Study of the impacts of pressures on groundwater in Europe

SERVICE CONTRACT No 3415/B2020/EEA.58185

Analysis of groundwater associated aquatic ecosystems (GWAAEs) and groundwater dependent terrestrial ecosystems (GWDTEs)

Sub-study 2 - First draft report

June 2021

Report for:

Nihat Zal & Caroline Whalley
European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Prepared by:

Alexander Psomas (Brilliant Solutions Engineering and Consulting P.C.)
George Bariamis (Brilliant Solutions Engineering and Consulting P.C.)
Josselin Rouillard (Ecologic Institut gemeinnützige GmbH)
Ulf Stein (Ecologic Institut gemeinnützige GmbH)
Susie Roy (Wood Group UK Ltd.)

Issued by:

....
Alexander Psomas, Project Manager

Brilliant Solutions Engineering and Consulting P.C.
V. Hugo St, 15, 74100, Rethymno, Greece

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Suggested citation:

Psomas, A., Bariamis, G., Rouillard, J., Stein, U., Roy, S., 2021. *Analysis of groundwater associated aquatic ecosystems (GWAAEs) and groundwater dependent terrestrial ecosystems (GWDTEs).* Study of the impacts of pressures on groundwater in Europe, Service Contract No 3415/B2020/EEA.58185. pp. 31

Version	Description	Date
1.0	First draft report	20.04.2021
1.1	Revised final draft report	11.06.2021
2.0	Approved consolidated final report	23.06.2021

Contents

List of abbreviations

This document uses a series of abbreviations, which are provided below for the sake of clarity to the reader.

BD	Birds Directive
EEA	European Environment Agency
EQS	Environmental Quality Standards
EQSD	Environmental Quality Standards Directive
ETC BD	European Topic Centre on Biodiversity
EU 27_2020	27 EU Member States by 2020, after exit of UK
GWAAE	Groundwater Associated Aquatic Ecosystems
GWB	Groundwater Body
GWD	Groundwater Directive
GWDTE	Groundwater Dependent Terrestrial Ecosystems
HD	Habitats Directive
IED	Industrial Emissions Directive
NBS	Nature-Based Solutions
NWRMs	Natural Water Retention Measures
RBMPs	River Basin Management Plans
SWB	Surface Water Body
WFD	Water Framework Directive, Directive 2000/60/EC
WISE	Water Information System for Europe

Key findings

- Groundwater associated aquatic ecosystems (GWAAEs) and groundwater dependent terrestrial ecosystems (GWDTE) are an important part of Europe's natural capital and heritage, and they provide numerous ecosystems services, including carbon sequestration, climate change mitigation and adaptation, purification of surface and groundwater, natural water retention, biodiversity conservation, and provision of cultural services.

- However, 81% of habitats and 63% of species in Europe have less than favourable conservation status, while 62% of rivers, 51% of lakes, 61% of transitional waters and 51% of coastal waters have less than good ecological status/potential in the 2nd RBMPs. Ecology in Europe is in critical situation, despite observed progress, which should be acknowledged and continued

- Approximately 44% of the total GWB area in the EU 27 is linked with GWAAEs, and 53% with GWDTEs, which makes them quite widespread and exposed to pressures. GWAAEs and GWDTEs are mainly affected by agricultural pressures, while other significant pressures are related to public water supply, industrial development, and mining activities. The most significant type of pressures causing less than good groundwater status is those pressures related to water quality. Over-abstraction by different economic activities is also a main type of pressures. Increased frequency and intensity of droughts, due to climate change, may exacerbate the existing pressures on GWBs linked with GWAAEs and GWDTEs.

- The most affected types of aquifers linked with GWAAEs and GWDTEs are shallow porous aquifers, as well as fissured and karstic aquifers, in the uppermost groundwater horizons.

- Approximately one third of the GWB area, which is linked with GWAAEs or GWDTEs, was in poor quantitative or chemical status in the 2nd RBMPs. Furthermore, around 5% of the total GWB area in the EU 27 had poor quantitative or chemical status, and it was also linked with GWAAEs having less than good ecological or chemical status and less than favourable habitat conservation status. Similarly, 7% of the total GWB area had poor quantitative or chemical status, and it was also linked with GWDTEs having less than favourable habitat conservation status.

- A wide policy framework is in place to support the sustainable management of GWBs linked with GWAAEs and GWDTEs, such as: the EU Biodiversity Strategy 2030, which is a cornerstone of the European Green Deal; the Habitats and the Birds Directives; the Water Framework Directive, supported by the Groundwater Directive and the Environmental Quality Standards Directive; the EU Climate Change Adaptation Strategy; the Zero Pollution Action Plan.

1 Introduction

1.1 Key benefits and EU actions for the protection of groundwater associated surface waters and dependent terrestrial ecosystems

The surface waters which are associated with groundwater, as well as the ecosystems contained in them (GWAAEs), and the terrestrial ecosystems which are dependent on groundwater (GWDTEs), encompass a wide variety of freshwater, coastal and terrestrial habitats spread all across Europe. These habitats are considered an important part of Europe's **natural capital and heritage** (CIS, 2015) and they provides important ecosystems services.

The **key benefits** from the protection and conservation of GWWAEs and GWDTEs include (Klöve et al., 2011):

- Intensive *sequestration* of carbon dioxide (CO_2), with wetlands and peatlands having a carbon capture capacity which is double that of forests. Hence, they serve as global carbon sinks, regulating the climate and contributing to climate change mitigation goals. Their destruction could release high amounts of CO_2 in the atmosphere (Loisel et al., 2021).
- *Purification* of surface and groundwaters through geochemical and microbiological processes, which retard and remove pollutants. This partly contributes to the delivery of high quality and safe raw water. Thus, the necessary treatment costs for drinking water use are reduced.
- Facilitation of *water storage*, *infiltration* and *deep percolation*, as well as retardation of surface run-off, supporting *flood mitigation*. Therefore, they serve as natural water retention measures ("NWRMs") and nature-based solutions ("NBS"), contributing to climate change adaptation goals.
- Enhanced *biodiversity*, since they serve as hubs for numerous species and complex ecosystems.
- Provision of a stable *source of water abstraction* for households, agriculture and industries, which has the capacity to buffer the impacts of climate variability on water supply.
- Economic gains for society, due to increased *resilience* of exploitable populations of fish, animals and vegetation, and the provision of *breeding sites* for wildfowl and game stocks.
- Delivery of *cultural services*, such as leisure, recreational, aesthetic or spiritual services.

