions.

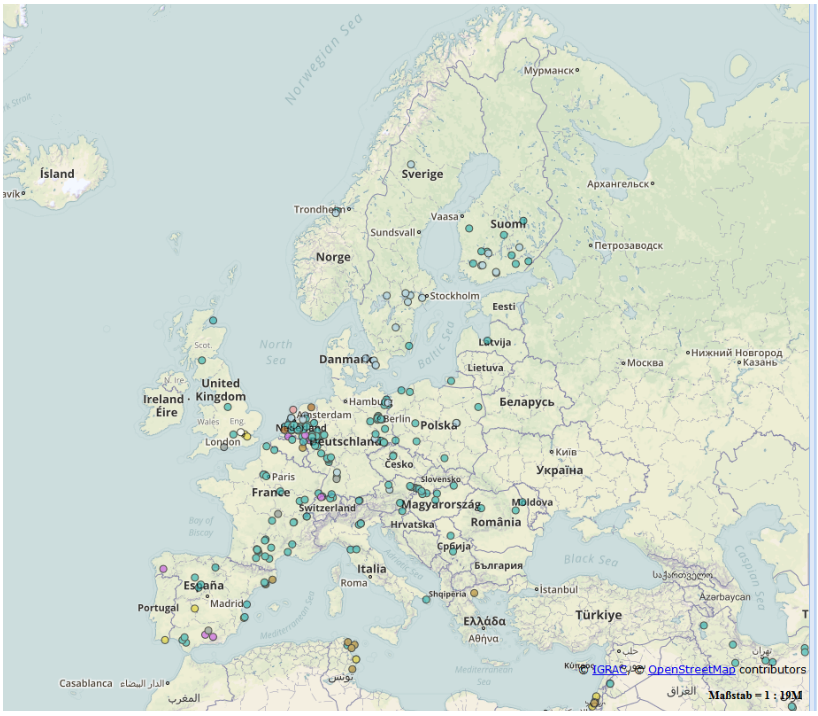


Figure 1.6 Managed aquifer recharge (MAR) sites in Europe (Source: https://ggis.un-igrac.org)

In order to avoid any deterioration of groundwater quality while using reclaimed water, stringent treatment requirements prior to recharge need to be fulfilled. Water quality requirements for MAR operations usually consider requirements of the EU regulations including the Groundwater Directive and Drinking Water Directive. However, where *de facto* reuse in surface water sources prior to recharge is occurring no specific additional regulatory requirements exist in any member state that should be met prior to groundwater recharge. Instead, drinking water providers might implement additional treatment barriers in their facilities to address higher concentrations of contaminants and to assure a safe final product water quality (Regnery et al., 2013; Mujeriego et al., 2017).

2. Methodology

This study attempted to quantify the degree of unplanned water reuse in various river basin districts throughout Europe. Unfortunately, consistent and readily available data of surface water discharge along selected stretches of individual rivers; location, design capacity and actual discharge volume of municipal wastewater treatment plants; or water quality data of receiving stream quality directly up- and downstream of wastewater effluent discharges does not exist in Europe. Some national and international databases are providing consolidated data on stream flow or locations and flow information of wastewater treatment plants at the Member State or EU level, but these data sources should be validated and complemented by local agencies of individual Member States. Thus, in this study we have chosen different strategies to compile relevant information to assess the degree of unplanned water reuse in selected river basin districts considering the availability of data for specific Member States.

2.1 Selection of study sites

The sites selected for this study represent river basin districts with significant irrigation activities using surface water and include locations where artificial groundwater recharge with surface water is being practiced. The sites are located in river basin districts within different climatic regions throughout Europe. These study sites are located in the following EU member states: Spain, Italy, France and Germany.

In order to identify regions with a high degree of agricultural irrigation within these countries, the online FAO 'Global Map of Irrigation Areas'[1] was used, which provides a link to an interactive Google Earth map of Europe illustrating irrigation activities (FAO, 2017). Areas with more than 35% irrigation were identified in Spain, Italy and France (Figure 2.1) as they are also characterized by major rivers and streams. Locations of MAR facilities in Europe and in particular in France and Germany were derived from the European MAR database (https://ggis.un-igrac.org/).

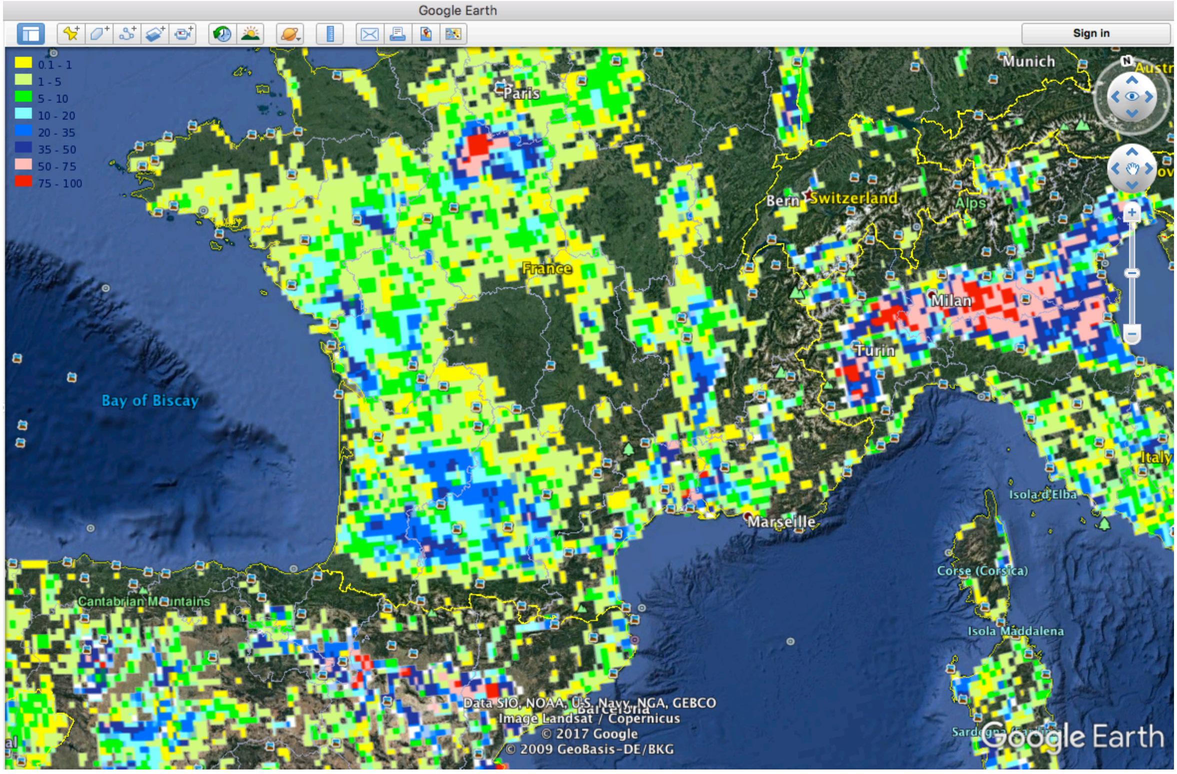


Figure 2.1 Irrigation areas in southern Europe extracted from the FAO Global Map of Irrigation Areas (FAO, 2017)

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[1] http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm

2.2 Determining dilution ratios

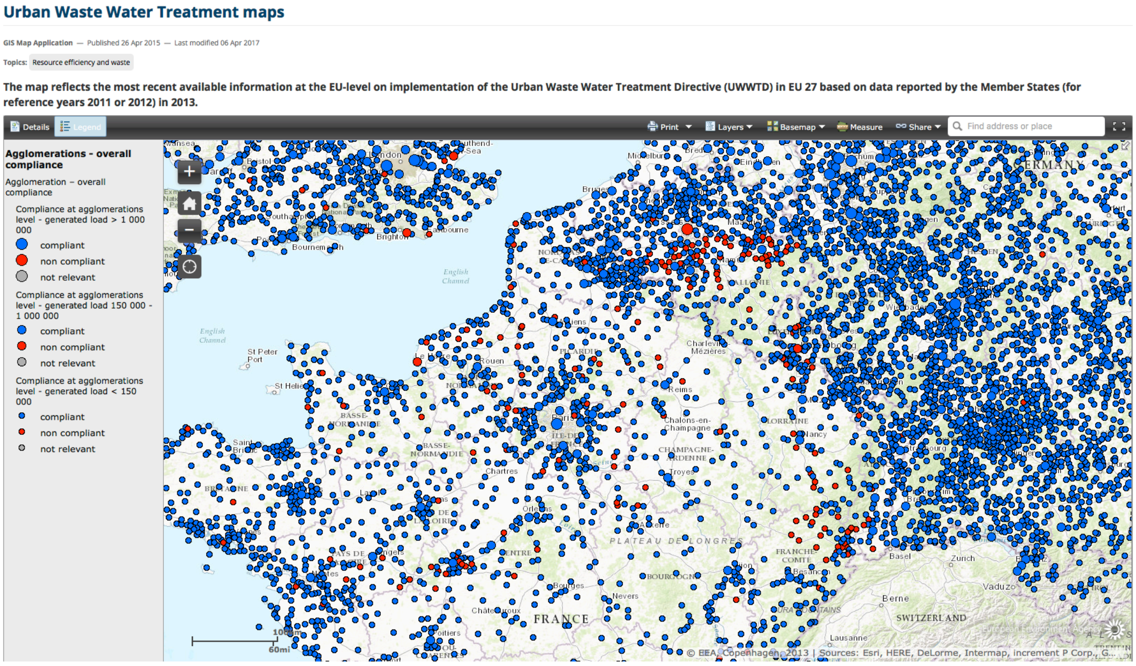
The basic numerical indicator used in this study to assess the degree of unplanned or *de facto* reuse has been the 'dilution ratio', representing the ratio between the flow of treated wastewater effluent to stream flow for a particular location or section assuming similar discharge volumes (equation 1).

$$dilution\ ratio = \frac{Q\ WWTP\_effluent}{Q\ River} \qquad (1)$$

The high variability of river hydraulics in many watersheds required a series of approximations and assumptions while determining the dilution ratio for a given river stretch or watershed. The river flow data were abstracted from national online hydrological databases (as specified in Table 2.1 and later sections) and considered low and high flow conditions (corresponding to dry and wet weather flows). These flows were determined for existing gauging stations as provided by the specific national hydrological network considering minimum, maximum and average annual or monthly flow data. For each river, a linear river flow progression from its headwaters to major tributaries and to its final discharge point into the ocean was assumed.

In this study, wastewater effluent discharges to the river only considered discharge from municipal wastewater treatment facilities. The flow balance did not consider contributions from industrial wastewater treatment facilities directly discharging to the river, agricultural return flows, urban run-off, combined sewer overflows, or drainage of native groundwater to the stream. The volume of treated wastewater effluents discharged to the river was calculated by adding up effluent flows of the WWTPs upstream of a reference point for which we usually considered specific gauging stations along the river (Table 2.1).

The location and average annual load and design capacity data of urban wastewater treatment plants (UWWTP) in Europe (reported in population equivalent, PE), discharging their effluent to specified river sections, was extracted from the Urban Waste Water Treatment Directive data base of the European Environment Agency maintaining an interactive map[2] (Figure 2.2).



Urban Waste Water Treatment maps

GIS Map Application — Published 26 Apr 2015 — Last modified 06 Apr 2017

Topics: Resource efficiency and waste

The map reflects the most recent available information at the EU-level on implementation of the Urban Waste Water Treatment Directive (UWWTD) in EU 27 based on data reported by the Member States (for reference years 2011 or 2012) in 2013.

Figure 2.2 Examples of locations of Urban Waste Water Treatment Facilities in Europe (EEA, 2017)

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[2] http://www.eea.europa.eu/themes/water/water-pollution/uwwtd/interactive-maps/urban-waste-water-treatment-maps-1

Table 2.1 Average river flow data and average WWTP flow data for different case studies of interest

Country	River Basin (RBD)	Gauging station	Q_river [m^3/day]			Q_WWTPe [m^3/day]	Sources	
			min	max	Average	Average	Q_river	Q_WWTPe
Spain	Llobregat	Navás	114048	185328	142560	10741	Agència Catalana de l'Aigua (ACA)	Agència Catalana de l'Aigua (ACA)
		El Pont de Vilomara	155520	252720	194400	23271		
		Cardener	94003	152755	117504	28772		
		Martorell	274752	343440	343447	79391		
		Anoia	28339	38966	36014	29622		
		San Joan Despí	297216	482976	371520	165626		
		Mouth of Llobregat	304128	494208	380160	214696		
	Ebro	Segre-Balaquer	285120	4769280	630720	28443	Confederación Hidrográfica del Ebro	Agència Catalana de l'Aigua (ACA) & EU EPA UWWTP Map
		Segre-Lleida	319680	9936000	1149120	123096		
		Segre -Serós	501120	22248000	4527360	130637		
		Cinca Fraga	1891296	35930304	5223744	55720		
		Gallego	282528	18036864	1759968	25993		
		Arba	141696	7826112	629856	16697		
Italy	Po	Adda-Pizzighettone	4446144	87075648	15077479	820080	Agenzia Regionale per la Protezione dell'Ambiente (ARPA Lombardia)	Agenzia Regionale per la Protezione dell'Ambiente (ARPA Lombardia) - S.I.R.e.Acque
		Adda-Serio-Montodine	220927	8668059	747652	297572		
		Adda-Rivolta d'Adda	1756636	35726925	6748201	482794		
		Adda-S.Maria Lavello	3692009	25307054	11676930	169581		
		Adda-Gera Lario Fuentes	1495916	25791346	7097620	98086		
		Oglio-Marcaria	526383	13630536	6765149	356365		
		Chiese-Asola - v.Carducci	234509	12358215	863655	33175		
		Mella-Manerbio	168936	7618800	674774	103606		
		Oglio-Soncino	410102	9796589	1578570	145639		
		Oglio-Capriolo	192388	7142746	1455122	75686		

Country	River Basin (RBD)	Gauging station	Q_river [m^3/day]			Q_WWTPe [m^3/day]	Sources	
			min	max	Average	Average	Q_river	Q_WWTPe
France	Le Vistre	Le Cailar	317088	2574720	108864	42615	Ministère de la Transition écologique et solidaire-HYDRO	Ministère de la Transition écologique et solidaire-Portail d'information sur l'assainissement communal
		Bernis	238464	1745280	49248	37098		
	La Mosson	Saint-Jean-de-Védas (34)	63590	389664	3542	8790		
	Le Lez	Montpellier (34)	149472	2306880	32314	2191		
		Lattes (34)	186624	2738880	65664	94725		
	Loir	Trizay-lès-Bonneval (28)	83376	1650240	6048	1438		
		Saint-Maur-sur-le-Loir (28)	192672	2116800	22464	4112		
		Conie-Molitard (28)	123552	224640	44064	3194		
		Saint-Hilaire-sur-Yerre (28)	87264	691200	17280	698		
		Romilly-sur-Aigre (28)	108000	198720	31104	341		

This database reflects the most recent available information at the EU-level on implementation of the Urban Waste Water Treatment Directive (UWWTD) in 27 EU Member States based on data reported by each state (for reference years 2011 or 2012) (EEA, 2017). However, information regarding the location and load of WWTPs in Italy is not included in this database. Thus, for Italy national databases were consulted.

The load data commonly reported in PE reported by EEA for facilities in Spain was converted to actual flow data (m^3/day) by assuming an average BOD_5 concentration of 290 mg/L for all UWWTPs. This conversion has been validated by flow data (in m^3/day) provided by national environmental agencies. In general, the total number of WWTP provided by national agencies was higher in comparison to the inventory of WWTPs reported in the EEA data base since only facilities of a certain size were considered in the database. For all other countries, flow data in m^3/day of WWTP discharging to rivers of interest were directly obtained from national agencies. For all wastewater treatment plants considered in case studies of this study, it was assumed that the effluent quality is in compliance with the requirement of the Urban Waste Water Treatment Directive (91/271/EEC).

For a better refinement of these overall assessments of wastewater discharges to streams, other urban discharges and agricultural run-off or return flows should be considered in future refinements of this assessment. Also, groundwater flows augmenting surface water bodies were not considered, but could have a significant impact at a local scale. Surface water extractions within a river segment for non-potable or potable purposes were assumed to be of uniform quality, although in practice water quality usually shows a spatial distribution due to incomplete mixing in the stream. Although these factors might compromise estimations of the degree of unplanned water reuse, we believe that the methodologies applied and results obtained can be considered a valid first approximation of dilution ratios and therefore an estimation of the degree of unplanned water reuse for selected stretches of river basins in Europe.

3. Benchmarking Irrigation Water Qualities

3.1 International and European recommendations regarding microbiological and chemical parameters for irrigation water qualities

Irrigated agriculture is dependent upon an adequate water supply of appropriate quality. Water quality has an immediate effect on crop yield and soil properties. According to the Food and Agriculture Organization of the United Nations (FAO), the main water quality issues of surface water or groundwater use in irrigated agriculture are associated with salinity, specific ion toxicity, excessive nutrients, and a change of the water infiltration rate (Ayers and Westcot, 1994). In order to address these issues, the FAO has proposed water quality guidelines for irrigation considering surface or groundwater as source water (Table 3.1).

Salinity issues derive from salt accumulation in the crop root zone to concentrations that result in a loss of yield. Salinity problems can be avoided by applying appreciable extra volumes of irrigation water, which results in leaching of salts preferably into underlying drainage pipes. Toxicity problems can occur if certain constituents (mainly ions) in the irrigation water or native soil are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced yields (Ayers and Westcot, 1994). Excessive nutrient concentrations may cause excessive vegetative growth, lodging, and delayed crop maturity. The two most common water quality factors which can influence the infiltration rate are the salinity of the water and its sodium content relative to the calcium and magnesium content, also referred to as sodium-adsorption ratio (SAR) (Ayers and Westcot, 1994). A high salinity water will result in increased infiltration. A low salinity water or a water with a high sodium to calcium ratio will decrease infiltration. When a soil is irrigated with water characterized by high SAR, a high sodium surface soil develops which weakens the soil structure. Subsequently, the surface soil aggregates disperse to much smaller particles which can clog soil pores.

Table 3.1 FAO Guidelines for interpretations of water quality for irrigation (Source: Ayers, Westcot, 1994)

Potential Irrigation Problem				**Units**	**Degree of Restriction on Use**		
					None	**Slight to Moderate**	**Severe**
Salinity *(affects crop water availability)*	**EC_w**			dS/m	< 0.7	0.7 – 3.0	> 3.0
	TDS			mg/L	< 450	450 – 2,000	> 2,000
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*							
SAR	= 0 – 3	**and EC_w**	=		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6		=		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12		=		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20		=		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40		=		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*							
Sodium (Na)	surface irrigation			SAR	< 3	3 – 9	> 9
	sprinkler irrigation			me/L	< 3	> 3	
Chloride (Cl)	surface irrigation			me/L	< 4	4 – 10	> 10
	sprinkler irrigation			me/L	< 3	> 3	
Boron (B)				mg/L	< 0.7	0.7 – 3.0	> 3.0
Nitrogen (NO_3 - N)				mg/L	< 5	5 – 30	> 30
Bicarbonate (HCO_3)	*(overhead sprinkling only)*			me/L	< 1.5	1.5 – 8.5	> 8.5
pH					**Normal Range 6.5 – 8.4**		

While water is an important ingredient for the production of fresh produce, the source of irrigation water can be impaired by for instance the occurrence of pathogens, resulting in potentially adverse effects for farm workers and consumers of fresh produce (Uyttendaele et al., 2015; Thebo et al., 2017). To date, no comprehensive databases on microbial quality of irrigation water have been compiled (Pachepsky et al., 2011). However, increasing evidence of contamination of produce from irrigation water justifies the need to pay more attention to the fate and transport of pathogens in irrigation waters. In addition, the occurrence of trace organic chemicals (e.g., pesticides, antibiotics) could be an additional concern if they have the potential to accumulate in produce, but these issues are not further specified in the FAO guidelines.

The degree of microbial contamination of natural sources of water (like lake or river water, shallow groundwater or rainwater) and sources partially impaired by wastewater discharges can vary significantly and is dependent upon several factors (Uyttendaele et al., 2015). There is a substantial database available on microbial water quality parameters of surface waters based on indicator organisms or human-specific pathogens including bacteria, viruses and protozoa. However, this information is of limited value for estimating risk for produce contamination due to deficiencies in location, timing and/or frequency of sampling, and incomplete consideration of all transmission and exposure paths (Pachepsky et al., 2011).

Information on the microbiological contamination of fresh produce irrigated with impaired water sources is available (Table 3.2), but these studies have mostly been conducted “after the fact” subsequent to an outbreak and monitoring usually is less frequent than for drinking water sources or recreational water bodies and does not necessarily occur during periods of peak usage (i.e., during drought conditions) (Pachepsky et al., 2011; Uyttendale et al., 2015).

Table 3.2 Foodborne outbreaks linked to use of impaired quality of irrigation water (adopted from Uyttendaele et al., 2015)

Causative agent	Year	Location	Human cases	Implicated food	Likely source of contamination
Salmonella	2006/2007	Australia	26	Papaya	Untreated river water was used for washing papayas
E. coli 0157	2006	USA	205	Prepacked spinach	River water used for irrigation
E. coli 0157	2005	Sweden	135	Iceberg lettuce	Lettuce was irrigated with water from a small stream
Salmonella	1999/2000	Brazil	26	Mango	Exposure of produce to non-disinfected water

The major drawback of these epidemiological investigations is that in many instances the true source of contamination is not certain and due to the lack of detailed data regarding the transmission investigators can only speculate with respect to the potential source (Uyttendaele et al., 2015). However, where the degree of discharge of non-disinfected wastewater or partially treated wastewater to a receiving stream is high and this impaired source water is used in close vicinity for downstream agriculture irrigation, the likelihood that elevated levels of pathogens might be present in the irrigation water is high (Thebo et al., 2017).

In general, the Urban Waste Water Treatment Directive (91/271/EEC) does not require disinfection prior to discharge to receiving streams and it is well established that municipal wastewater effluents still contain elevated levels of pathogens (Figure 3.1) (Costan-Longares et al., 2008; Levantesi et al., 2010; Eftim et al., 2017; Gerba et al., 2017).

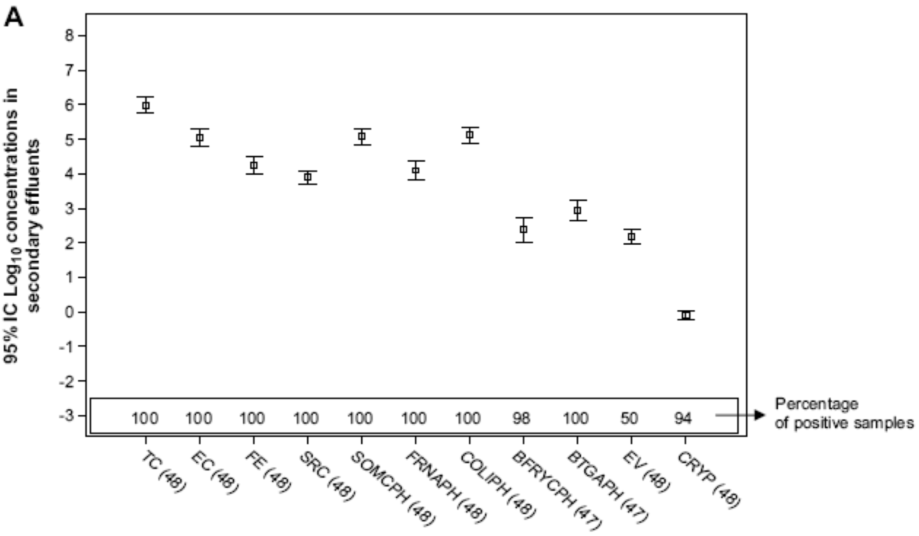


Figure 3.1 Occurrence of various pathogens in non-disinfected municipal wastewater effluents after biological nutrient removal (Source: Costan-Longares et al., 2008)

Only a few countries have specified microbial requirements for surface water used in agriculture irrigation (Table 3.3). Due to the scarcity of information of how microbiological water quality affects pathogen concentrations in produce and therefore consumer health, some national or regional irrigation water quality standards have been based on microbiological standards for recreational water. The use of recreational water standards is considered to be problematic because they were established assuming human health risk posed by full-body contact during swimming which does not properly reflect the exposure risk during consumption of produce (Pachepsky et al., 2011).

Agricultural growers in EU Member States are commonly following good agricultural practices to control water-borne hazards. The Commission has recently asked the European Food Safety Authority (EFSA) to advise on the public health risks posed by pathogens in food of non-animal origin (FNAO), addressing in particular the risk factors and the mitigation options including possible microbiological criteria (EU Commission, 2017). As a practical approach, this *'Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene'* suggests a risk assessment considering the source and the intended use of agricultural water defining the suitability for agricultural purposes, the recommended microbiological threshold values of a fecal indicator (i.e. *Escherichia coli*), and the frequency of monitoring. It also recommends that microbial analyses of the potential water sources should be performed to determine the suitability of the water source for its use as agricultural water (EU Commission, 2017). The criteria of this guidance document to assess the suitability of different water sources are summarized in Table A-9 (Appendix).

In addition to the recommendations on water control, growers are encouraged to consider the *'Guidelines for treated wastewater use for irrigation projects'* developed by the International Standard Organization (ISO) (ISO, 2015), the FAO recommendation on the quality of irrigation water (Ayers and Westcot, 1994), and the WHO guidelines on *'Safe use of wastewater and excreta in agriculture and aquaculture*' (WHO, 2006). The ISO guidelines specify chemical constituents including maximum levels of nutrients and salinity factors and also recommend regular monitoring of the concentration of microbial indicators, namely thermo-tolerant coliforms (including fecal coliforms or *Escherichia coli*) (ISO, 2015). However, the ISO guideline does not specify guideline value for this parameter or appropriate monitoring frequencies.

Compared to the FAO and ISO guidelines, the *'Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene'* of the EU Commission provides more specific guidance by suggesting threshold values for a fecal indicator including monitoring frequencies. Specific national guidelines or regulations for irrigation water quality requirements for surface or groundwater do not exist in any of the EU Member States likely due to the high monitoring effort required to generate meaningful results and challenges of enforcing compliance.

In contrast, criteria for reuse of treated wastewater effluents (reclaimed water) have been developed by multiple countries and international agencies, but these differ widely as further discussed in Section 3.3 of this report.

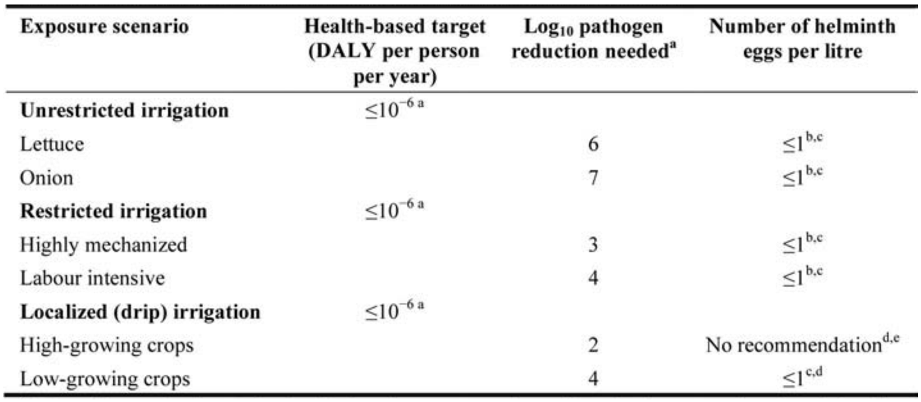
Table 3.3 Irrigation water quality guidelines and regulations (adopted from Uyttendaele et al., 2015; EU Commission, 2017)

Country/Region	Water type	Regulation/guideline	Criterion
Australia/New Zealand	Reclaimed water for irrigation of commercial crops eaten raw	Guideline	<1 *E. coli*/100 mL
Canada (Alberta)	Surface water	Guideline	1,000 total coliforms/100 mL <100 fecal coliforms/100 mL
Canada (British Columbia)	Surface water	Guideline	200 fecal coliforms/100 mL 77 *E. coli*/100 mL <20 fecal streptococci/100 mL
USA	Surface water	Guideline	<126 *E. coli*/100 mL
USA	Reclaimed water	Guideline	Fecal coliforms absent in 100 mL
California	Reclaimed water	Regulation	<2.2 total coliforms/100 mL fecal coliforms absent
Denmark	Surface water	Notification[2]	*E. coli* absent in 100 mL
Portugal	Surface water	Regulation[3]	5 or 500 total coliforms/ 100 mL
EU Commission	Untreated surface water/open water channels	Guideline[1]	<100 *E. coli*/100 mL to <10,000 E. coli/100 mL (depending on crop type)

Note: [1]see further details in Appendix Table A-9 (EU Commission, 2017).
[2]https://www.retsinformation.dk/Forms/R0710.aspx?id=160400
[3]Decree-Law No. 236/98 of August 1, 1998

The World Health Organization (WHO) has proposed a risk-based approach for using reclaimed water in agriculture irrigation and has formulated beside other requirements health-based log removal values for select pathogens (Table 3.4) (WHO, 2006).

Table 3.4 WHO Health-based targets for treated wastewater use in agriculture (Source: WHO, 2006)



Exposure scenario	Health-based target (DALY per person per year)	Log_{10} pathogen reduction needed[a]	Number of helminth eggs per litre
Unrestricted irrigation	$\leq 10^{-6\,a}$		
Lettuce		6	$\leq 1^{b,c}$
Onion		7	$\leq 1^{b,c}$
Restricted irrigation	$\leq 10^{-6\,a}$		
Highly mechanized		3	$\leq 1^{b,c}$
Labour intensive		4	$\leq 1^{b,c}$
Localized (drip) irrigation	$\leq 10^{-6\,a}$		
High-growing crops		2	No recommendation[d,e]
Low-growing crops		4	$\leq 1^{c,d}$

These health-based log removal values proposed by WHO as illustrated in Figure 3.2 can be achieved by proper preventative measures as well as treatment options or a combination of both and are specified for certain irrigation practices (Table 3.4). The WHO risk framework has also been considered by ISO and EU Member States in formulating individual national water reuse regulations (see Section 3.3).

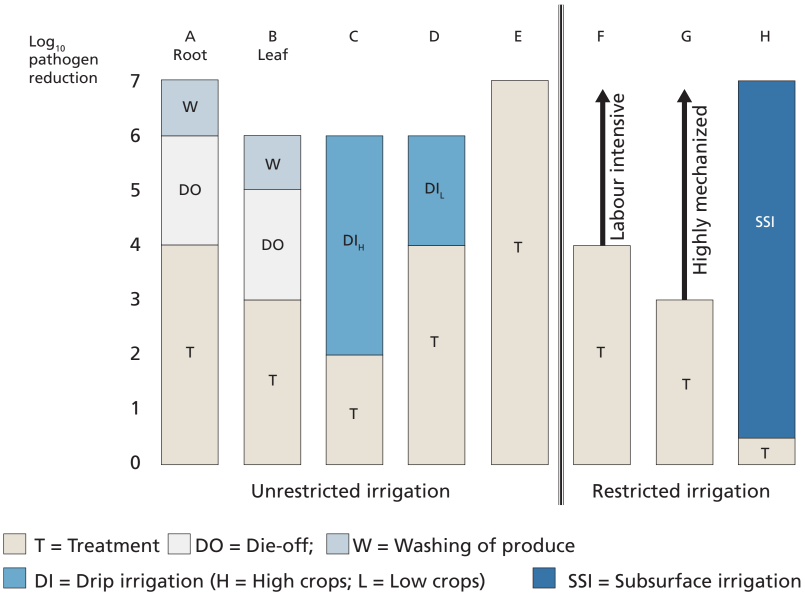


Figure 3.2 Options for the reduction of viral, bacterial and protozoan pathogens by different combinations of health protection measures to achieve the health-based target of $<10^{-6}$ Daly per person and year (WHO, 2006)

3.2 Current requirements for irrigation water qualities using reclaimed water in EU Member States

Of the Member States where water reuse is being practiced, standards have been developed by Cyprus, France, Greece, Italy, Portugal, and Spain. In all countries apart from Portugal these standards are legally binding (Amec Foster Wheeler, 2016). All the standards cover water reuse practices for agricultural irrigation of crops and orchards and all but Cyprus's cover water reuse for irrigation of pastures. Aquifer recharge (by surface spreading or direct injection) is only considered as a permitted use in Cyprus, Greece and Spain. The specific regulations for Italy, France and Spain are summarized in Tables A-2 to A-4 (Appendix). Many of the standards developed at Member State level have been informed by the 2006 WHO Water Reuse Guidelines (WHO, 2006), the ISO guidelines on safe use of wastewater for irrigation use (ISO, 2015), and regulatory approaches in other countries (e.g. Australia, Israel, USA) but also by specific national considerations. In general, there is little harmony among the water reuse standards proposed by individual EU Member States. Thus, there is concern that this lack of harmonized requirements can create some trade barriers for agricultural goods irrigated with reclaimed water and a perception that there are different levels of safety for similar irrigation practices (JRC, 2014).

To overcome this issue and to foster water reuse as a core element of the EU action plan for the Circular Economy, the Joint Research Centre (JRC) was asked by the European Commission to develop a technical proposal for minimum quality requirements for water reuse in agricultural irrigation and groundwater recharge. The findings of the JRC have been published in an initial draft document in October 2016 and after several iterations and advice provided by the independent Scientific Committee on Health, Environmental and Emerging Risks (SCHEER)[3] and the European Food Safety Authority (EFSA) (SCHEER, 2017; EFSA,

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[3] The SCHEER Committee provides opinions on health and environmental risks related to pollutants in the environmental media and other biological and physical factors or changing physical conditions which may have a negative impact on health and the environment (e.g. in relation to air quality, waters, waste and soils). It also provides opinions on life cycle environmental assessment. It shall also address health and safety issues related to the toxicity and eco-toxicity of biocides.

2017), the findings and proposed requirements were revised in June 2017 (JRC, 2017). The core water quality requirements for water reuse in agricultural irrigation proposed in the JRC report are summarized in Tables 3.5 and 3.6.

Table 3.5 Minimum quality requirements for reclaimed water in agricultural irrigation (JRC, 2017).

Reclaimed water quality	**Indicative technology target**	**Quality criteria**				
		E. coli **(cfu/100 mL)**	**BOD_5 (mg/L)**	**TSS (mg/L)**	**Turbidity (NTU)**	**Additional criteria**
Class A	Secondary treatment, filtration, and disinfection (advanced water treatments)	≤10 or below detection limit	≤10	≤10	≤5	*Legionella* spp.: <1,000 cfu/l when there is risk of aerosolization in greenhouses. Intestinal nematodes (helminth eggs): ≤1 egg/l when irrigation of pastures or fodder for livestock.
Class B	Secondary treatment, and disinfection	≤100	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	
Class C	Secondary treatment, and disinfection	≤1,000	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	
Class D	Secondary treatment, and disinfection	≤10,000	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	

Table 3.6 Classes of reclaimed water quality and associated agricultural uses (JRC, 2017).

Crop category	**Reclaimed water quality class**	**Irrigation method**
Food crops consumed raw where the edible portion is in direct contact with reclaimed water **Root crops consumed raw**	Class A	All irrigation methods allowed
Food crops consumed raw where the edible portion is produced above ground **Food crops consumed raw with inedible skin (skin removed before consumption)**	Class A Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Processed food crops	Class A Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Non-food crops including also crops to feed milk- or meat-producing animals	Class A Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Industrial, energy, and seeded crops	Class A Class B Class C Class D	All irrigation methods allowed

A comparison of water reuse standards of individual Member States with the standards proposed in the JRC report is provided in Table 3.7. Also included are the requirements for irrigation water quality to address microbial risk for fresh produce proposed by the EU Commission (2017). These values are being discussed with focus on situations in four Member States for which case studies have been selected.

Table 3.7 Comparison of maximum limit values for selected parameters considered in national standards for water reuse in EU Member States for different crops and irrigation practices (adopted from JRC, 2014), the Guidance document on addressing microbial risk (EU Commission, 2017), and the proposed minimum quality requirements for agricultural irrigation by JRC (JRC, 2017).