The EU has taken significant action to protect and conserve ecosystems. The **Nature Directives** (i.e. HD and BD) are from the oldest, and the Natura 2000 areas are a well-established effort to designate areas that need special protection in the EU. The HD (EU, 1992) aims at supporting the conservation of a wide range of rare, threatened or endemic animal and plant species, establishing conservation areas for about 200 habitat types of EU interest. Furthermore, the BD (EU, 2009) requires the creation of special protection areas to protect key bird species of EU interest. Many of these areas also include ecosystems which are dependent on groundwater in varying degrees. In 2016, the HD and the BD were assessed to be fit-for-purpose. However, the fulfilment of their objectives also relies upon better implementation and coordination with other EU directives and policies.

The **EU Biodiversity Strategy 2030** (EU, 2020), which is a key component of the **European Green Deal** (EU, 2019), sets ambitious restoration targets for improving biodiversity condition and reversing fragmentation of habitats, sustaining wetlands and enforcing environmental flows in surface waters (e.g. through improved abstraction control).

Many habitats characterised as GWAAEs/GWDTEs are already protected under of the EU Nature Directives (HD, BD) and the EU Biodiversity Strategy. This was a result of the priority given to Natura 2000 sites, when assessing their potential habitats to be characterised as GWAAEs/GWDTEs.

Furthermore, the **Water Framework Directive** (WFD; EU, 2000), supported by the daughter directives, the **Groundwater Directive** (GWD; EU, 2006) and **Environmental Quality Standards Directive** (EQSD; EU, 2008), sets out standards for water quality (including sediments and biota), as well as assessment tests for the condition of GWAAEs and GWDTEs, as part of the overall assessment for the GWB status. Therefore, the WFD promotes explicitly an ecosystem-based approach for the management of GWB status.

The latest WFD implementation report on the 2nd RBMPs (EC, 2019a) shows that an increasing number of EU Member States consider the impacts of groundwater management on low flow conditions of associated rivers, the impacts of chemical pressures from groundwater on surface waters (mostly rivers), and the impacts of groundwater status on the condition of Natura 2000 sites. Furthermore, Member States reported that they have established or they were establishing water allocation regimes (e.g. permits, concessions, water rights), whose objectives include meeting ecological flow requirements (EC, 2019a). However, the link between GWBs and GWAAEs/GWDTEs is not always made, with several countries not accounting for GWAAEs/GWDTEs in their groundwater status assessments. In addition, challenges remain in the implementation and effective enforcement of existing water allocation regimes. The remaining gaps in groundwater and ecosystem management also require better, smarter and more coordinated monitoring efforts. The 3rd RBMPs for the 2021-2027 period, which are currently in preparation, will include an update on progress made towards targets.

The recent Fitness Check of the WFD (EC, 2019b) put emphasis on the need to adopt more integrated approaches, highlighting the systemic linkages between drivers, pressures, state, impacts and responses to environmental degradation.

The **EU Communication on water scarcity and drought policy** is also in place (EU, 2007). However, the implementation of the relevant policy options and the development of Drought Management Plans, or even their integration with River Basin Management Plans, has been slow and insufficient (EC, 2019a).

The new **EU Climate Change Adaptation Strategy** (EC, 2021a) and the **Zero Pollution Action Plan** (EC, 2021b) have been recently added in the EU policy framework, addressing significant aspects of water management, such as climate change adaptation and mitigation of pollution.

1.2 Scope and outline of this report

This report presents an **analysis of groundwater associated aquatic ecosystems (GWAAEs) and groundwater dependent terrestrial ecosystems (GWDTEs)** in the 27 EU Member States (EU 27_2020)[1].

Initially, the report takes into account the *concepts and definitions of GWAAEs and GWDTEs* according to the WFD, as well as relevant *literature* on the topic. Based on them, it identifies European habitats, which are commonly classified under these categories (i.e. **"conceptual" cross-walk analysis between the WFD and HD definitions**), and explores their conservation status (see section 1.3).

Furthermore, the report analyses the *interdependencies* between the chemical or quantitative status of GWBs, the chemical or ecological status/potential of associated SWBs, and the conservation status of GWAAEs and GWDTEs.

As a start, the above analysis of interdependencies is based on an EU-wide analysis of spatial and tabular data, which are reported at the EU level, including those reported under the WFD and the HD

[1] EU 27_2020, or EU 27 in short, is used in this report for the 27 EU Member States as of 1 February 2020; thus, accounting for the withdrawal of the United Kingdom from the European Union

(i.e. **"technical" cross-walk analysis between the WFD and HD data**). The reporting under the BD was not in the scope of the analysis. The underlying data on ecological and chemical status/potential of SWBs, as well as on the quantitative and chemical status of GWBs, have been extracted from the WFD reporting of the 2nd River Basin Management Plans (RBMPs) for the period 2009-2015. Furthermore, the underlying data on the conservation status of aquatic and terrestrial habitats have been extracted from the HD reporting under Art. 17 for the period 2007-2013.

As a result of the above technical cross-walk analysis, the study identified various cases, where interdependencies between the GWBs and the GWAAEs/GWDTEs are "highly likely"[2]. Moreover, the analysis addressed the **key drivers and pressures causing less than good status** in those GWBs linked with GWAAEs/GWDTEs in less than favourable conservation status.