Parameters	Cyprus	France	Greece	Italy	Portugal	Spain	EU Com. (2017)*	JRC Report (2017)
E. coli (cfu/100 mL)	5-10^3	250-10^5	5 – 200	10	-	0 - 10^4	100 - 10^4	10 - 10^4
E. coli (logs)	-	-	-	-	-	-	-	>5
Fecal coliforms (cfu/100 mL)	-	-	-	-	100 - 10^4	-	-	-
Enterococci (logs)	-	≥2 - ≥4	-	-	-	-	-	-
Anaerobic sulf. red. spores (logs)	-	≥2 - ≥4	-	-	-	-	-	-
Clostridium perf. spores (logs)	-	-	-	-	-	-	-	>5
Bacteriophages (logs)	-	≥2 - ≥4	-	-	-	-	-	-
F-spec. coliphages (logs)	-	-	-	-	-	-	-	>6
TSS (mg/L)	10 – 30	15	2 – 35	10	60	5 – 35	-	10 – 35
Turbidity (NTU)	-	-	2 – no limit	-	-	1 – 15	-	5
BOD$_5$ (mg/L)	10 – 70	-	10 – 25	20	-	-	-	10 – 25
COD (mg/L)	70	60	-	100	-	-	-	-
Total nitrogen (mg/L)	15	-	30	15	-	10	-	-

Note: **'Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene' (EU Commission, 2017)*

In **Italy**, standards under national legislation are stricter than those presented in the JRC draft report on minimum quality requirements for water reuse (with the exception of BOD) (JRC, 2017) and more stringent than the EU guidance document on addressing microbiological risks based on the fecal indicator organism threshold value for *E. coli* (EU Commission, 2017). In **Spain,** Royal Decree 1620/2007 establishes thresholds for reuse of reclaimed water in agricultural irrigation that are more stringent than what is being considered in the JRC proposal for the EU level, both in terms of quality criteria (maximum acceptable values; presence/absence of certain parameters according to type of water use) and risk management measures.

France already has well developed regulations on water reuse for irrigation purposes and is not anticipated to change relatively more stringent elements of the national standards, e.g. parameters to be monitored. On the other hand, alignment of the less stringent thresholds (for the parameters shared with the proposed EU approach such as TSS, *E. coli* and COD) would result in introducing more stringent numerical thresholds for these parameters. However, as far as bacteriological parameters are concerned, the French regulation imposes further restrictions that are not included in the JRC proposal. Nevertheless, both French regulations and the EU proposed minimum requirements are based on the same quality categories, which means that the French regulation could be adjusted to the proposed EU regulation by changing the numerical values of parameters. **Germany** does not have and currently is not foreseeing the development of national regulations for water reuse (UBA, 2017).

3.3 Risk exemplar of the current irrigation practice using impaired surface water qualities, wastewater effluent discharge qualities and reclaimed water qualities

Since many surface waters in the majority of EU regions that practice agriculture irrigation are also receiving discharge from municipal wastewater effluents, the quality of these streams can be impaired due to the introduction of pathogens, organic chemicals or elevated levels of nutrients and other salts. While previous studies have quantified the degree of wastewater discharge to a stream mainly based on relative flow contributions (see Section 1.1), assessing the degree of impact on water quality is more difficult since site-specific conditions need to be considered (i.e., local degree of mixing and dilution; upstream load prior to discharge; in-stream attenuation processes like biodegradation and photolysis; etc.). In addition, specific studies that have investigated impacts on river water quality are available, but frequently these are limited to certain river stretches, specific water quality parameters, or have not quantified the degree of upstream wastewater discharge. For the purpose of assessing the relevance of wastewater discharge and of providing a relative risk assessment, the following assumptions are made.

A hypothetical stream is impacted to different degrees by discharge of a secondary treated wastewater effluent (i.e., representing impacts of 5, 10, 20, and 50% discharge of wastewater). It is assumed that the secondary effluent meets the requirements of the EU UWWT Directive. The residual concentrations of selected pathogens in non-disinfected secondary effluent are adopted from the peer-reviewed literature (as noted). The water quality of the receiving river upstream of the discharge is considered pristine, carrying no detectable levels of pathogens or any anthropogenically-derived chemicals. It is further assumed that the pathogens being discharged to the river will survive for a few days, potentially a few weeks. Table 3.8 summarizes the assumptions and results of this risk exemplar.

Table 3.8 Concentrations of microbial water quality parameters considering different dilution ratios after discharge of secondary treated effluent to a pristine river.

Parameters	Assumption secondary effl. quality	Scenario 5%	Scenario 10%	Scenario 20%	Scenario 50%	EU Com. (2017)*	JRC (2017)
E. coli (cfu/100 mL)	10^4 *	$5*10^2$	10^3	$2*10^3$	$5*10^3$	100 - 10^4	10 - 10^4
Enterococci (cfu/100 mL)	10^4 *	$5*10^2$	10^3	$2*10^3$	$5*10^3$	-	-
Clostridium perf. spores (cfu/100 mL)	10^3 *	$5*10^1$	10^2	$2*10^2$	$5*10^2$	-	-
Somatic coliphages (pfu/100 mL)	10^5 *	$5*10^3$	10^4	$2*10^4$	$5*10^4$	-	-
Noro viruses (gc/L)	10^4 **	$5*10^2$	10^3	$2*10^3$	$5*10^3$	-	-

Note: *****'*Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene' (EU Commission, 2017);* *Levantesi et al. 2010; Costan-Longares et al., 2008*;* **NRC, 2012

Although the assumptions of this exercise might get criticized, the results suggest that even a high degree of dilution (10% and less) will result in a downstream water quality that will likely exceed the fecal indicator values of *E. coli* as specified in the EU Commission guidance document for good produce hygiene as well as the values proposed in the JRC report for irrigation of crops eaten raw (Class A and Class B). While the survival of these pathogens will depend on local environmental conditions (i.e., temperature; biomass present; photolysis, etc.), it is very likely that any surface water that is being abstracted within a few hours to days downstream of this discharge point will be compromised and exceed background levels of pathogens by several orders of magnitude.

3.4 Conclusions regarding relative risks considering different qualities of sources for agricultural irrigation

Water reuse for agricultural irrigation is frequently perceived as more risky than using surface water for the same purpose. Indeed, the FAO noted that the risks (actual and perceived) to public health and the environment presented by water reuse are a serious obstacle to the greater acceptance of the practice and that this trend can be observed worldwide (FAO, 2010). One of the most common concerns relates to the actual and perceived risks to human health from consuming and being in contact with food irrigated with reclaimed water particularly from exposure to pathogens (bacteria, protozoa, viruses), potentially toxic contaminants, and persistent organic contaminants.

For planned water reuse projects, appropriate management approaches and treatment barriers are in place to mitigate these risks. However, in unplanned water reuse settings where upstream wastewater discharge occurs to surface water that is subsequently used for agricultural irrigation, an elevated risk might exist but existing operational barriers can be less sufficient to properly manage it. Based on the analysis performed in this study and presented in Table 3.8 (Section 3.4), even high dilution ratios (less than 10% wastewater impact) after discharge of non-disinfected secondary treated effluent (meeting the requirements of the UWWT Directive) will result in concentrations of pathogens that exceed background levels by several orders of magnitude and likely also exceed microbial water quality standards of the EU Commission guidance document for good produce hygiene (EU Commission, 2017) as well as the values proposed in the JRC report for irrigation of crops eaten raw (Class A and Class B) (JRC, 2017). This situation has been documented in other countries and the National Research Council (NRC) (1996) reported that the quality of treated effluent in the USA for most parameters is generally well below the levels measured in the Colorado River and recommended minimum irrigation water quality criteria for surface water.

While this exceedance could be mitigated before this impaired surface water is being applied in agriculture irrigation, as envisioned by the *'Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene'* of the EU Commission (2017), a monitoring program characterized by high sampling frequencies and a comprehensive microbial screening needs to be in place. Where stream flows vary and the use of irrigation water is occurring only seasonally, the need to execute a comprehensive monitoring program with high frequency for microbial parameters might not be obvious, feasible, or affordable.

4. Estimating the Degree of Impact from Unplanned Water Reuse

4.1 Introduction to unplanned water reuse in the EU

In order to assess the degree of wastewater discharge to receiving streams in the context of downstream practices including agricultural irrigation and groundwater recharge (*de facto* water reuse), various case studies in four EU Member States (namely Spain, Italy, France and Germany) were selected for this study. For agricultural irrigation, the focus has been on areas in Spain with the Cinca, Segre and Llobregat river districts, in Italy with the Adda and Oglio rivers in the Po catchment area, and in France with the Loir and the Montepellier river basin districts (Figure 4.1). The issue of managed aquifer recharge using surface water potentially impaired by wastewater effluents was investigated north of Toulouse, France and for the City of Berlin, Germany.

Figure 4.1 Selected river basin districts to assess unplanned reuse in agricultural irrigation in the EU

Regarding agricultural irrigation, the degree of groundwater and surface water usage for this practice differs in these Member States (Table 4.1). Italy, Spain and France use primarily surface water for irrigation, where Germany favors groundwater sources for agricultural irrigation. The specific regions in these four countries practicing agriculture irrigation are equipped with irrigation systems using either groundwater or surface water. This information for the four Member States is summarized in Tables A-5 to A-8 (Appendix).

Table 4.1 Water sources used for irrigation in percent in selected member states (adopted from Daccache et al., 2014; EuroStat, 2016)

Country	Water Source (%)	
	Groundwater	Surface Water
France	36	64
Germany	62	38
Italy	29	71
Spain	21	79

In Spain, the total area equipped for irrigation was 3,575,488 ha. In Italy, the irrigable area is totaling up to 3,892,202 ha, while the area actually used for irrigation is summing up to 2,471,379 ha. The irrigable area of France is estimated to be 2,906,081 ha. According to the agricultural census, the main irrigated crops were maize (56% of the irrigated area), vegetables and potatoes (12% of irrigated area), and fruits and vines (9% of the irrigated area).

In Germany, irrigation is mainly practiced on arable land and in most irrigation areas only specific crops in a crop rotation are irrigated (e.g., potatoes, sugar beets, maize, vegetables). Therefore, the area actually irrigated was only 220,907 ha in 2002. Arable crops covered about 79% of the irrigation area, horticulture 17%, and perennial crops about 4% (FAO, 2017).

The specific irrigation areas by country are documented by FAO in its ‘Global Water Irrigation Map’ via a Google Earth link (FAO, 2017). Using the FAO ‘Global Water Irrigation Map’, specific surface water sources located in areas which are characterized by more than 35% agricultural irrigation were selected. Dry weather flow data for these rivers were determined using annual averages provided by national hydrology agencies as specified below for each case study. In addition, the location of municipal wastewater treatment plants was identified using various national[4] and international dissemination platforms like the European Commission Urban Waste Water Treatment maps[5] maintained by the European Environment Agency, which also provided information on capacity and dry weather loads (EEA, 2017).

4.2 Unplanned agricultural irrigation water reuse in selected EU river basins

To estimate the degree of unplanned water reuse for agricultural irrigation in EU river basins, various case studies were selected in three EU Member States (namely Spain, Italy, and France). The dilution ratio, representing the ratio between treated wastewater effluent flows to stream flow for a particular location or flow measurement section, was derived using different methodologies as indicated below to assess the degree of unplanned water reuse.

CASE STUDY 1: Ebro River Basin, Spain

The Ebro River is located in northeastern Spain and characterized by significant agricultural activities (Figure 4.2).

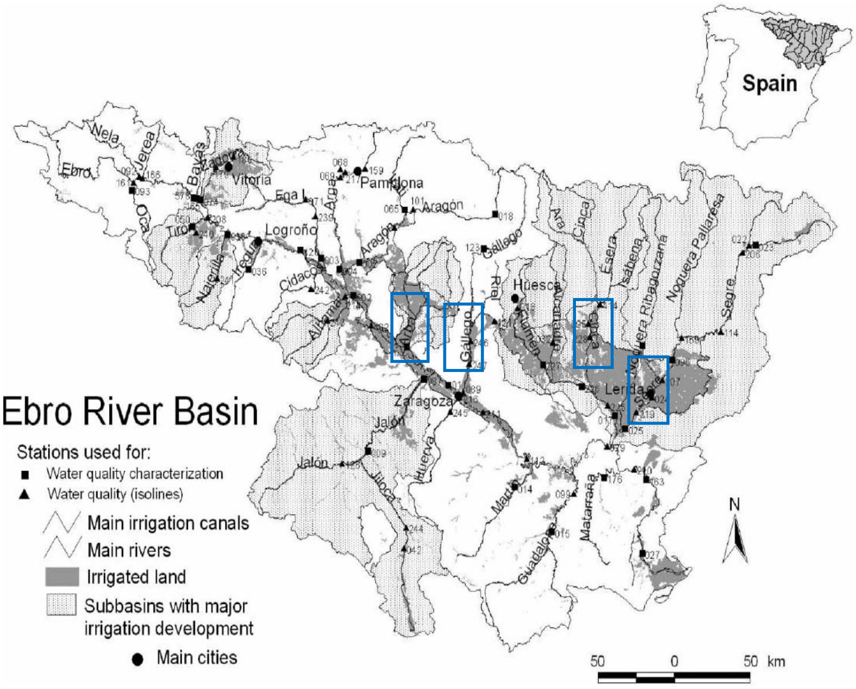

Figure 4.2 Ebro river basin with highlighted study areas of selected tributaries (adopted from Isidoro and Aragües, 2007)

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[4] http://uwwtd.oieau.fr

[5] http://www.eea.europa.eu/themes/water/water-pollution/uwwtd/interactive-maps/urban-waste-water-treatment-maps-1

Within the river basin, four sub-river basin sections including the Segre, Cinca, Gallego, and Arbo tributaries were selected to determine maximum, minimum and average flow data using the national online database of Confederacíon Hidrográfica del Ebro (CHEbro, 2017). As an example, Figure 4.3 shows the Segre River watershed, a tributary to the Ebro River including gauging stations and flow data.

The location of wastewater treatment plants within this watershed was determined using the European Urban Waste Water Treatment Map (Figure 4.4) (EEA, 2017). This database provides the location, design capacity and current load information in people equivalent (PE). The load data were subsequently converted to flow (in m^3/day). For the case studies in Spain, actual load data of wastewater treatment plants (in m^3/day) were validated by utilizing data provided by the regional environmental agency L'Agència Catalana de l'Aigua (Robuste Cartro, 2017). Dilution ratios for each sub-river basin section were subsequently determined and are summarized in Table 4.2. These results for selected river sections are also illustrated in Figure 4.5 using a color code to represent different dilution ratios.

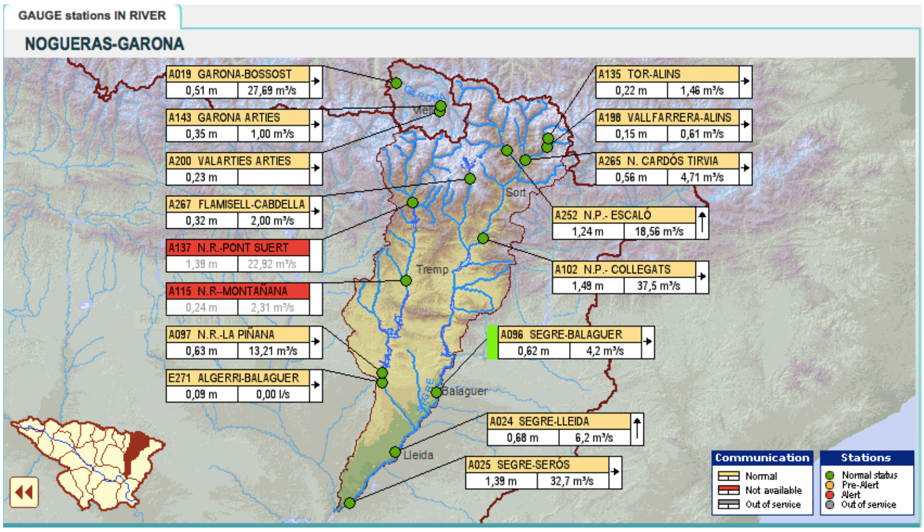

Figure 4.3 Map of Segre river basin, marked with gauging stations (adopted from Automatic Hydrologic Information System of the Ebro river basin, 2017)

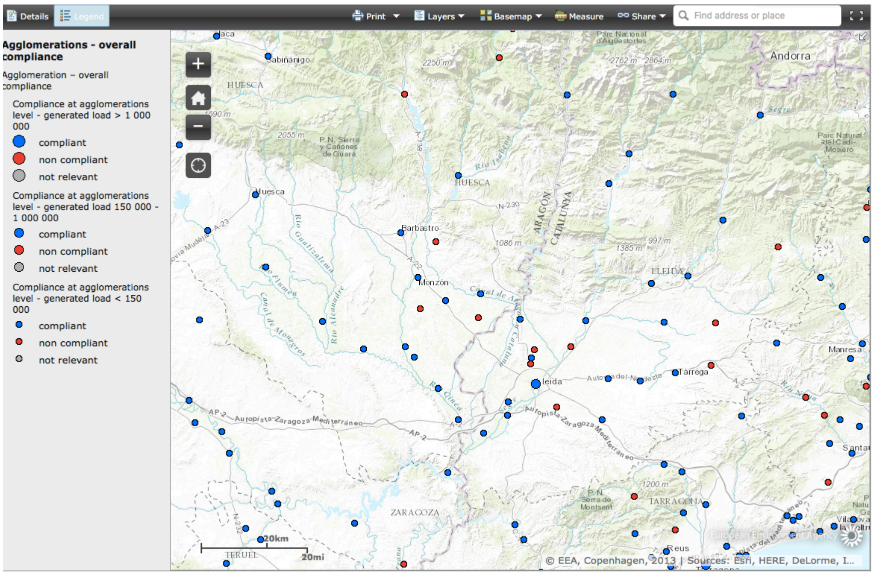

Figure 4.4 Location of WWTPs within the Segre river basin[6]

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[6] adopted from http://www.eea.europa.eu/themes/water/water-pollution/uwwtd/interactive-maps/urban-waste-water-treatment-maps-1

Table 4.2 Degree of wastewater impact in river basins of the Segre, Cinca, Gallego and Arba rivers

Gauging station	Q_river [m^3/day]			Q_WWTPe [m^3/day]	Degree of wastewater Impact (%)		
	min	max	Average	Average	max	min	Average
Segre-Balaquer	285,120	4,769,280	630,720	28,443	10.0	0.6	4.5
Segre-Lleida	319,680	9,936,000	1,149,120	123,096	38.5	1.2	10.7
Segre -Serós	501,120	22,248,000	4,527,360	130,637	26.1	0.6	2.9
Cinca Fraga	1,891,296	35,930,304	5,223,744	55,720	2.9	0.2	1.1
Gallego	282,528	18,036,864	1,759,968	25,993	9.2	0.1	1.5
Arba	141,696	7,826,112	629,856	16,697	11.8	0.2	2.7

Figure 4.5 Estimates of wastewater impact for selected river stretches in the Ebro and Llobregat river basins

These results suggest that the degree of impact from wastewater discharge in the Segre river basin can vary between 3 and 11% on average, and potentially can even be higher depending on seasonal flow conditions in the stream. In particular, river stretches of the Segre river from Balaguer to Lleida are characterized by 5% and 11% wastewater impact on average and are located in areas that widely use surface water for agricultural irrigation. However, for the Cinca and Gallego river basins the degree of wastewater impact was determined to be less than 2%.

CASE STUDY 2: Llobregat River Basin, Spain

The Llobregat River located in northeastern Spain is one of the main water courses in Catalonia. It has a length of 160 km, a basin surface area of 5,000 km^2, and its downstream stretches serve as a source of drinking water supply for more than 45% of approximately four million people living in the Barcelona metropolitan area (Mujeriego et al. 2017). Most of the

Llobregat river basin is characterized by semi-arid climatic conditions, resulting in largely variable stream flows at its final stretches that can range from an annual average of 400,000 m^3/d in a dry year (2007) to 931,000 m^3/d in a wet year (2013) (Mujeriego et al. 2017). The Llobregat River has two main tributaries, the Cardener River (107 km) and the Anoia River (68 km). Within the Llobregat river basin, there are 32 wastewater treatment plants discharging about 110,000 m^3/d (2007, 2008 and 2013) of treated effluent into the Llobregat River and its tributaries upstream of the last abstraction point for urban water supply at Sant Joan Despí (Mujeriego et al. 2017).

The locations of wastewater treatment plants within this river basin were determined using the European Urban Waste Water Treatment Map (EEA, 2017). For the Llobregat case study, actual load data of wastewater treatment plants (in m^3/day) as well as flow data in the river (based on the reference year 2006) were provided by the regional environmental agencies (L'Agència Catalana de l'Aigua) (ACA, 2016). Dilution ratios for each sub-river basin section were determined and are summarized in Table 4.3. Results for selected river sections are presented in Figure 4.5 using a color code to illustrate different dilution ratios.

Based on these results, the degree of wastewater effluents in the river can vary between 8 and 82% on average. In particular, downstream of the Anoia River tributary the degree of impact becomes very significant representing conditions of a wastewater-dominated stream. In this area, the river has an important water abstraction for agricultural irrigation. It is also noteworthy, that further downstream of the Llobregat River right after the Sant Joan Despí gauging station water is abstracted as raw water supply of the Sant Joan Despí drinking water plant serving the larger Barcelona metro area (with a capacity of 88 million m^3/year in 2008, plus 34 million m^3/year from nearby groundwater wells).

Table 4.3 Degree of wastewater impact in river basins of the Llobregat river

Gauging station	Q_river [m^3/day]			Q_WWTPe [m^3/day]	Degree of wastewater Impact (%)		
	min	max	Average	Average	max	min	Average
Navás	114,048	185,328	142,560	10,741	9.4	5.8	7.5
El Pont de Vilomara	155,520	252,720	194,400	23,271	15.0	9.2	12.0
Cardener	94,003	152,755	117,504	28,772	30.6	18.8	24.5
Martorell	274,752	343,440	343,447	79,391	28.9	23.1	23.1
Anoia	28,339	38,966	36,014	29,622	104.5	76.0	82.3
San Joan Despí	297,216	482,976	371,520	165,626	55.7	34.3	44.6
Mouth of Llobregat	304,128	494,208	380,160	214,696	70.6	43.4	56.5

CASE STUDY 3: Adda and Oglio River Basins, Italy

The most intensively irrigated agricultural area in Italy is the northern Lombardy region, producing rice, wheat, corn, beets and other grains. The river Po and its tributaries flow through this region and are the major source of surface water for agricultural irrigation in this area. Two rivers, which are heavily used for irrigation purposes and are characterized by the highest resolution of gauging stations, were selected as case studies for this report: the Adda and Oglio rivers (Figure 4.6). The main gauging station used for the river Adda was Pizzighettone and the main gauging station for the river Oglio was Marcaria. Both stations are located at the headwaters, where the respective rivers meet the river Po.

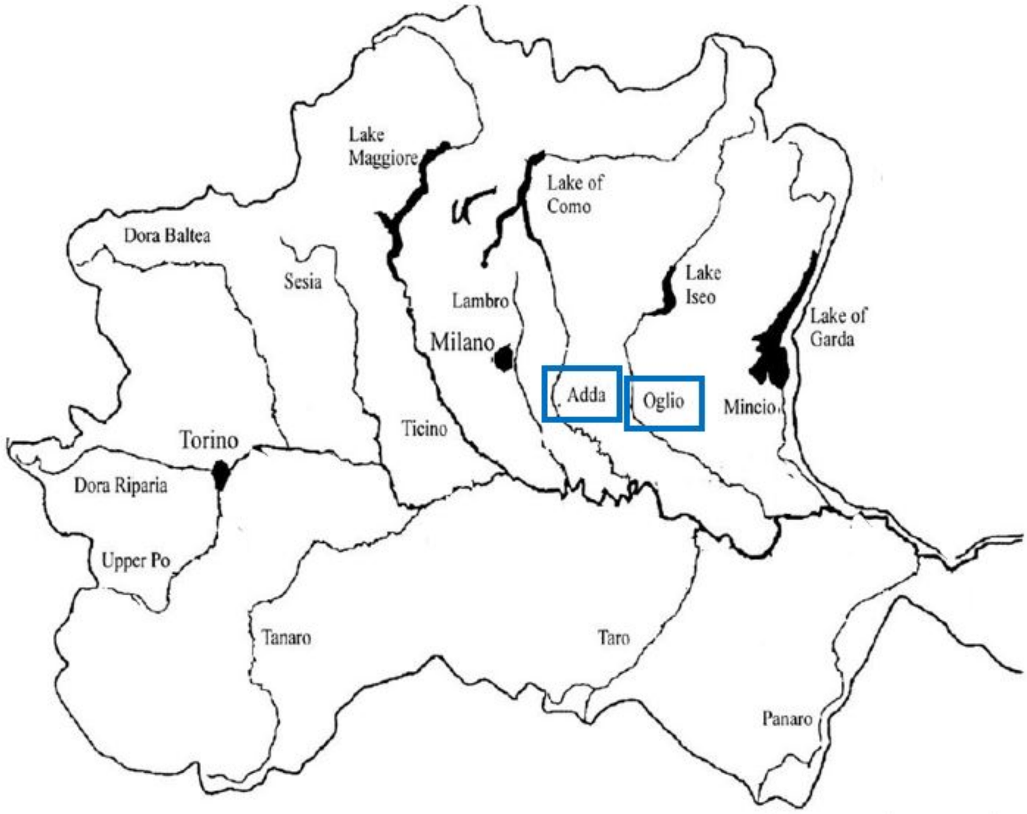

Figure 4.6 Po river basin with highlighted sub-river basin sections (adopted from Davide et al., 2003)

The ARPA Lombardia website was consulted to provide stream flow data for the upstream gauging stations of the selected river basins[7]. The interactive map of this website allows users to choose and to obtain detailed information regarding specific gauging stations and valid river level data for a defined period of time within the watersheds of Lombardy[8]. Unfortunately, only piezometric water height levels were available for the chosen gauging stations, which require a site-specific equation to convert water level height to flow rate. Most gauging stations of interest were directly located on the Adda or Oglio rivers, with only 3 out of 10 located on smaller tributaries to larger rivers.

Once the piezometric level was obtained, the stream flow was calculated by a rating curve, constantly validated and updated by ARPA Lombardia to ensure reliable data. Table 4.4 summarizes calculated flow rates at each gauging station of the Adda and Oglio rivers. Table A-10 presents validity ranges of rating curve equations used to calculate flow rate for both the Adda and Oglio gauging stations. For data consistency, the time period from 1 June 2015 through 1 June 2016 was considered.

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[7] (only available in Italian) http://idro.arpalombardia.it/pmapper-4.0/map.phtml?dg=idro,scaledeflusso,lomb,fiumi,laghi,CTR10,CTR50,ORTO,PANO&me=1485100.67086,4975948.753160001,1651967.5901799998,5103179.82466&language=it&config=default

[8] http://www2.arpalombardia.it/siti/arpalombardia/meteo/richiesta-dati-misurati/Pagine/RichiestaDatiMisurati.aspx

Table 4.4 Adda and Oglio river gauging stations

River	Tributary	Gauging station	Q_river (m^3/d)		
			Average	Minimum	Maximum
Adda	-	Pizzighettone	15,077,478	4,446,144	87,075,648
	Serio River	Montodine	747,652	220,927	8,668,059
	-	Rivolta d'Adda	6,748,201	1,756,636	35,726,925
	-	S.Maria Lavello	11,676,930	3,692,009	25,307,054
	-	Gera Lario Fuentes	7,097,620	1,495,916	25,791,346
Oglio	-	Marcaria	6,765,149	526,383	13,630,536
	Chiese	Asola - v.Carducci	863,655	234,509	12,358,215
	Mella	Manerbio	674,774	168,936	7,618,800
	-	Soncino	1,578,570	410,102	9,796,589
	-	Capriolo	1,455,122	192,388	7,142,746

As Italian wastewater treatment plant information is omitted from the EEA map and database, another PDF catalogue containing data on all WWTPs in Lombardy was used to obtain effluent discharge volumes (http://sireacque.arpalombardia.it/). Two plugins of Google Earth were used to visualize WWTPs in the areas of interest and to distinguish the rivers (see Figures A-1 and A-2, Appendix). The previously mentioned ARPA Lombardia map was again consulted for a more precise overview of the water network[7]. Unfortunately, the Google Earth WWTPs plugin was not completely reliable, therefore an additional visual check for small villages and towns along the river path in the WWTP PDF catalogue was performed. Once the location of the WWTP was verified on Google Earth, the PDF catalogue was consulted to determine WWTP effluent discharge volume expressed in m^3/s and converted to m^3/day for further calculations.

Once all the WWTP data and flow rates from selected gauging stations was compiled, the dilution ratio for river stretches was calculated. Table 4.5 summarizes calculated dilution factors for each gauging station. For a more comprehensive visualization, results were plotted in Google Earth (Figure 4.7).

Table 4.5 Dilution ratios in percent for Adda and Oglio rivers gauging stations.

River	Gauging station	Degree of wastewater impact (%)		
		Average	Minimum	Maximum
Adda	Pizzighettone	5.4	0.9	18.4
	Serio River - Montodine	39.8	3.4	135
	Rivolta d'Adda	7.2	1.4	27.5
	S.Maria Lavello	1.5	0.7	4.6
	Gera Lario Fuentes	1.4	0.4	6.6
Oglio	Marcaria	5.3	2.6	67.7
	Chiese River - Asola	3.8	0.3	14.2
	Mella River - Manerbio	15.4	1.4	61.3
	Soncino	9.2	1.5	35.5
	Capriolo	5.2	1.1	39.3

The results suggest that the upper watershed of the Adda river basin (i.e., S. Mario Lavello; Gera Lario Fuentes) exhibits only a negligible impact of wastewater effluent discharge. At the gauging station Rivolta d'Adda the impact has increased to 7% on average with maximum values of 27% during low-flow conditions. The tributary Serio River, however, exhibits an average degree of impact of 40% with a large range of variability. Further downstream, this degree of impact within the Adda river decreases again due to dilution to approximately 5% on average.

For the Oglio River, the average degree of wastewater impact in the river varies between 4 and 15%. While during high-flow conditions, the impact of wastewater is negligible, low flow conditions in the river can result in significant degrees of impact varying between 14 and 68%. The lower portions of both watersheds are characterized by extensive use of surface water for agricultural irrigation (FAO, 2017).

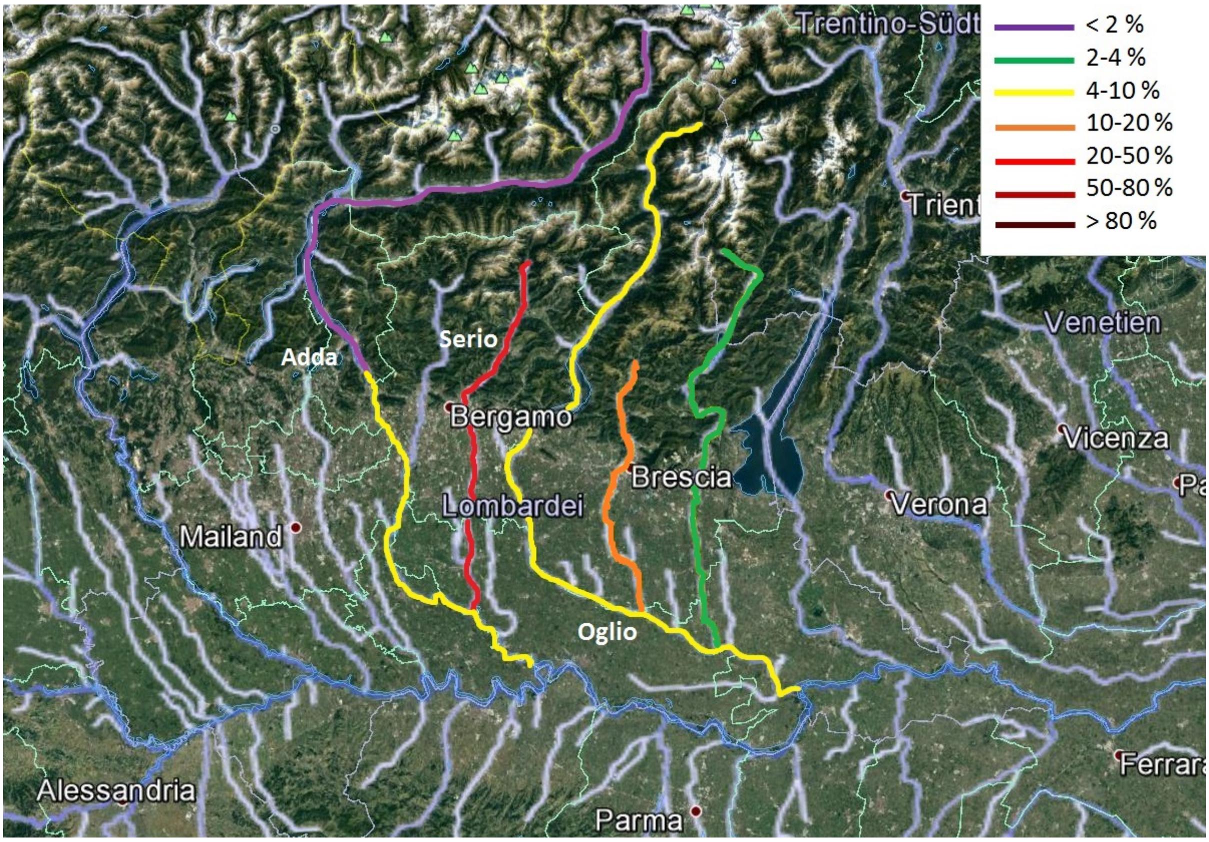

Figure 4.7 Estimates of wastewater impact for selected river stretches in the Adda and Oglio river basins with indicated dilution ratios.

CASE STUDY 4: Loir and Montpellier River Basins, France

The case study in France represents an area in the Loir and Montpellier river basins (Figure 4.1). The Eure-et-Loir département is characterized by the highest ratios of irrigated area to total area in France. Several tributaries of the Loir river were selected, as they flow through areas with a high degree of agricultural irrigation (FAO, 2017). Of the area equipped for agricultural irrigation, the Hérault département uses 80-90% surface water according to the FAO database (FAO, 2017). The region of Montpellier was selected due to its high population density on the southern coast of France.

The methodology for analyzing the French case studies was more computational than for Spain or Italy. The approach utilized an open source GIS platform to delineate catchment areas originating at gauging stations of interest, then calculating dilution ratios for WWTP effluent contributions to the flow of the watershed sections. For collecting spatial information, a Shuttle Radar Topography Mission (SRTM) map of France, with 90 meter resolution, was downloaded from the CFIAR Consortium for Spatial Information, located at http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp. Maps are available for download in WGS84 format, the standard format used for further GIS analysis.

Five gauging stations were selected within each river basin area (Table 4.6). Annual average daily flow was retrieved from the online database for each gauging station. A shapefile of French gauging station locations is available at https://www.data.gouv.fr/fr/datasets/stations-hydrometriques-metropole/. Online (read-only) gauge data is available at http://www.hydro.eaufrance.fr/. Locations from the online data must be converted from the Lambert II étendu format to the WGS84 format using an online converter (http://geofree.fr/gf/coordinateconv.asp#listSys).

Table 4.6 Flow rates, WWTP discharges, and gauging stations for the irrigation with surface water case study areas near Eure-et-Loir and Montpellier

Surface Water Irrigation		Q_river in 2015 (m^3/d)			Q_WWTP (m^3/d)
River	**Gauging Station**	**Average**	**Minimum**	**Maximum**	**Upstream discharge in 2015**
Loir	Trizay-lès-Bonneval (28)	83,376	1,650,240	6,048	1,438
	Saint-Maur-sur-le-Loir (28)	192,672	2,116,800	22,464	4,112
	Conie-Molitard (28)	123,552	224,640	44,064	3,194
	Saint-Hilaire-sur-Yerre (28)	87,264	691,200	17,280	698
	Romilly-sur-Aigre (28)	108,000	198,720	31,104	341
Montpellier- Le Vistre	Le Cailar - Le Vistre	317,088	2,574,720	108,864	42,615
	Bernis - Le Vistre	238,464	1,745,280	49,248	37,098
Montpellier - La Mosson	Saint-Jean-de-Védas (34) - La Mosson	63,590	389,664	3,542	8,790
Montpellier - Le Lez	Montpellier (34) - Le Lez	149,472	2,306,880	32,314	2,191
	Lattes (34) - Le Lez	186,624	2,738,880	65,664	94,725

The open-source desktop GIS and remote sensing software Whitebox GAT was used to delineate catchment areas in the selected case study areas. SRTM digital elevation models (DEMs) were mosaicked and then corrected with the Breach Depressions (fast) tool. Catchment outlet locations in WGS84 format, corresponding to previously selected gauging stations, were imported as comma separated value (CSV) files. Catchment outlet locations were further refined by snapping to the closest accumulation point with the Jenson Snap Pour Points tool. Catchments were then derived using the Watershed tool. Resulting raster were converted to polygon shapefiles for subsequent input into QGIS.