The analysis of interdependencies between GWBs and GWAAEs/GWDTEs is further complemented with relevant cases from literature, reporting such interdependences.

1.3 Methodology: Key conventions and definitions for this study

Definition of "GWAAE" and "GWDTE" in the study

This study adopts the definitions of the WFD for a GWAAE and a GWDTE (Box 1.1).

Box 1.1 Definition of "GWAAE" and "GWDTE" in the WFD

"*GWAAE*" is a term introduced in the WFD to describe "an aquatic ecosystem that is contained within one or more surface water bodies (e.g. rivers, lakes, transitional or coastal water bodies), whose ecological or chemical status, or the relevant environmental objectives, could be affected by alterations of the groundwater level or concentrations of pollutants transmitted through groundwater" (CIS, 2015).

"*GWDTE*" is "a terrestrial ecosystem that is directly dependent on a GWB, which provides the necessary water flow, water level or water quality to sustain the terrestrial ecosystem. It is more likely to have a critical dependence upon a GWB, where a GWB supplies water to the terrestrial ecosystem for a significant part or a significant time period of the year" (CIS, 2011).

Four common cases can be distinguished for GWDTEs (CIS, 2011).:

a) a groundwater source directly supplies the ecosystem and is visible as a spring or seepage, for instance a spring-fed terrestrial ecosystem, where high calcium content of the groundwater precipitates as tufa in the terrestrial ecosystems;

b) groundwater collected above impermeable strata, such as clay, in depressions in the landscape (e.g. fens and marshes) in which characteristic flora is directly influenced by the chemical composition of the groundwater it receives;

c) high groundwater tables maintain a seasonally waterlogged condition, for instance dune sands discharges in so-called 'wet slacks';

[2] It is not in the scope of the current study to investigate further the local evidence for each and every area illustrated on the generated maps. Therefore, the reader should understand the illustrated areas on maps as potential cases where such interdependencies may occur. Such cases require more detailed analysis at the local level, though. In addition, the maps may not illustrate cases with real interdependencies, if relevant data are not reported at all or there are reporting gaps which do not allow their illustration.

d) a seasonally fluctuating groundwater table floods depressions intermittently, creating seasonal (ephemeral) lakes with a characteristic flora.

It should be noted that there are also other ecosystems associated with groundwater, such as "*stygofauna*". These are rare and unique life forms dwelling within groundwater bodies (e.g. water found in caves, cavities, holes, etc.), and affecting nutrient cycling through storage, processing, recycling, and acquisition of nutrients (Smith et al., 2016; Iannella et al., 2020). However, these types of ecosystems are not further studied in this report and they are not part of the analysis.

Cross-walk analysis between the WFD and HD definitions and data

The European Topic Centre on Biodiversity (ETC BD) and EEA have conducted recent work to categorise the HD Annex I habitats types in broad ecological groups (ecogroups). The current study has adopted the proposed grouping (Halada et al., 2020), in order to identify those ecogroups which match more closely the WFD definitions of GWAAEs and GWDTEs.

The study has conducted a conceptual and technical cross-walk analysis, which has resulted in the **working definition and mapping of GWAAEs and GWDTEs for the purposes of this study** (see further below and next chapters).

For **key methodological challenges** regarding this cross-walk analysis between the WFD and the HD, please read further *Annex 5*.

A) Definition of GWAAEs with spatial analysis of HD Annex I habitat types under the ecogroup "freshwater aquatic habitats" (see further *Annex 3*) and reported data under the WFD on SWBs linked with GWBs.

In general, aquatic habitats include ecosystems contained in inland freshwaters, transitional waters, coastal waters and (off-shore) marine waters. Although, conceptually, a GWAAE may be hosted in any of the above types of waters, except for marine waters, the primary focus of this study is placed on freshwater aquatic habitats.

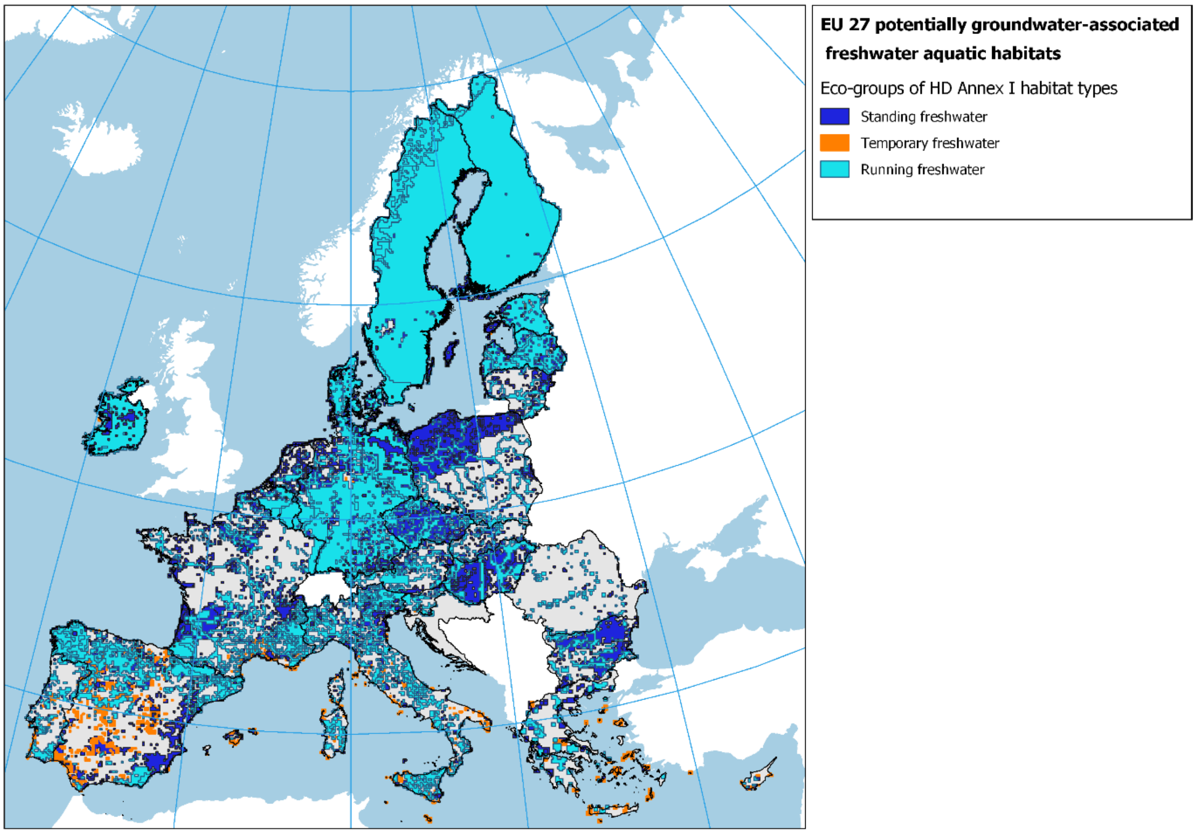
Inland freshwater aquatic habitats include ecosystems, which are commonly contained in permanent freshwaters (either running or standing), as well as in intermittent/ephemeral or temporary freshwaters. Typically, when using the term "freshwater aquatic habitats", we are referring to ecosystems contained in streams, rivers, ponds, lakes, springs, artificial reservoirs, canals, etc.