The national data of wastewater treatment plants in France for 2015, with approximately 21,000 facilities, is available at http://assainissement.developpement-durable.gouv.fr/services.php. The database includes WWTP locations, year-averaged daily discharges, and type of receiving water body. Instead of given WWTP outlet locations, the true locations of WWTPs were used due to noticeable differences regarding the correct locations. The data set was then reduced to only those WWTPs that discharge to surface water bodies. The remaining data was reduced to WGS84 longitude/latitude and year-averaged daily discharge.

The upstream catchment shapefile specific to each gauging station was loaded into QGIS. Nationwide WWTP locations, along with year-averaged daily discharges, were overlaid onto the shapefile as attributes. The joint 'Attribute by Location' tool was selected and run to identify the intersection of both datasets, as well as cumulative attributes (i.e., cumulative year-averaged daily discharge of all WWTPs located upstream of the gauging station). This resulted in river flow as well as WWTP discharge totals, from which a dilution ratio could be derived.

The results of these calculations are summarized in Table 4.7. The case study of the Loir river in Eure-et-Loir region demonstrates that significant dilution is occurring even in areas that are less populated resulting in average degrees of impact from wastewater effluents of 0.3 to 2.6%. This area has the highest ratios of irrigated land to total land, demonstrating that certain stretches of the Loir and its tributaries are only seasonally impacted, particularly during times of low flow rates when the degree of impact could increase up to 24%. The case study area in the Montpellier region exhibited high percentages of WWTP effluent discharge into the river on average, with extreme percentages occurring during low baseline river or tributary flows (Figure 4.8). Since agricultural irrigation with surface water is an important factor in the Montpellier region, the seasonal high percentage suggests that *de facto* water reuse is occurring.

Table 4.7 Degree of wastewater impact for the Loir, Le Vistre, La Mosson, and Le Lez river gauging stations for the irrigation with surface water case study areas near Eure-et-Loir and Montpellier

Surface Water Irrigation		**Degree of wastewater impact (%)**		
River	**Gauging Station**	**Average**	**Maximum**	**Minimum**
Loir	Trizay-lès-Bonneval (28)	1.7	23.8	0.1
	Saint-Maur-sur-le-Loir (28)	2.1	18.3	0.2
	Conie-Molitard (28)	2.6	7.3	1.4
	Saint-Hilaire-sur-Yerre (28)	0.8	4.0	0.1
	Romilly-sur-Aigre (28)	0.3	1.1	0.2
Montpellier-Le Vistre	Le Cailar (30) - Le Vistre	13.4	39.2	1.7
	Bernis (30) - Le Vistre	15.6	75.3	2.1
Montpellier -La Mosson	Saint-Jean-de-Védas (34) - La Mosson	13.8	248	2.3
Montpellier -Le Lez	Montpellier (34) - Le Lez	1.5	6.8	0.1
	Lattes (34) - Le Lez	50.8	144	3.5

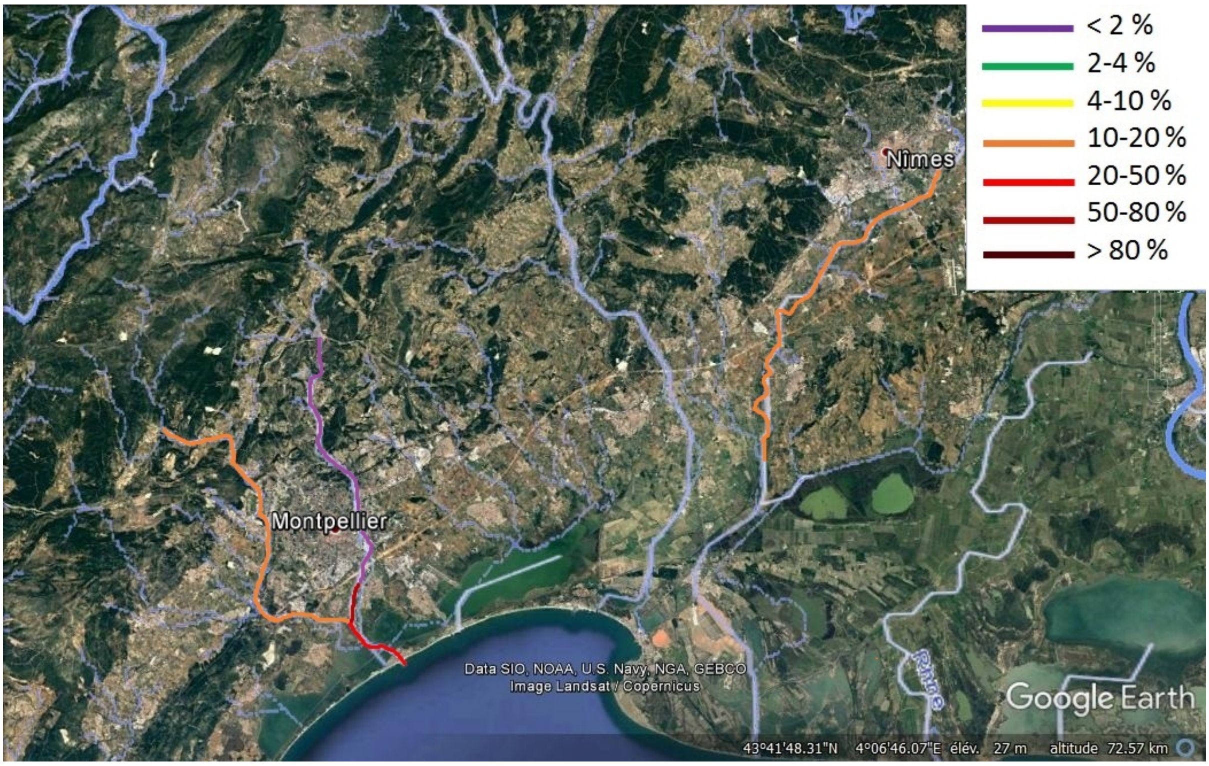

Figure 4.8 Estimates of wastewater impact for selected river stretches in the Le Vistre, La Mosson, and Le Lez river basins with indicated dilution ratios

4.3 Water reuse via groundwater recharge in selected EU river basins

4.3.1 Degree of unplanned water reuse via groundwater recharge in selected EU river basins

The degree of unplanned water reuse via artificial groundwater recharge using impaired surface water has not been comprehensively assessed yet. In contrast to agricultural irrigation where surface water is directly applied, estimating the degree of impact from wastewater discharge on groundwater recharge operations is more difficult since dilution with native groundwater and additional attenuation of contaminants can occur in the subsurface. Some studies have used conservative wastewater-borne tracers to estimate the degree of impact. These source tracking approaches might include certain conservative ions that are elevated in municipal wastewater effluents (e.g., chloride, sulfate, sodium, potassium) or persistent and polar trace organic chemicals.

Occurrence data of trace organic chemicals that are anthropogenically-derived and behave conservatively (i.e., well water soluble, not biologically or photolytically degradable) can serve as indicators to assess the degree of wastewater impact on a receiving stream. For example, the average concentration of the anti-depressant drug carbamazepine in surface water bodies of North Rhine-Westphalia has been reported to be 226 ng/L (Götz et al., 2012). Carbamazepine has been recognized as a chemical that might cause adverse effects in aquatic life and has been assigned a tentative environmental quality standard based on eco-toxicological data of 500 ng/L. Considering its conservative behavior in the aqueous environment and a background level of carbamazepine in pristine surface water and average concentrations in wastewater effluents, an average percentage of wastewater in surface can be calculated. In surface waters in North Rhine-Westphalia immediately downstream of locations with wastewater treatment plant discharge carbamazepine concentrations varied between 100 and 500 ng/L (Figure 4.9), which corresponded to cumulative wastewater contributions between 20 and 60% at average dry weather flow conditions in the receiving streams (Götz et al., 2012).

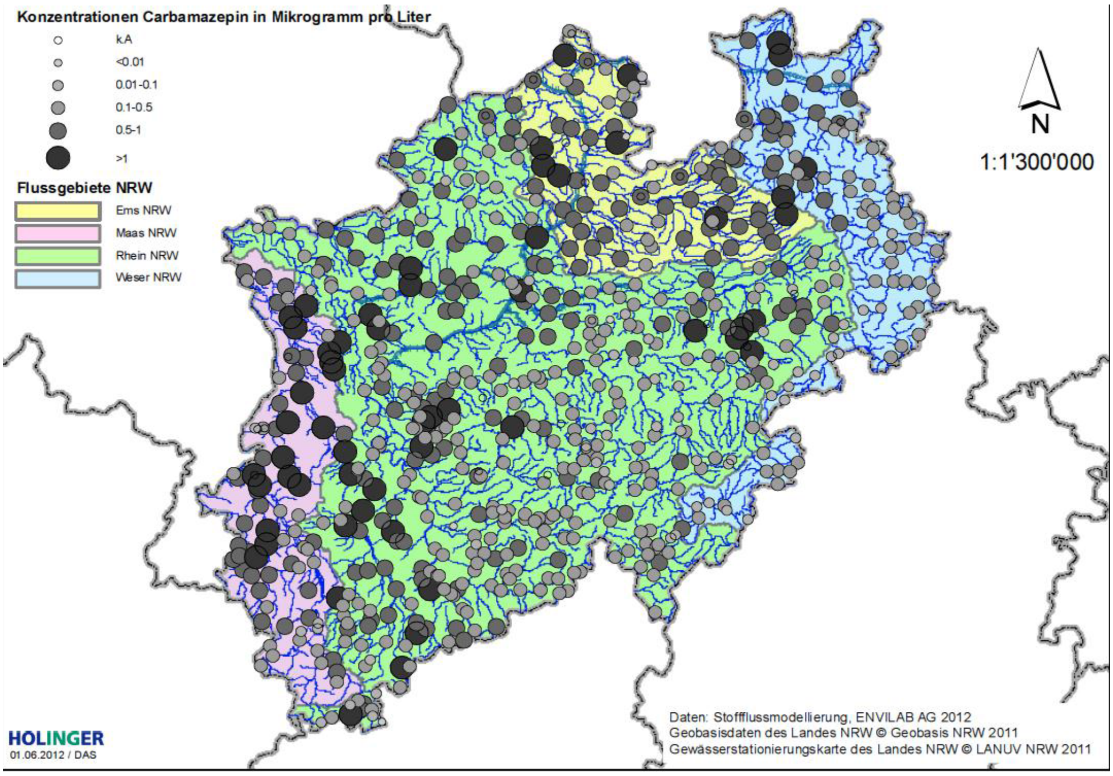

Figure 4.9 Concentrations of carbamazepine (in μg/L) in river stretches in North-Rhine Westphalia, Germany (Source: Götz et al., 2012).

CASE STUDY 5: Garonne River, Toulouse, France

The case study in France represents an area near Toulouse where managed aquifer recharge (MAR) along the Garonne River is being practiced (Figure 4.1). An online interactive map is available through the Global Managed Aquifer Recharge Portal[9] in order to identify locations where surface water is used for artificial groundwater recharge. A more complete overview of sites in France is available in Casanova et al. (2012). The specific case study area selected for this study was the Garonne River between the cities of Carbonne and Agen and the Ariège River between the cities of Cintegabelle and Toulouse.

Five gauging stations were selected within the case study area (Table 4.8). Annual average daily flow was retrieved from the online database for each gauging station. A shapefile of French gauging station locations is available at https://www.data.gouv.fr/fr/datasets/stations-hydrometriques-metropole/. The data was processed as described above (see Case Study #4).

Table 4.8 Flow rates, WWTP discharges, and gauging stations for the MAR case study area near Toulouse

MAR facilities near Toulouse		Q_river in 2015 (m^3/d)			Q_WWTP (m^3/d)
River	Gauging Station	Average	Minimum	Maximum	Upstream discharge in 2015
Garonne	Lamagistère (82)	28,598,400	189,216,000	6,307,200	389,672
	Verdun-sur-Garonne (82)	17,625,600	91,584,000	4,760,640	248,171
	Portet-sur-Garonne (31)	16,243,200	125,280,000	4,587,840	62,200
	Marquefave (31)	9,763,200	47,001,600	3,879,360	17,149
Ariège	Auterive (31)	5,132,160	32,227,200	1,572,480	21,021

The results of this estimate are summarized in Table 4.9. The MAR case study area near Toulouse demonstrates that the degree of wastewater effluents discharged to the Garonne and Ariege rivers could account for 0.4 to 1.4% on average. This is a rather low degree of impact and considering further attenuation processes of any potential contaminants that might be present in the surface water during travel in the subsurface does not represent any concern for drinking water production at this site.

Table 4.9 Degree of wastewater impact at various gauging stations of the Garonne and Ariège rivers near MAR facilities near Toulouse

MAR facilities near Toulouse		Degree of wastewater impact (%)		
River	Gauging Station	Average	Maximum	Minimum
Garonne	Lamagistère (82)	1.36	6.18	0.21
	Verdun-sur-Garonne (82)	1.41	5.21	0.27
	Portet-sur-Garonne (31)	0.38	1.36	0.05
	Marquefave (31)	0.18	0.44	0.04
Ariège	Auterive (31)	0.41	1.34	0.07

CASE STUDY 6: City of Berlin, Germany

More than 70% of the drinking water for the city of Berlin originates from induced bank filtration or surface spreading using the city's surface water sources (Heberer et al., 2004). As one of these drinking water resources, Lake Tegel located in the northwestern part of Berlin is receiving water from the River Havel and the confluence of the Tegeler Fliess and the Nordgraben (Figure 4.10) (Schimmelpfennig et al., 2012). The flow of the Nordgraben is

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[9] https://ggis.un-igrac.org/ggis-viewer/viewer/globalmar/public/default

strongly impacted (70-90%) by discharge of the WWTP Schönerlinde resulting in a contribution of 17 to 35 % of treated WWTP effluent to Lake Tegel water (Figure 4.11). While the installation of an additional surface water treatment plant using coagulation/flocculation, sedimentation and dual-media filtration efficiently reduced phosphorus concentration, other wastewater-derived contaminants can be detected in the lake. Several studies investigated the occurrence of trace organic contaminants in Lake Tegel and confirmed the serious impact of wastewater-derived contaminants on lake water quality, which serves as a major drinking water source for the city (Heberer, 2002; Schimmelpfennig et al., 2012; Wiese et al., 2011). More than one hundred drinking water wells along the lake's shores extract water from the lake via induced bank filtration. The extracted water from the wells is treated by aeration and filtration and distributed without any additional disinfection step.

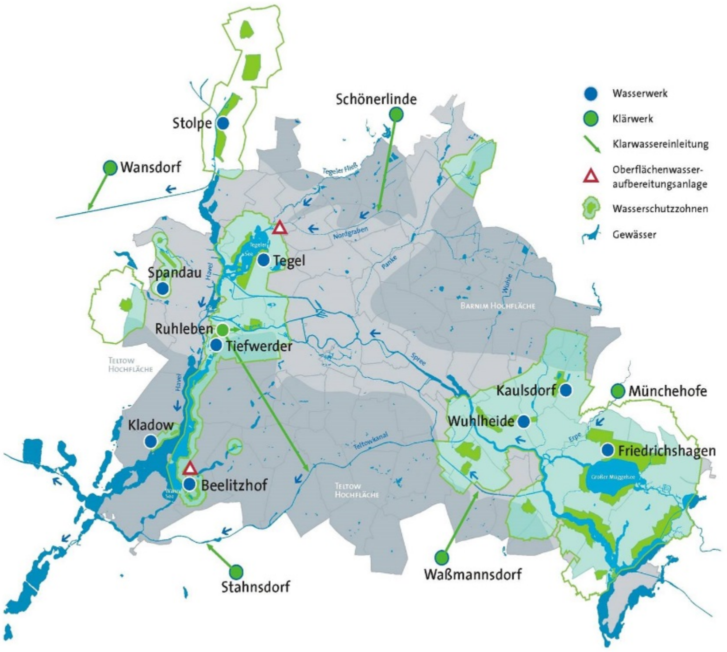

Figure 4.10 Water cycle of the City of Berlin, Germany with locations of drinking water facilities (in blue) and wastewater treatment plants (in green) (Source: Berliner Wasserbetriebe, 2016)

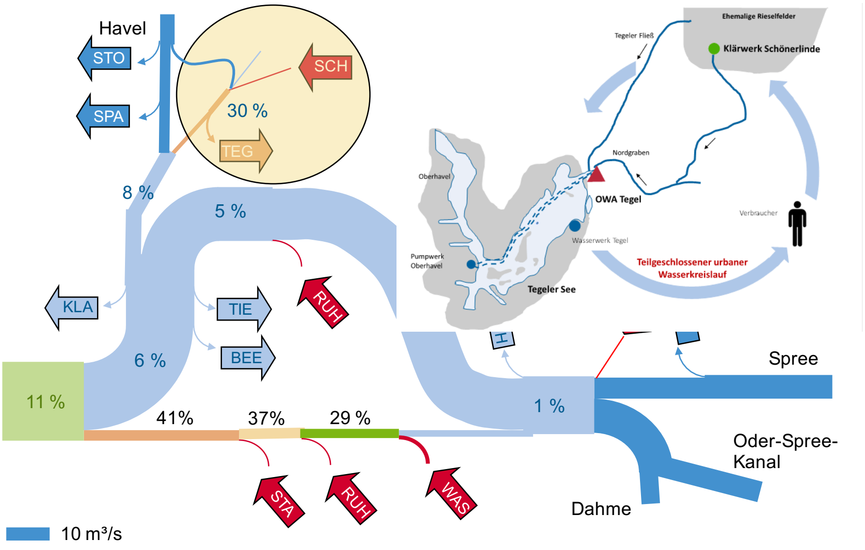

Figure 4.11 Estimates of wastewater contributions in sections of surface water bodies within the Berlin urban water cycle (Source: Berliner Wasserbetriebe, 2016)

Up to now, no adverse risks from human pathogens have been associated with the current practice of *de facto* potable water reuse in Berlin. However, especially persistent and polar chemicals can be detected in extracted groundwater at elevated concentrations. While these compounds are mostly unregulated, the German EPA has published health advisory values for most detected trace organic chemicals. In Berlin, some of these values are exceeded in several production wells forcing the Berlin Water Company to properly manage pumping rates to minimize final concentration in the blended finished drinking water.

4.4 Potential benefits and drawbacks to the environment by engaging more broadly in planned non-potable water reuse

The planned use of reclaimed water in agriculture is an option that is increasingly being adopted in regions with water scarcity, increasing urban populations, and growing demand for irrigation water. Reclaimed water use can help mitigating the damaging effects of local water scarcity and to substitute limited freshwater supplies for other urban and industrial uses with higher economic value than for most agricultural purposes (FAO, 2010). Remaining nutrients contained in reclaimed water can help reducing fertilizer needs in agriculture. The planned reuse of wastewater effluents instead of their discharge will also result in a significant load reduction of organic matter, nutrients, pathogens, and trace organic chemicals which might represent immediate benefits to the environmental health of receiving streams. In regions where freshwater supplies are already scarce or might become more stressed in the future due to climate change impacts, the degree of effluent discharge to a receiving stream can increase further due to a lack of dilution, which might represent an additional driver to engage in planned water reuse programs instead. The Case Studies presented in this study clearly illustrated that surface water qualities in areas where agricultural irrigation is practiced are impacted by wastewater effluents to a significant degree. These irrigation water qualities in particular during times of low-flow conditions very likely are currently not meeting the EU Commission document for good produce hygiene, the values proposed in the JRC report for irrigation of crops eaten raw, or existing national water reuse guidelines of individual Member States.

Engaging more broadly in planned non-potable water reuse requires that the reclaimed water quality used for various non-potable reuse practices is safe for the users and not compromising local groundwater, surface water or soil qualities. Multiple planned reuse applications in Europe and around the world have demonstrated that the use of reclaimed water for such an application can be a safe practice. It should be noted that re-directing flows towards reuse instead of receiving streams might also negatively affect ecological conditions of the stream in particular during low-flow conditions where wastewater effluents have contributed a steady stream flow supply in the past. Thus, not the entire volume of wastewater effluents in areas of high reuse demand might be available where environmental base flows also need to be maintained. Many non-potable reuse applications (e.g., agricultural irrigation; cooling water) exhibit high seasonal dependencies which requires either storage options or alternative reuse practices during off-season. While storing reclaimed water or alternative reuse options might not be feasible in many locations, reclaimed water is commonly discharged to streams during off-season periods, which might result in highly dynamic changes of the receiving water body.

Irrigation water from surface and groundwater is only measured where water is supplied by public networks or in well managed irrigation districts. However, a substantial portion of irrigation water in Southern Europe is abstracted illegally for example from groundwater wells on site, unless metering and reporting is enforced by law (Weirdt et al., 2008). This short-sighted and not sustainable abstraction practice due to economic considerations is important to address where planned water reuse programs are being proposed. Multiple studies have been performed in the past to demonstrate long-term environmental and economic benefits of planned water reuse. A feasibility study for a reuse scheme in Northern Italy conducted a cost benefit analysis of water reuse for agriculture. The benefits from reducing the impact of droughts on agriculture were estimated to be more than €1 million per year. There were also environmental benefits estimated at €5.3 million based on the improvement of the quality of the water of the canal currently receiving the effluent. The conclusion of the study was that, despite important investment costs, the switch to reuse was financially sound with a payback period of 20 years (Amec Foster Wheeler, 2016).

Planned water reuse does challenge the traditional frameworks of water allocation, funding structures, deriving water quality standards, regulatory framework and compliance, and institutional mandates (FAO, 2010). These issues need to be addressed and properly managed. The concern about the risks to public health from an increasing use of reclaimed water is a serious obstacle to a wider acceptance of this practice. However, unplanned water reuse is also associated with a risk that might not be properly managed in all cases, as illustrated in this study for case studies representing examples for agriculture irrigation and also managed aquifer recharge. This consequence of assuming “pristine” surface water conditions for current irrigation practices should be considered in overall water resource planning. Thus, well planned and executed water reuse programs and applying consistent risk-based standards for agricultural irrigation have the potential to reduce the overall risk to workers, the public and the environment while offering an alternative and sustainable water supply.

5. Conclusions

Scope of the Study

Every time municipal wastewater treatment plant effluents are discharged to the aquatic environment the water reenters the hydrological cycle. This unintentional or *de facto* water reuse scenario is likely widespread but a comprehensive documentation quantifying the degree of impact by wastewater effluent discharge on European river basins is lacking. As a consequence, where wastewater effluents account for a substantial fraction of a river the source water quality might adversely impact downstream non-potable and potable use options, aquatic life, or local groundwater qualities.

Many downstream users and regulatory bodies have not made any explicit notion of this conditions and common water resource management refers to ‘surface’ or ‘river’ water assuming an appropriate quality for various non-potable and potable uses. Thus, assessments are urgently needed to identify situations where acceptable risk levels using effluent-impacted surface water are exceeded and proper mitigation strategies are needed. In order to establish safer practices, these strategies might involve additional treatment barriers or the use of alternative supplies including direct use of treated wastewater effluents (reclaimed water) providing it meets approved standards.

Criteria for reuse of reclaimed water have been developed by several EU Member States (i.e., Cyprus, France, Greece, Italy, Portugal and Spain). In general, there is little harmony among existing water reuse standards of Member States and there is concern that this can create some trade barriers across Europe for agricultural goods irrigated with reclaimed water and a perception among end users that there are different levels of safety for similar irrigation practices. To overcome this issue and to foster water reuse as a core element of the EU action plan for the Circular Economy, the Joint Research Centre (JRC) was asked by the European Commission to develop a technical proposal for minimum quality requirements for water reuse in agricultural irrigation and groundwater recharge. This most recent draft of this proposal was presented in June 2017 (JRC, 2017).

In order to assess policy options regarding requirements for water reuse via agricultural irrigation and groundwater recharge, the European Commission requested an additional source of information. The aim of this study was to benchmark the current degree of unplanned water reuse in Europe, in particular in areas that are practicing agriculture irrigation using surface water. This assessment included a characterization of qualities of water sources currently used in agricultural irrigation in the EU, including direct and indirect reuse of treated wastewater. In addition, the extent of unplanned reuse and the impact of the development of planned (and direct) water reuse has been assessed for case studies in selected EU river basins in Spain, Italy, France and Germany.

Characterization of qualities of water sources currently used in agricultural irrigation in the EU

The abstraction of water for irrigation varies by member state and according to location and season and water use for agriculture can increase to 60% during the summer. Consumption is markedly higher in southern and southeastern Europe than elsewhere across the continent, accounting for more than 60% of total freshwater abstraction. More than half of the water used in agriculture is from groundwater abstraction in Austria, Denmark, Hungary, Germany, the Netherlands, and Slovakia. For over 40% of farms in Italy, Greece, Slovenia and Cyprus, irrigation water comes from off-farm water supply sources, which are usually fed by surface water sources like rivers or lakes, surface run-off, groundwater, and reclaimed water.

According to the Food and Agriculture Organization of the United Nations (FAO), the main water quality issues of surface water or groundwater use in irrigated agriculture are associated with salinity, specific ion toxicity, excessive nutrients, and a change of the water infiltration rate. These issues are being addressed in the FAO water quality guidelines for irrigation considering surface or groundwater (Ayers and Westcot, 1994). The source of irrigation water can be impaired by the presence of pathogens resulting in potentially adverse effects for farm workers and consumers of fresh produce. In addition, the occurrence of trace organic chemicals (e.g., pesticides, antibiotics) could be an additional concern if they have the potential to accumulate in produce, but these issues are not further specified in the FAO guidelines.

To date, no databases on microbial quality of irrigation water have been compiled. The degree of microbial contamination of natural sources of water (like lake or river water, shallow groundwater or rainwater) and sources partially impaired by wastewater discharges can vary significantly and is dependent upon several factors. There is a substantial database available on microbial water quality parameters of surface waters based on indicator organisms or human-specific pathogens including bacteria, viruses and protozoa. However, this information is of limited value for estimating risk for produce contamination due to deficiencies in location, timing and/or frequency of sampling, and incomplete coverage of the entire transmission and exposure path.

The EU Commission has recently proposed a *'Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene'* to address the public health risks posed by pathogens in food of non-animal origin, addressing in particular the risk factors and the mitigation options including possible microbiological criteria. This guidance document suggests a risk assessment considering the source and the intended use of agricultural water defining the suitability for agricultural purposes, the recommended microbiological threshold values of a fecal indicator (i.e. *Escherichia coli*), and the frequency of monitoring. It also recommends that microbial analyses of the potential water sources should be performed to determine the suitability of the water source for its use as agricultural water.

Extent of unplanned reuse in select EU river basins

Since many surface waters in the majority of EU regions that practice agriculture irrigation are also receiving discharge from municipal wastewater effluents, the quality of these streams can be impaired due to the introduction of pathogens, organic chemicals or elevated levels of nutrients and other salts. While previous studies have quantified the degree of wastewater discharge to a stream mainly based on flow data, assessing the degree of impact on water quality is more difficult since site-specific conditions (i.e., local degree of mixing and dilution; upstream load prior to discharge; in-stream attenuation processes like biodegradation or photolysis; etc.) need to be considered. In addition, specific studies that have investigated impacts on river water quality are available, but frequently these are limited to certain river stretches, specific water quality parameters, or did not quantify the degree of upstream wastewater discharge.

Thus, for the purpose of providing a relative risk assessment of unplanned water reuse using impaired surface water, the following assumptions were made for a risk exemplar. A hypothetical pristine stream is impacted to different degrees by discharge of a secondary treated wastewater effluent (i.e., representing impacts of 5, 10, 20, and 50% discharge of wastewater). It is assumed that the secondary effluent meets the requirements of the EU UWWT Directive and that pathogens being discharged to the river will survive for a few days, potentially a few weeks. Where the degree of discharge of non-disinfected wastewater to a receiving stream is exceeding a certain value and this impaired source water is used downstream for agriculture irrigation, it is likely that elevated levels of pathogens might be present in the irrigation water.

The results of this risk exemplar suggest that even high dilution ratios (10% and less wastewater effluents in the receiving streams) will result in a downstream water quality that will likely exceed the fecal indicator values of *E. coli* as specified in the EU Commission guidance document for good produce hygiene as well as the values proposed in the JRC report for irrigation of crops eaten raw (Class A and Class B). While the survival of these pathogens will depend on local environmental conditions (i.e., biomass present; photolysis, etc.), it is very likely that any surface water that is being abstracted within a few hours to days downstream of this discharge point will be compromised and exceed background levels of pathogens my several orders of magnitude.

To estimate the degree of unplanned agricultural water reuse in EU river basins, various case studies were selected in three EU Member States (namely Spain, Italy and France). The dilution ratio was used to assess the degree of unplanned water reuse, representing the ratio between treated wastewater effluent flows to stream flow for a particular location or flow measurement section. Within the Ebro river basin in Spain, these results suggest that the degree of impact from wastewater discharge to the Segre river basin can vary between 3 and 11% depending on flow conditions in the stream. In particular, river stretches of the Segre river from Balaguer to Lleida were characterized by 5 and 11% wastewater impact and are located in areas that widely use surface water for irrigation in agriculture. For the Llobregat river district, the degree of impact from wastewater effluents was estimated to vary between 8 and 82% on average, in particular in river stretches that are dominated by agricultural irrigation. In Italy, watersheds in the Lombardy were selected and both the Adda and the Oglio rivers exhibited degrees of impact varying between 7-27% and 4-15%, respectively. During times of high flow this degree of impact seems not be significant, but during low flow conditions which usually occur during periods of high irrigation demand, the degree of impact can vary between 14 and 68%. In France, river basins of the Loir and Montpellier rivers were selected. The degree of impact from wastewater effluents along the Loir river varied only between 0.3 and 2.6% on average, which is not of concern, but during low flow conditions values can increase up to 24%. For the Montpellier river basin, the degree of impact varied between 1.5 and 51% on average.

The Case Studies presented in this study clearly illustrated that surface water qualities in areas in different regions of Europe where agricultural irrigation is practiced are impacted by wastewater effluents to a significant degree. These irrigation water qualities in particular during times of low-flow conditions are - very likely - currently not meeting the EU Commission document for good produce hygiene, the values proposed in the JRC report for irrigation of crops eaten raw, or existing national water reuse guidelines of individual Member States.

Potential benefits and drawbacks to the environment by engaging more broadly in planned non-potable water reuse

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This study is considered a first quantitative attempt to estimate the degree of *de facto* reuse in European river basins. However, additional work is needed in order to update the assessment of unplanned water reuse within selected river basins of the EU since data availability of the degree of impact and the scope of this study has been limited.

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Appendix

Table A-1 Existing standards for water reuse for agriculture in various countries

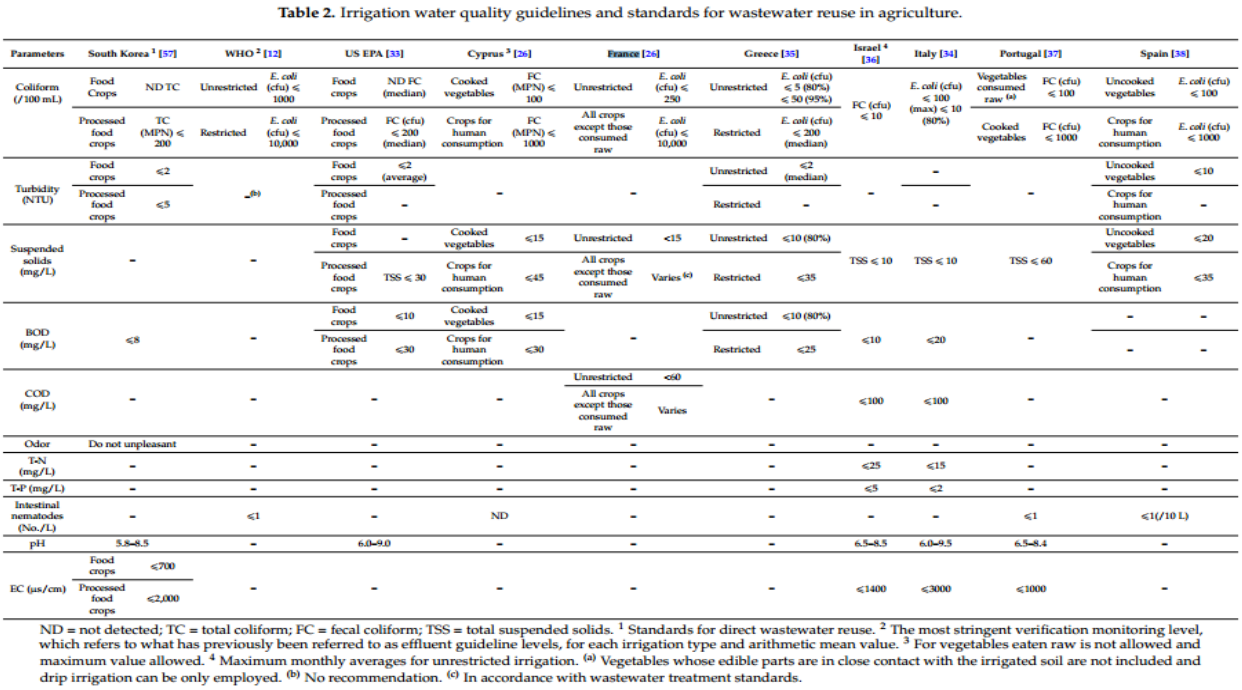


Table 2. Irrigation water quality guidelines and standards for wastewater reuse in agriculture.

Parameters	South Korea [1] [57]		WHO [2] [12]		US EPA [33]		Cyprus [3] [26]		France [26]		Greece [35]		Israel [4] [36]	Italy [34]	Portugal [37]		Spain [38]	
Coliform (/100 mL)	Food Crops	ND TC	Unrestricted	*E. coli* (cfu) ≤ 1000	Food crops	ND FC (median)	Cooked vegetables	FC (MPN) ≤ 100	Unrestricted	*E. coli* (cfu) ≤ 250	Unrestricted	*E. coli* (cfu) ≤ 5 (80%) ≤ 50 (95%)	FC (cfu) ≤ 10	*E. coli* (cfu) ≤ 100 (max) ≤ 10 (80%)	Vegetables consumed raw (a)	FC (cfu) ≤ 100	Uncooked vegetables	*E. coli* (cfu) ≤ 100
	Processed food crops	TC (MPN) ≤ 200	Restricted	*E. coli* (cfu) ≤ 10,000	Processed food crops	FC (cfu) ≤ 200 (median)	Crops for human consumption	FC (MPN) ≤ 1000	All crops except those consumed raw	*E. coli* (cfu) ≤ 10,000	Restricted	*E. coli* (cfu) ≤ 200 (median)			Cooked vegetables	FC (cfu) ≤ 1000	Crops for human consumption	*E. coli* (cfu) ≤ 1000
Turbidity (NTU)	Food crops	≤2	–(b)		Food crops	≤2 (average)	–		–		Unrestricted	≤2 (median)	–	–	–		Uncooked vegetables	≤10
	Processed food crops	≤5			Processed food crops	–					Restricted	–		–			Crops for human consumption	–
Suspended solids (mg/L)	–		–		Food crops	–	Cooked vegetables	≤15	Unrestricted	<15	Unrestricted	≤10 (80%)	TSS ≤ 10	TSS ≤ 10	TSS ≤ 60		Uncooked vegetables	≤20
					Processed food crops	TSS ≤ 30	Crops for human consumption	≤45	All crops except those consumed raw	Varies (c)	Restricted	≤35					Crops for human consumption	≤35
BOD (mg/L)	≤8		–		Food crops	≤10	Cooked vegetables	≤15	–		Unrestricted	≤10 (80%)	≤10	≤20	–		–	–
					Processed food crops	≤30	Crops for human consumption	≤30			Restricted	≤25					–	–
COD (mg/L)	–		–		–		–		Unrestricted	<60	–		≤100	≤100	–		–	
									All crops except those consumed raw	Varies								
Odor	Do not unpleasant		–		–		–		–		–		–	–	–		–	
T-N (mg/L)	–		–		–		–		–		–		≤25	≤15	–		–	
T-P (mg/L)	–		–		–		–		–		–		≤5	≤2	–		–	
Intestinal nematodes (No./L)	–		≤1		–		ND		–		–		–	–	≤1		≤1(/10 L)	
pH	5.8–8.5		–		6.0–9.0		–		–		–		6.5–8.5	6.0–9.5	6.5–8.4		–	
EC (μs/cm)	Food crops	≤700	–		–		–		–		–		≤1400	≤3000	≤1000		–	
	Processed food crops	≤2,000																

ND = not detected; TC = total coliform; FC = fecal coliform; TSS = total suspended solids. [1] Standards for direct wastewater reuse. [2] The most stringent verification monitoring level, which refers to what has previously been referred to as effluent guideline levels, for each irrigation type and arithmetic mean value. [3] For vegetables eaten raw is not allowed and maximum value allowed. [4] Maximum monthly averages for unrestricted irrigation. (a) Vegetables whose edible parts are in close contact with the irrigated soil are not included and drip irrigation can be only employed. (b) No recommendation. (c) In accordance with wastewater treatment standards.