This study considers as "freshwater aquatic habitats", all those HD Annex I habitat types which have been defined by Halada et al. (2020) under the ecogroup "4A – Freshwater aquatic habitats". This ecogroup consists of 22 HD Annex I habitat types, which are presented in more detail in *Annex 3*.

Map 1.1 shows the HD Annex I habitat types belonging to the ecogroup of freshwater aquatic habitats (in three sub-categories; i.e. standing, temporary and running freshwaters). The map focuses on the extent of the EU27.

The proposal for the above ecogroup by Halada et al. (2020), was already based on a conceptual cross-walk analysis, which was conducted by EC(2013) and defined freshwater aquatic habitats using HD Annex I habitat types. Furthermore, it was linked to work conducted by Solheim et al. (2019) on a broad typology of European rivers and lakes.

Map 1.1 EU 27 freshwater aquatic habitats.



Note: The term "freshwater aquatic habitats" includes all those HD Annex I habitat types which have been defined by Halada et al. (2020) under the ecogroup "4A – Freshwater aquatic habitats".
Source: Authors' compilation based on data from Habitats Directive – HD Art. 17 reporting (2007-2013) (EEA, 2020c)

It should be highlighted that the SWBs containing freshwater aquatic ecosystems are not necessarily linked with GWBs. Therefore, only those SWBs linked to GWBs could be potentially characterised as GWAAEs. Since EU Member States report under the WFD which SWBs are linked with GWBs, this reporting is used in this study to identify and map the relevant SWBs and linked GWBs.

Finally, the study has conducted a technical crosswalk analysis between the HD and WFD spatial data for the types of habitats and SWBs mentioned above. The relevant boundaries of freshwater aquatic habitats and the boundaries of SWBs linked with GWBs have been overlayed. Where matching, the relevant SWBs have been isolated, and they have been considered as "SWBs containing freshwater aquatic habitats, while also being linked with GWBs". Therefore, they are assumed as GWAAEs to be further explored in this study.

In section 3.2, the study has identified and mapped those GWBs which are linked with GWAAEs, and meet the following criteria:

- GWBs in poor quantitative or chemical groundwater status under the WFD.
- SWBs in less than good ecological or poor chemical status under the WFD, which are linked with the previous GWBs.
- GWAAEs in less than favourable conservation status under the HD, which spatially overlay the previous SWBs.

B) Definition of GWDTEs with spatial analysis of HD Annex I habitat types under the ecogroups "terrestrial habitats in need of high level of groundwater" and "freshwater riparian and alluvial habitats" (see further *Annex 4*) and reported data under the WFD on SWBs linked with GWDTEs.

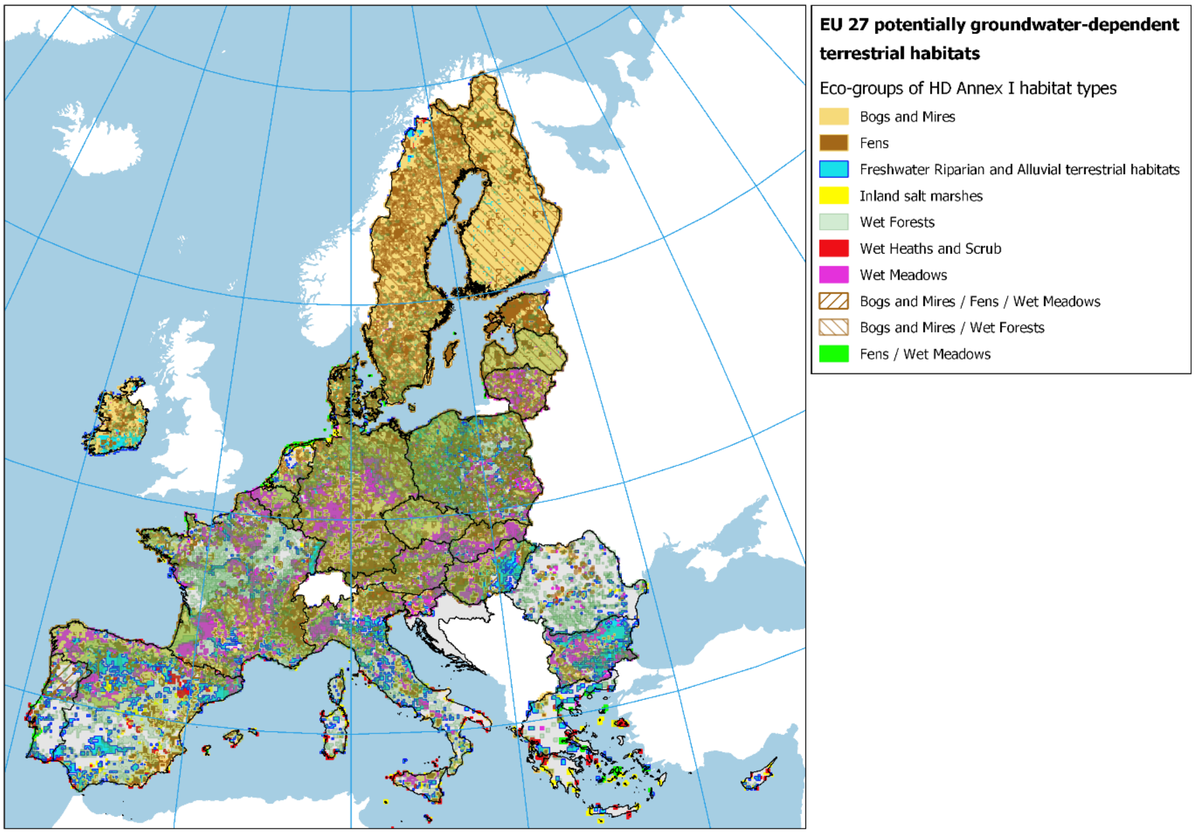
Terrestrial habitats can rely on a series of sources for the necessary supply of water to sustain their ecosystem functions, including: precipitation; lateral inundation from adjacent rivers or lakes with fluctuating stages; groundwater flows in the form of seepage, spring discharges, fluctuating groundwater tables and waterlogging. Such terrestrial ecosystems are generally considered water-dependent, because water supply and the respective water quality are significant to them.

Where a water-dependent terrestrial ecosystem is particularly more dependent on groundwater supply and its quality, then it may be characterised as a GWDTE. Typically, GWDTEs may include habitats, such as marshes, meadows, swamps, wet slacks, wet heaths and scrubs, wet forests/woodlands, mangroves, wetlands and peatlands (e.g. fens, bogs and mires).

This study considers as "potentially groundwater-dependent terrestrial habitats", all those HD Annex I habitat types which have been defined by Halada et al. (2020) under the ecogroup "4E – Terrestrial habitats in need of high level of groundwater" and "4D - Freshwater riparian and alluvial habitats". These two ecogroups include 25 HD Annex I habitat types, which are presented in more detail in *Annex 4*.

Map 1.2 shows the HD Annex I habitat types belonging to the ecogroups of terrestrial habitats in need of high level of groundwater (in nine sub-categories; e.g. bogs and mires, fens, inland salt marshes), as well as freshwater riparian and alluvial habitats. The map focuses on the extent of the EU27.

Map 1.2 EU 27 potentially groundwater-dependent terrestrial habitats



Note: The term "potentially groundwater-dependent terrestrial habitats" includes all those HD Annex I habitat types which have been defined by Halada et al. (2020) under the ecogroup "4E – Terrestrial habitats in need of high level of groundwater" and "4D - Freshwater riparian and alluvial habitats".
Source: Authors' compilation based on data from Habitats Directive – HD Art. 17 reporting (2007-2013) (EEA, 2015)

It should be highlighted that the above habitats considered as potential groundwater-dependent terrestrial habitats are not necessarily linked with GWBs. These habitats may be commonly characterised as dependent on groundwater, but the attestation of each case relies upon detailed hydrogeological and hydro-ecological analysis locally and regionally. Since EU Member States report under the WFD which GWBs are linked with GWDTEs, this reporting is used in this study to identify the relevant GWBs and map their locations.

As a note, endemic habitats, which are specific only to a specific geographical location, have been excluded. Therefore, the study focuses only on common and widespread habitats across Europe.

Finally, the study has conducted a technical crosswalk analysis between the HD and WFD spatial data for the habitats and GWBs mentioned above. The relevant boundaries of potential groundwater-dependent terrestrial habitats and the boundaries of GWBs linked with GWDTEs have been overlayed. Where matching, the relevant GWBs have been isolated, and they have been considered as "GWBs linked with GWDTEs". Therefore, they are further explored in this study.

In section 3.2, the study has identified and mapped those GWBs which are linked with GWDTEs, and meet the following criteria:

- GWBs in poor quantitative or chemical groundwater status under the WFD.
- GWDTEs in less than favourable conservation status under the HD, which spatially overlay the previous GWBs.

Labelling potential combinations of WFD status of water bodies in the study

According to the WFD, a GWB is assessed for both its quantitative and chemical status, and a surface water body for both its ecological and chemical status. Further, heavily modified or artificial surface water bodies are assessed for their ecological potential and chemical status. For definition of these terms, please read further *Annex 1*.

Furthermore, according to the HD, species or habitats are assessed for their conservation status. For definition of these terms, please read further *Annex 2*.

In addition, for the purposes of this report, the labelling of the potential combinations of the quantitative and chemical status of GWBs or the potential combinations ecological and chemical status/potential of surface water bodies are labelled following the **conventions** shown in Table 1.1. This approach was used because the report aims at developing deeper insights into the different types of failure of good status, examining individual failures due to poor quantitative/chemical/ecological status, and especially combinations of these. It is noted that, according to the "one-out-all-out principle", the overall status assessment of a water body in the 1st and 2nd RBMPs is determined by the quality element or the status assessment with the worst classification according to the WFD. Thus, in WFD assessments, less than good overall status of GWBs corresponds to failure of the good quantitative status or chemical status or both. Similarly, less than good overall status of SWBs corresponds to failure of the good ecological status/potential or chemical status or both. The reader is reminded that "less than good ecological status/potential" of SWBs corresponds to moderate, poor or bad status/potential.