Table A-2 Existing regulation for water reuse for agriculture in Italy (according to Legislation DM185/2003)

Parameter	Unit	Value
pH		6-9,5
SAR		10
Gross materials		None
Total Suspended Solids	mg/L	10
BOD5	mg O_2/L	20
COD	mg O_2/L	100
P tot	mg P/L	2
N tot	mg N/L	15
NH4	mg NH_4/L	2
Electrical conductivity	µS/cm	3000
Al	mg/L	1
As	mg/L	2
Ba	mg/L	10
Be	mg/L	0.1
Cd	mg/L	0.005
Co	mg/L	0.05
Cr tot	mg/L	0.1
Cr VI	mg/L	0.005
Fenoli totali	mg/L	2
Mn	mg/L	0.2
Hg	mg/L	0.001
Ni	mg/L	0.2
Pb	mg/L	0.1
Cu	mg/L	1
Selenium	mg/L	0.01
Sn	mg/L	3
Tl	mg/L	0.001
Vanadium	mg/L	0.1
Zn	mg/L	0.5
Total cyanides	mg/L	0.05
Solphurs	mg H_2S/L	0.5
Active Cl	mg/L	0.2
Clorures	mg Cl/L	250
Fluorures	mg F/L	1.5
Animal/vegetable fats and oils	mg/L	10
Mineral oils	mg/L	0.05
Total phenols	mg/L	0.1
Pentachlorophenol	mg/L	0.003
Total aldeids	mg/L	0.5
Tetrechloroethylene, trichloroethylene	mg/L	0.01
Chlorinated solvents	mg/L	0.04
Trialomethanes	mg/L	0.03
Benzene	mg/L	0.001
Benzo(a)pyrene	mg/L	0.00001
Nitric organic solvents	mg/L	0.01
Total tensioactives	mg/L	0.5
Chrlorinate pesticides	mg/L	0.00001
Phosphorous pesticides	mg/L	0.00001
Other pesticides	mg/L	0.05
E. coli	CFU/100 mL	10
Salmonella		None

Table A-3 Existing regulation for water reuse for agriculture and landscape irrigation in France (according to Legislation JORF num. 0153, 4 July 2014)

Legislation: JORF num.0153, 4 July 2014		A	B	C	D
		Unrestricted irrigation of all crops, including those accessed by public	All crops except those consumed raw or green areas with public access	other ornamental crops, shrubs, cereals; horticultural crops drip irrigated, foressts with controlled acces	Forests with no access
TSS	mg/L	<15	In accordance with WWT standards		
COD	mg/L	<60			
Enterococci	logs	>= 4	>= 3	>= 2	>= 2
Bacteriophages	logs	>= 4	>= 3	>= 2	>= 2
Anaerobic sulforeducing bacteria spores	logs	>= 4	>= 3	>= 2	>= 2
E. coli	cfu/100 mL	<= 250, measured 1/week	<= 10,000, measured 1/15 days	<= 100,000, measured 1/month	-

Table A-4 Existing regulation for water reuse in Spain (according to Royal Decree 1620/2007)

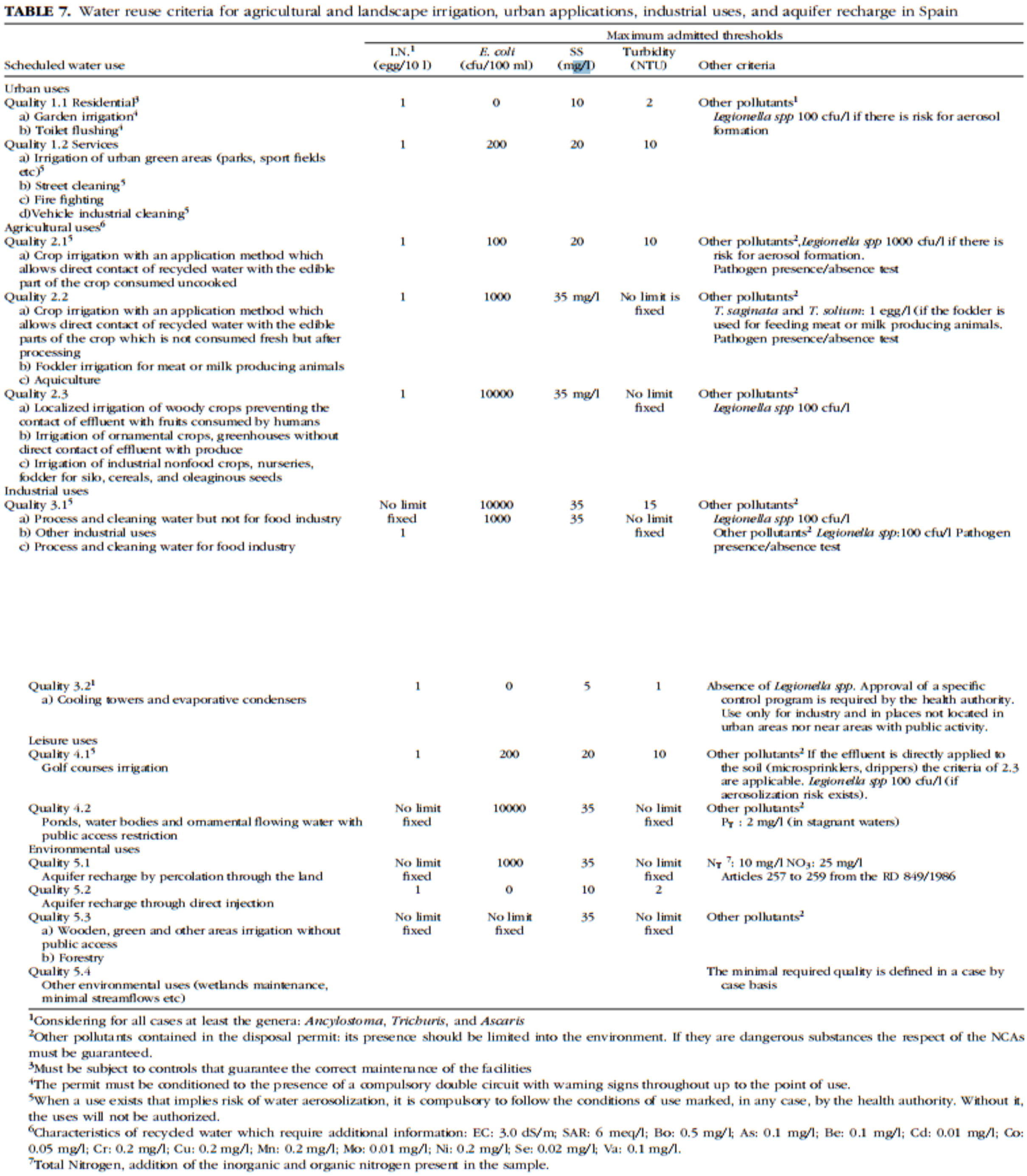


TABLE 7. Water reuse criteria for agricultural and landscape irrigation, urban applications, industrial uses, and aquifer recharge in Spain

	Maximum admitted thresholds				
Scheduled water use	I.N.[1] (egg/10 l)	*E. coli* (cfu/100 ml)	SS (mg/l)	Turbidity (NTU)	Other criteria
Urban uses					
Quality 1.1 Residential[3] a) Garden irrigation[4] b) Toilet flushing[4]	1	0	10	2	Other pollutants[1] *Legionella spp* 100 cfu/l if there is risk for aerosol formation
Quality 1.2 Services a) Irrigation of urban green areas (parks, sport fields etc)[5] b) Street cleaning[5] c) Fire fighting d)Vehicle industrial cleaning[5]	1	200	20	10	
Agricultural uses[6]					
Quality 2.1[5] a) Crop irrigation with an application method which allows direct contact of recycled water with the edible part of the crop consumed uncooked	1	100	20	10	Other pollutants[2],*Legionella spp* 1000 cfu/l if there is risk for aerosol formation. Pathogen presence/absence test
Quality 2.2 a) Crop irrigation with an application method which allows direct contact of recycled water with the edible parts of the crop which is not consumed fresh but after processing b) Fodder irrigation for meat or milk producing animals c) Aquiculture	1	1000	35 mg/l	No limit is fixed	Other pollutants[2] *T. saginata* and *T. solium*: 1 egg/l (if the fodder is used for feeding meat or milk producing animals. Pathogen presence/absence test
Quality 2.3 a) Localized irrigation of woody crops preventing the contact of effluent with fruits consumed by humans b) Irrigation of ornamental crops, greenhouses without direct contact of effluent with produce c) Irrigation of industrial nonfood crops, nurseries, fodder for silo, cereals, and oleaginous seeds	1	10000	35 mg/l	No limit fixed	Other pollutants[2] *Legionella spp* 100 cfu/l
Industrial uses					
Quality 3.1[5] a) Process and cleaning water but not for food industry b) Other industrial uses c) Process and cleaning water for food industry	No limit fixed 1	10000 1000	35 35	15 No limit fixed	Other pollutants[2] *Legionella spp* 100 cfu/l Other pollutants[2] *Legionella spp*:100 cfu/l Pathogen presence/absence test
Quality 3.2[1] a) Cooling towers and evaporative condensers	1	0	5	1	Absence of *Legionella spp*. Approval of a specific control program is required by the health authority. Use only for industry and in places not located in urban areas nor near areas with public activity.
Leisure uses					
Quality 4.1[5] Golf courses irrigation	1	200	20	10	Other pollutants[2] If the effluent is directly applied to the soil (microsprinklers, drippers) the criteria of 2.3 are applicable. *Legionella spp* 100 cfu/l (if aerosolization risk exists).
Quality 4.2 Ponds, water bodies and ornamental flowing water with public access restriction	No limit fixed	10000	35	No limit fixed	Other pollutants[2] P_T : 2 mg/l (in stagnant waters)
Environmental uses					
Quality 5.1 Aquifer recharge by percolation through the land	No limit fixed	1000	35	No limit fixed	N_T [7]: 10 mg/l NO_3: 25 mg/l Articles 257 to 259 from the RD 849/1986
Quality 5.2 Aquifer recharge through direct injection	1	0	10	2	
Quality 5.3 a) Wooden, green and other areas irrigation without public access b) Forestry	No limit fixed	No limit fixed	35	No limit fixed	Other pollutants[2]
Quality 5.4 Other environmental uses (wetlands maintenance, minimal streamflows etc)					The minimal required quality is defined in a case by case basis

[1] Considering for all cases at least the genera: *Ancylostoma*, *Trichuris*, and *Ascaris*

[2] Other pollutants contained in the disposal permit: its presence should be limited into the environment. If they are dangerous substances the respect of the NCAs must be guaranteed.

[3] Must be subject to controls that guarantee the correct maintenance of the facilities

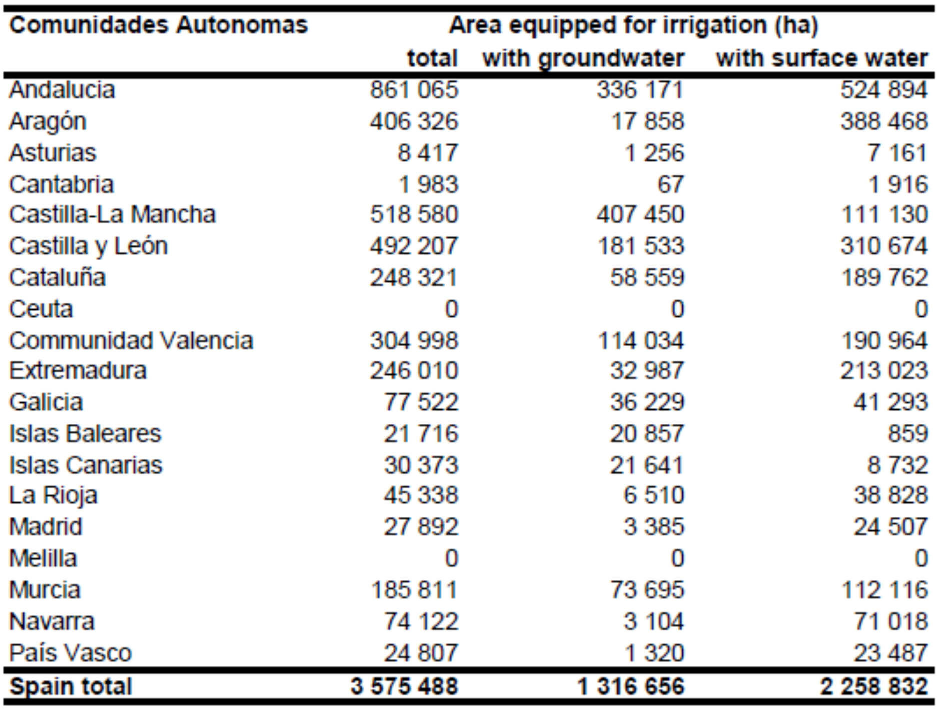
[4] The permit must be conditioned to the presence of a compulsory double circuit with warning signs throughout up to the point of use.

[5] When a use exists that implies risk of water aerosolization, it is compulsory to follow the conditions of use marked, in any case, by the health authority. Without it, the uses will not be authorized.

[6] Characteristics of recycled water which require additional information: EC: 3.0 dS/m; SAR: 6 meq/l; Bo: 0.5 mg/l; As: 0.1 mg/l; Be: 0.1 mg/l; Cd: 0.01 mg/l; Co: 0.05 mg/l; Cr: 0.2 mg/l; Cu: 0.2 mg/l; Mn: 0.2 mg/l; Mo: 0.01 mg/l; Ni: 0.2 mg/l; Se: 0.02 mg/l; Va: 0.1 mg/l.

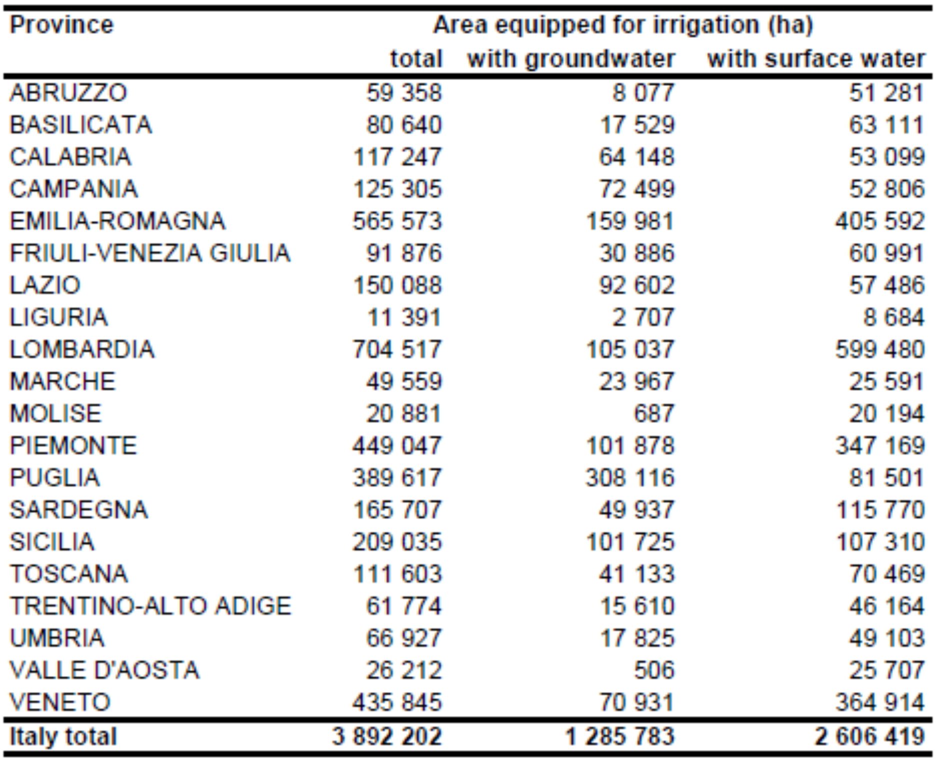
[7] Total Nitrogen, addition of the inorganic and organic nitrogen present in the sample.