Table 1.1 Conventions for labelling groundwater and surface water body status in this report

Groundwater body status label in this report	WFD Quantitative groundwater body status	WFD Chemical groundwater body status	WFD Overall groundwater body status
"Good quantitative & chemical"	Good	Good	Good
"Poor quantitative & chemical"	Poor	Poor	Less than good
"Failing good quantitative only"	Poor	Good	Less than good
"Failing good chemical only"	Good	Poor	Less than good
"Unknown mixed"	Unknown	Poor	Less than good
	Poor	Unknown	Less than good
	Unknown	Good	Unknown
	Good	Unknown	Unknown
"Unknown"	Unknown	Unknown	Unknown

Surface water body status label in this report	WFD Ecological surface water body status/potential	WFD Chemical surface water body status	WFD Overall surface water body status
"Good ecological & chemical"	High or Good	Good	Good
"Less than good ecological & chemical"	Less than good	Poor	Less than good
"Less than good ecological only"	Less than good	Good	Less than good
"Less than good chemical only"	High or Good	Poor	Less than good
"Unknown mixed"	Unknown	Poor	Less than good
	Less than good	Unknown	Less than good
	Unknown	Good	Unknown
	High or Good	Unknown	Unknown
"Unknown"	Unknown	Unknown	Unknown

2 Overview of key features of GWAAEs and GWDTEs

2.1 GWAAEs in a nutshell

Aquatic species (e.g. macrophytes, phytoplankton-algae, fish, benthic invertebrates) and their ecosystems rely on a continued supply of water to their aquatic habitats. The input groundwater quantity (e.g. volumes, stages, flows) or quality (e.g. temperature, oxygen level, acidity/alkalinity, nutrient load, etc.) may affect the ecological or chemical status of these ecosystems. It is noted that certain GWAAEs are more sensitive to groundwater quantity, others more sensitive to groundwater quality, and others are sensitive to both (CIS, 2015; Box 2.1). Consequently, depending on the type of sensitivity of the relevant GWAAE, a serious disruption to normal groundwater quantity or quality may impact the GWAAE significantly. Even if the pressures are mitigated, the recovery times of the respective species and ecosystems can be variant and very dependent on the type of the species and ecosystem.

Box 2.1 Indicative examples of GWAAEs across Europe.

Lakes: "turloughs/turluchs", Ireland (temporary lakes, critically dependent on groundwater quantity and quality); Ohrid lake, Albania and North Macedonia (permanent lake, critically dependent on groundwater quantity and quality);

Rivers: "winterbourne rivers", UK (temporary -ephemeral- rivers usually flowing in winter, critically dependent on groundwater quantity); River Itchen, UK (permanent alkaline river, critically dependent on groundwater quantity and quality);

Springs: Po river valley, Italy; "pingos", UK (spring waters, critically dependent on groundwater quantity);

Rivers/Lakes/Estuaries: Lule river, Sweden (small spaces in sediments, e.g. in hyporheic zones of rivers, used as spawning habitat of salmon and refugia for salmon fry, critically dependent on groundwater quality, e.g. stable oxic conditions and temperature);

Transitional/Coastal: Sylt, Germany (temporary groundwater-fed freshwater seeps on tidal flats, critically dependent on groundwater quantity); Horsens estuary, Denmark (estuary receiving permanent flow of groundwater, but not critically dependent on groundwater)

Source: CIS, 2015

In the 2nd RBMPs (2009-2015), EU 27 Member States reported that almost 4,000 individual GWBs are linked with over 30,000 individual SWBs. Therefore, we may estimate that there are at least 30,000 GWAAEs in the EU 27. GWAAEs are most commonly reported in Croatia, France, Hungary, Ireland, Latvia, Luxembourg, and Poland, taking into account the share of the total length or area of SWBs linked with GWBs.

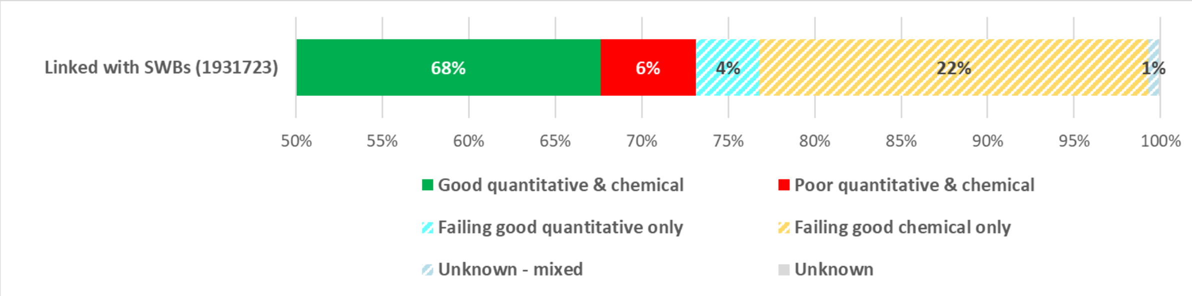
Furthermore, the GWAAEs are reported to be predominantly rivers (87%) and lakes (10%). Transitional and coastal waters represented less than 1% of the reported GWAAEs in total. There is currently no information, if this is a result of physical reality or knowledge gaps on such links between GWBs and transitional or coastal waters. Therefore, some caution is needed with interpretations about the extent of such links in the EU 27.

However, from a technical perspective, the above results support the exclusion of transitional and coastal aquatic habitats from the technical cross-walk analysis conducted between the WFD and HD data (see section: 1.3).

The GWBs linked with GWAAEs are widespread across Europe and, most commonly, they are shallow and porous aquifers. It is estimated that 28% of the total number of GWBs in the EU 27 are linked with GWAAEs, covering almost 44% of the total GWB area. In addition, nearly 50% of this GWB area linked with GWAAEs is made up of porous aquifers. Fissured (including karstic), fractured and insignificant aquifers take up the remaining 50%. The high dependence of GWAAEs on porous aquifers is rather expected because the porous aquifers are the most widespread geological formation in the GWBs reported under the WFD, and they are typically found in alluvial deposits in the riparian zones of rivers and lakes. In addition, the vertical and horizontal flow in these aquifers is usually easier and faster compared to other geological formations. Therefore, the establishment of links with SWBs is facilitated. The links between GWBs and GWAAEs are also more common, where the distance to the SWB is low (e.g. aquifers with shallow unsaturated zone; karstic formations discharging through surface springs into rivers and lakes). Around 85% of the total GWB area linked with GWAAEs is reported to be situated the uppermost groundwater horizons (e.g. horizon 1 or horizons linked to horizon 1). GWBs found in deeper horizons are less likely to be linked with GWAAEs, but such cases are also reported. Although the exact mechanism linking GWBs in deep horizons with GWAAEs is not reported, it is likely that this happens because of geological outcrops, significant slope changes in landscape morphology or (karstic) springs.

Around 32% of the GWB area reported to be linked with SWBs in the 2nd RBMPs were in less than good status, mostly due to a poor chemical status (28%), whereas a poor quantitative status was a less likely reason (10%) (Fig. 2.1). The reporting also shows that the GWBs not linked with SWBs are generally in better status, because surface pollution is less affecting them (see sub-study 1, Psomas et al., 2021).

Figure 2.1 Groundwater status for GWBs linked with SWBs in the EU 27 in the 2nd RBMPs (in % of total GWB area of linked GWBs).



Note: The reported total GWB area linked with SWBs is given in brackets (in km^2)

Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020b)

Finally, it should be noted that the links between GWBs and SWBs are complex, with multiple GWBs discharging into one SWB or multiple SWBs being recharged by one GWB. Inter alias, the size of the GWB area affects the number of such links, as larger GWBs are usually associated with a larger number of SWBs. Our technical analysis showed that half of the linked GWBs are discharging into up to 5 SWBs on average. Furthermore, the interactions between GWBs and SWBs can vary in time, as a result of natural processes or human-induced pressures.

Box 2.2 Temporal variations in interactions between GWBs and SWBs

In various landscapes and hydrogeological contexts, GWBs and SWBs can be linked. Such linkages may occur permanently or they can be seasonal. Such links may also be impacted by extreme periods of droughts or floods.

Water may flow from GWBs to SWBs or vice-versa, depending on the change of the water stages/pressures in the GWBs and SWBs. Thus, the direction of the flow may alter moving from higher stage/pressure to lower. The SWBs usually gain water from the GWBs throughout the year, with the greatest recharge occurring during the wet season (e.g. autumn-winter), when the groundwater tables are the highest. However, the recharge from GWBs to SWBs may be more critical during the dry season of the year or during prolonged periods of drought, when the surface run-off and rainfall are low (Cantor et al., 2018). The storage potential of groundwater in aquifers, and the relatively slow time for its discharge, mean that the recharge from GWBs to SWBs continues even when the SWB is not directly fed by recent rainfall. This baseflow provided by GWBs plays a significant role in sustaining minimum ecological flows (“e-flows”) in SWBs.

Furthermore, if reduced groundwater recharge or over-abstraction cause the groundwater table to fall below the bed of the linked river or lake, then the SWB becomes perched. In this case, the flow is reversed and the perched SWB recharges the GWBs. Where surface water quality is poor, this may lead to pollution of the groundwater (Cantor et al., 2018). Since groundwater abstractions points tend to be located within river plains, to take advantage of the higher transmissivity in such areas, the leakage of polluted surface water to groundwater can lead to pollution of drinking water sources.

2.2 GWDTEs in a nutshell

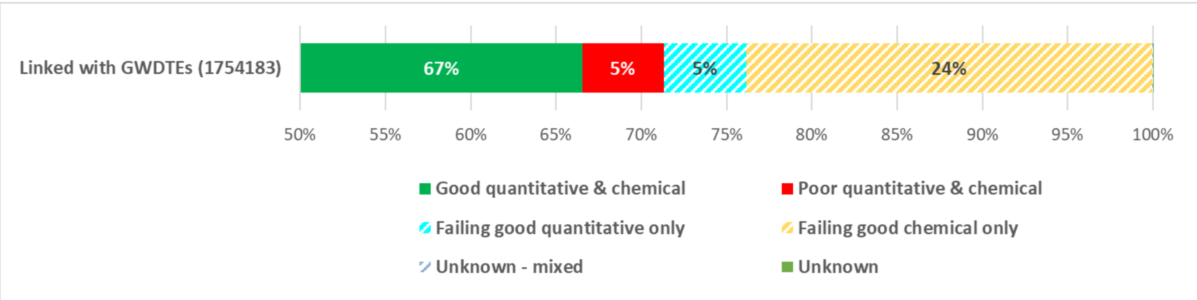
Certain terrestrial ecosystems are commonly dependent on groundwater quantity and quality. Typically, such terrestrial ecosystems include marshes, meadows, swamps, wet slacks, wet heaths and scrubs, wet forests/woodlands, mangroves, wetlands and peatlands (e.g. fens, bogs and mires). Therefore, where the normal supply of groundwater and/or groundwater quality are significantly altered, such GWDTEs, and the relevant species of wild flora or fauna they include, may be severely damaged.

In the 2nd RBMPs (2009-2015) EU Member States reported that there are over 3,000 individual GWBs linked with GWDTEs in the EU 27. GWDTEs take up significant shares of the total country area, where they are reported. For instance, they take up more than 50% of the country area in Austria, Belgium, Bulgaria, Croatia, Denmark, Estonia, France, Germany, Hungary, Latvia, Luxembourg, the Netherlands and Poland.