Table A-5. Areas equipped for Irrigation with groundwater or surface water in Spain (Source: FAO, 2017)



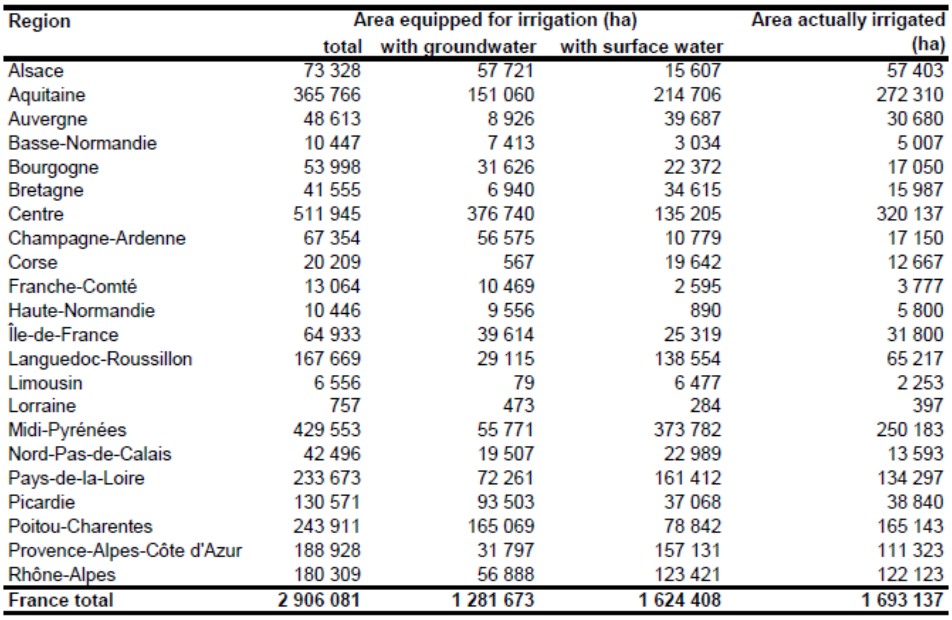
Comunidades Autonomas	Area equipped for irrigation (ha)		
	total	with groundwater	with surface water
Andalucia	861 065	336 171	524 894
Aragón	406 326	17 858	388 468
Asturias	8 417	1 256	7 161
Cantabria	1 983	67	1 916
Castilla-La Mancha	518 580	407 450	111 130
Castilla y León	492 207	181 533	310 674
Cataluña	248 321	58 559	189 762
Ceuta	0	0	0
Communidad Valencia	304 998	114 034	190 964
Extremadura	246 010	32 987	213 023
Galicia	77 522	36 229	41 293
Islas Baleares	21 716	20 857	859
Islas Canarias	30 373	21 641	8 732
La Rioja	45 338	6 510	38 828
Madrid	27 892	3 385	24 507
Melilla	0	0	0
Murcia	185 811	73 695	112 116
Navarra	74 122	3 104	71 018
País Vasco	24 807	1 320	23 487
Spain total	**3 575 488**	**1 316 656**	**2 258 832**

Table A-6. Areas equipped for Irrigation with groundwater or surface water in Italy (Source: FAO, 2017)



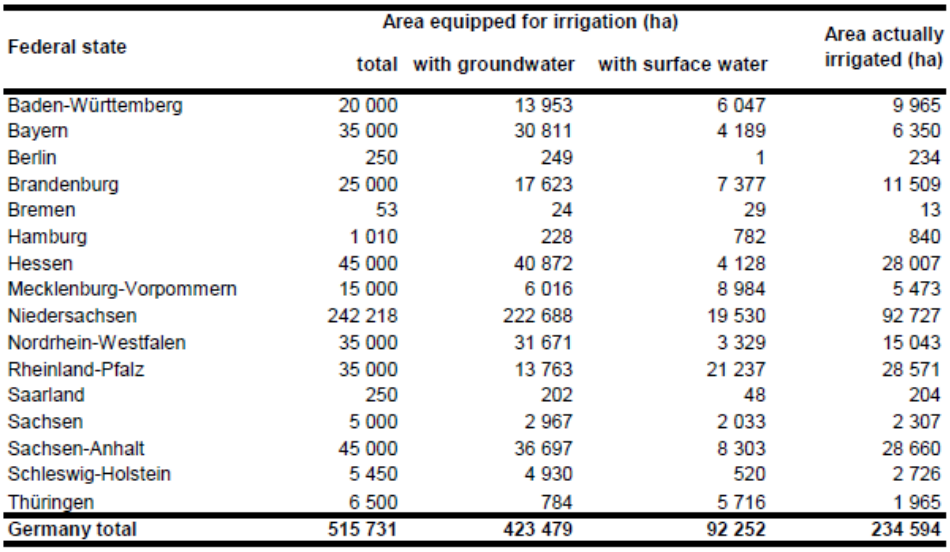
Province	Area equipped for irrigation (ha)		
	total	with groundwater	with surface water
ABRUZZO	59 358	8 077	51 281
BASILICATA	80 640	17 529	63 111
CALABRIA	117 247	64 148	53 099
CAMPANIA	125 305	72 499	52 806
EMILIA-ROMAGNA	565 573	159 981	405 592
FRIULI-VENEZIA GIULIA	91 876	30 886	60 991
LAZIO	150 088	92 602	57 486
LIGURIA	11 391	2 707	8 684
LOMBARDIA	704 517	105 037	599 480
MARCHE	49 559	23 967	25 591
MOLISE	20 881	687	20 194
PIEMONTE	449 047	101 878	347 169
PUGLIA	389 617	308 116	81 501
SARDEGNA	165 707	49 937	115 770
SICILIA	209 035	101 725	107 310
TOSCANA	111 603	41 133	70 469
TRENTINO-ALTO ADIGE	61 774	15 610	46 164
UMBRIA	66 927	17 825	49 103
VALLE D'AOSTA	26 212	506	25 707
VENETO	435 845	70 931	364 914
Italy total	**3 892 202**	**1 285 783**	**2 606 419**

Table A-7. Areas equipped for Irrigation with groundwater or surface water in France (Source: FAO, 2017)



Region	Area equipped for irrigation (ha) total	with groundwater	with surface water	Area actually irrigated (ha)
Alsace	73 328	57 721	15 607	57 403
Aquitaine	365 766	151 060	214 706	272 310
Auvergne	48 613	8 926	39 687	30 680
Basse-Normandie	10 447	7 413	3 034	5 007
Bourgogne	53 998	31 626	22 372	17 050
Bretagne	41 555	6 940	34 615	15 987
Centre	511 945	376 740	135 205	320 137
Champagne-Ardenne	67 354	56 575	10 779	17 150
Corse	20 209	567	19 642	12 667
Franche-Comté	13 064	10 469	2 595	3 777
Haute-Normandie	10 446	9 556	890	5 800
Île-de-France	64 933	39 614	25 319	31 800
Languedoc-Roussillon	167 669	29 115	138 554	65 217
Limousin	6 556	79	6 477	2 253
Lorraine	757	473	284	397
Midi-Pyrénées	429 553	55 771	373 782	250 183
Nord-Pas-de-Calais	42 496	19 507	22 989	13 593
Pays-de-la-Loire	233 673	72 261	161 412	134 297
Picardie	130 571	93 503	37 068	38 840
Poitou-Charentes	243 911	165 069	78 842	165 143
Provence-Alpes-Côte d'Azur	188 928	31 797	157 131	111 323
Rhône-Alpes	180 309	56 888	123 421	122 123
France total	**2 906 081**	**1 281 673**	**1 624 408**	**1 693 137**

Table A-8. Areas equipped for Irrigation with groundwater or surface water in Germany (Source: FAO, 2017)



Federal state	Area equipped for irrigation (ha) total	with groundwater	with surface water	Area actually irrigated (ha)
Baden-Württemberg	20 000	13 953	6 047	9 965
Bayern	35 000	30 811	4 189	6 350
Berlin	250	249	1	234
Brandenburg	25 000	17 623	7 377	11 509
Bremen	53	24	29	13
Hamburg	1 010	228	782	840
Hessen	45 000	40 872	4 128	28 007
Mecklenburg-Vorpommern	15 000	6 016	8 984	5 473
Niedersachsen	242 218	222 688	19 530	92 727
Nordrhein-Westfalen	35 000	31 671	3 329	15 043
Rheinland-Pfalz	35 000	13 763	21 237	28 571
Saarland	250	202	48	204
Sachsen	5 000	2 967	2 033	2 307
Sachsen-Anhalt	45 000	36 697	8 303	28 660
Schleswig-Holstein	5 450	4 930	520	2 726
Thüringen	6 500	784	5 716	1 965
Germany total	**515 731**	**423 479**	**92 252**	**234 594**

Table A-9. Matrix to support microbial risk assessment of agricultural water (EU Commission, 2017)

Intended use of the water	Source of water[60]						Indicator of fecal contamination: *E. coli* [61]
	Untreated surface water/ open water channels[62]	Untreated ground water collected from wells[63]	Untreated Rain water	Treated[64] sewage/ surface/ waste water/ water reuse	Disinfected water [65]	Municipal water	
PRE-HARVEST and HARVEST							
Irrigation of FFVs likely to be eaten uncooked (i.e. ready-to-eat FFV) (irrigation water comes into direct contact with the edible portion of the FFV) Dilution or application of pesticide, fertiliser or agrochemicals and cleaning equipment for ready-to-eat FFV and direct contact.	x	x	▲	●	●	√	100 CFU/100ml
Irrigation of FFVs likely to be eaten uncooked (i.e. ready-to-eat FFV) (irrigation water does not come into direct contact with the edible portion of the FFV) Dilution or application of pesticide, fertiliser or agrochemicals and cleaning equipment for ready-to-eat FFV and no direct contact	x	x	▲	●	●	√	1,000 CFU/100ml[66]
Irrigation of FFVs likely to be eaten cooked (irrigation water comes into direct contact with the edible portion of the FFV). Dilution or application of pesticide, fertiliser or agrochemicals and cleaning equipment used in this FFV direct contact).	▲	▲	●	●	●	√	1,000 CFU/100ml
Irrigation of FFVs likely to be eaten cooked (irrigation water does not come into direct contact with the edible portion of the FFV). Dilution or application of pesticide, fertiliser or agrochemicals and cleaning equipment used in this FFV (no direct contact)	●	●	√	√	√	√	10,000 CFU/100ml
POST-HARVEST							
Post-harvest cooling and post-harvest transport for non-ready-to-eat FFVs. Water used for first washing of products in case of ready-to-eat products. Cleaning equipment and surfaces where the products are handled.	x	x	▲	●	●	√	100 CFU/100ml
Water used for washing of products likely to be eaten cooked (potatoes…) – non ready-to-eat FFVs.	▲	▲	●	●	●	√	1,000 CFU/100ml
ONLY POTABLE WATER[67]							
Final washing and ice/water for cooling applied for ready-to-eat FFV	x	x	▲	●	●	√	Microbiological requirements of potable water

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[60] Water applied by irrigation within two weeks prior to harvest of FFVs that may be eaten uncooked (ready-to-eat) should be free of contamination, i.e. as potable quality wherever possible.

[61] These recommended thresholds relate to maximum concentration in samples.

[62] Surface water and Ground water from wells (e.g. boreholes) might be of good microbiological quality and meet the 100 CFU/100 ml thresholds without treatment.

[63] Surface water and Ground water from wells (e.g. boreholes) might be of good microbiological quality and meet the 100 CFU/100 ml thresholds without treatment.

[64] For the purpose of this matrix, treated sewage water means wastewater that has been treated so that its quality is fit for the intended use and complies with the standards established by the national legislation of the MS or, in the absence of such national legislation, with WHO guidelines on the safe use of wastewater and excreta in agriculture.

[65] Disinfection treatment should be well controlled and monitored. The applied disinfection treatment is under control of the grower or producer.

[66] Since the irrigation water does not come into contact with the edible part of the FFV a higher standard should be applied. Irrigation methods such as drip or sub-surface will present a lower risk of contaminating the edible part of a lettuce FFV than overhead irrigation.

[67] Multiple sources of water of be used but it must be potable water quality which needs to be delivered. So, in practice it will be municipal water or disinfected water which can be used here.

The meaning of the signs' code and the numbers are the following (Water source):

x Dark Grey: should not be used. If the grower has no alternative but to use it, he should carry out high frequency testing or consider water treatment/disinfection, taking *E. coli* thresholds in column 8, as a meaningful indicator for an acceptable quality water to use in that activity.

▲ Medium-Dark Grey: can be used but subject to sampling. The grower should carry out testing with medium frequency, taking *E. coli* thresholds in column 8, as a meaningful indicator for an acceptable quality water to use in that activity.

● Light Grey: can be used but subject to sampling. The grower should carry out testing with low frequency, taking *E. coli* thresholds in column 8, as a meaningful indicator for an acceptable quality water to use in that activity.

√ White: can be used without any sampling or analysis or with only analysis required to monitor the disinfection of water.

Table A-10 presents validity ranges of rating curve equations used to calculate flow rate for both the Adda and Oglio gauging stations. This procedure was followed for all stations except the Pizzighettone station, for which flow rate data was sent separately, as it is the only station of interest with a working flow meter. Certain stations have more than one rating curve equations due to different natural and specific characteristics of the river sections, as well as fitting to different validity ranges.

Table A-10 Rating curve equations for Adda and Oglio river gauging stations.

River	Gauging station	Rating curve equation (m^3/s)	Validity range (m)
Adda	River Serio - Montodine	Q = 0.00027*(h+3.9249)^8.656	-3.0 < h ≤ -0.35
		Q = 41.71+91.43*h+58.775*h^2	-0.35 < h < 1
	Rivolta d'Adda	Q = 165.079*(h+1.71)^1.706	-1.345 < h < 0.25
	S.Maria Lavello	Q = 49.581*(h)^1.783	1.030 < h < 3.840
	Gera Lario Fuentes	Q = 188.3589*(h-0.5249)^1.5729	1.03 < h < 2.06
		Q = 127.116*(h-0.308)^2.0886	0.68 < h ≤1.03
Oglio	Marcaria	Q = 43.098*(h+1.399)^1.49	-1.09 < h < 3.29
	River Chiese - Asola	Q = 8.606*(h+0.026)^0.753	0.05 < h ≤ 0.335
		Q = 47.081*(h-0.1876)^1.309	0.335 < h ≤ 0.84
		Q = 56.922*(h-0.342)^1.127	0.84 < h < 3.56
	River Mella - Manerbio	Q = 32.051*(h-0.495)^1.407	0.60 < h < 2.98
	Soncino	Q = 119.785*(h+0.148)^1.587	0.01 < h < 1.11
		Q = 54.737*(h+0.535)^3.548	-0.10 < h ≤ 0.01
	Capriolo	Q = 27.141*(h+2.415)^2.274	-2 < h < -0.15

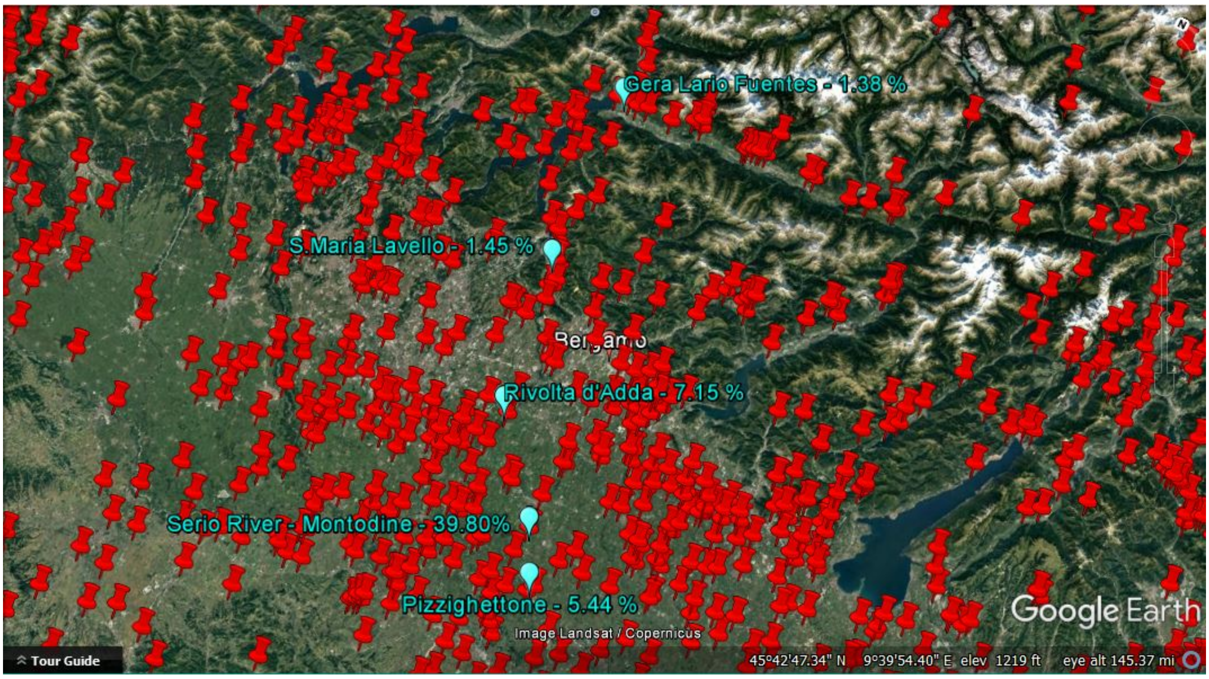

Figure A-1 Location of wastewater treatment plants in the Adda river basin district with the degree of wastewater impact for specific gauging stations

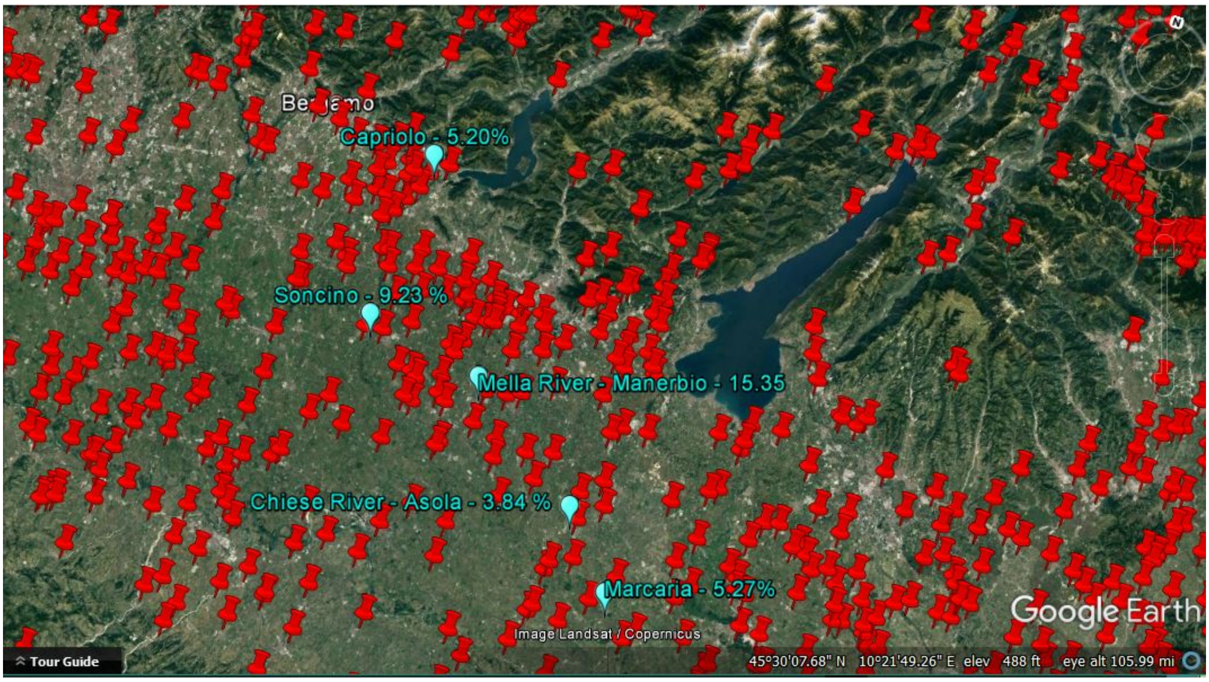

Figure A-2 Location of wastewater treatment plants in the Oglio river basin district with the degree of wastewater impact for specific gauging stations

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