The GWBs linked with GWDTEs are widespread across Europe and, most commonly, they are shallow and porous aquifers, similarly to the observations made for GWBs linked with GWAAEs. These GWBs account for 23% of the total number of the GWBs in the EU 27, and they cover almost 53% of the total GWB area. Approximately 50% of this GWB area linked with GWDTEs is made up of porous aquifers, while the remaining 50% is made up of fissured (including karstic), fractured and insignificant aquifers. In addition, 79% of the total GWB area linked with GWDTEs is reported to be situated in the uppermost groundwater horizons (e.g. horizon 1 or horizons linked to horizon 1). GWBs found in deeper horizons are less likely to be linked with GWDTEs, but such cases are also reported in Austria, Bulgaria, Denmark, Hungary, Italy, Latvia and Sweden. The reasons for the high dependence on porous aquifers in the uppermost groundwater horizons are similar to those explained previously for GWBs linked with GWAAEs (see section 2.1).

Around 34% of the GWB area reported to be linked with GWDTEs in the 2nd RBMPs were in less than good status, mostly due to a poor chemical status (29%), whereas a poor quantitative status was a less likely reason (10%) (Fig. 2.2). The results are similar to those observed for GWBs linked with GWAAEs (see section 2.1).

Figure 2.2 Groundwater status for GWBs linked with GWDTEs in the EU 27 in the 2nd RBMPs (in % of total GWB area of linked GWBs).



Note: The reported total GWB area linked with GWDTEs is given in brackets (in km^2)

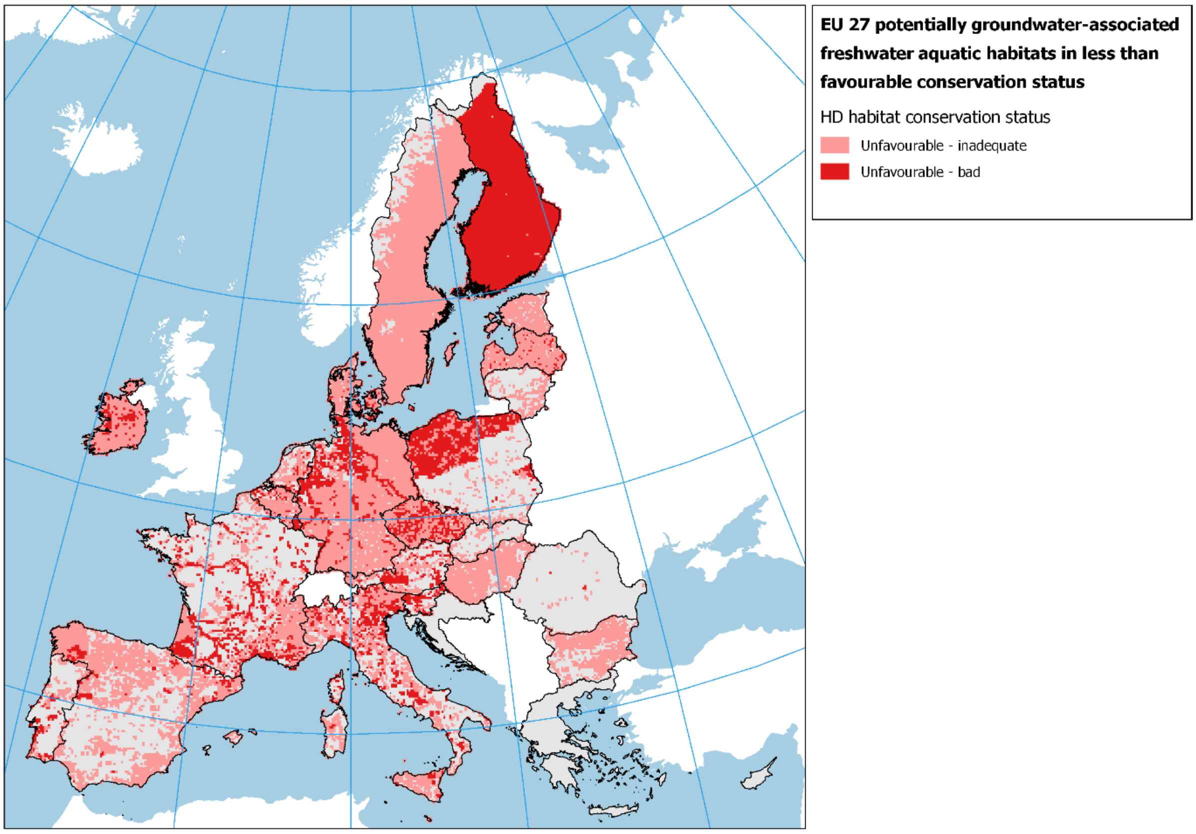
Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020b)

3 Key drivers and pressures affecting GWBs linked with GWAAEs and GWDTEs

3.1 Pressures causing less than favourable conservation status of habitats

According to the most recent reporting under the Habitats Directive (HD; EU, 1992) and the Birds Directive (BD; EU, 2009), 81% of habitats and 63% of species in Europe are in less than favourable conservation status (EEA, 2020a). Freshwater aquatic habitats (Map 3.1), as well as terrestrial habitats in need of high level of groundwater and freshwater riparian and alluvial habitats (Map 3.2), commonly have less than favourable conservation status according to the HD reporting (EEA, 2020c). Wetlands in Europe have been significantly affected in the past decades, with nearly two thirds of them having vanquished before the 1990s. The situation was reversed between 2006-2012, with land use trends suggesting a slight increase (EEA, 2018). Furthermore, 62% of rivers, 51% of lakes, 61% of transitional waters and 51% of coastal waters were in less than good ecological status/potential, according to the 2nd RBMPs (EEA, 2020b). The above results underline the critical situation of ecology in Europe, despite observed progress, which should be acknowledged and continued.

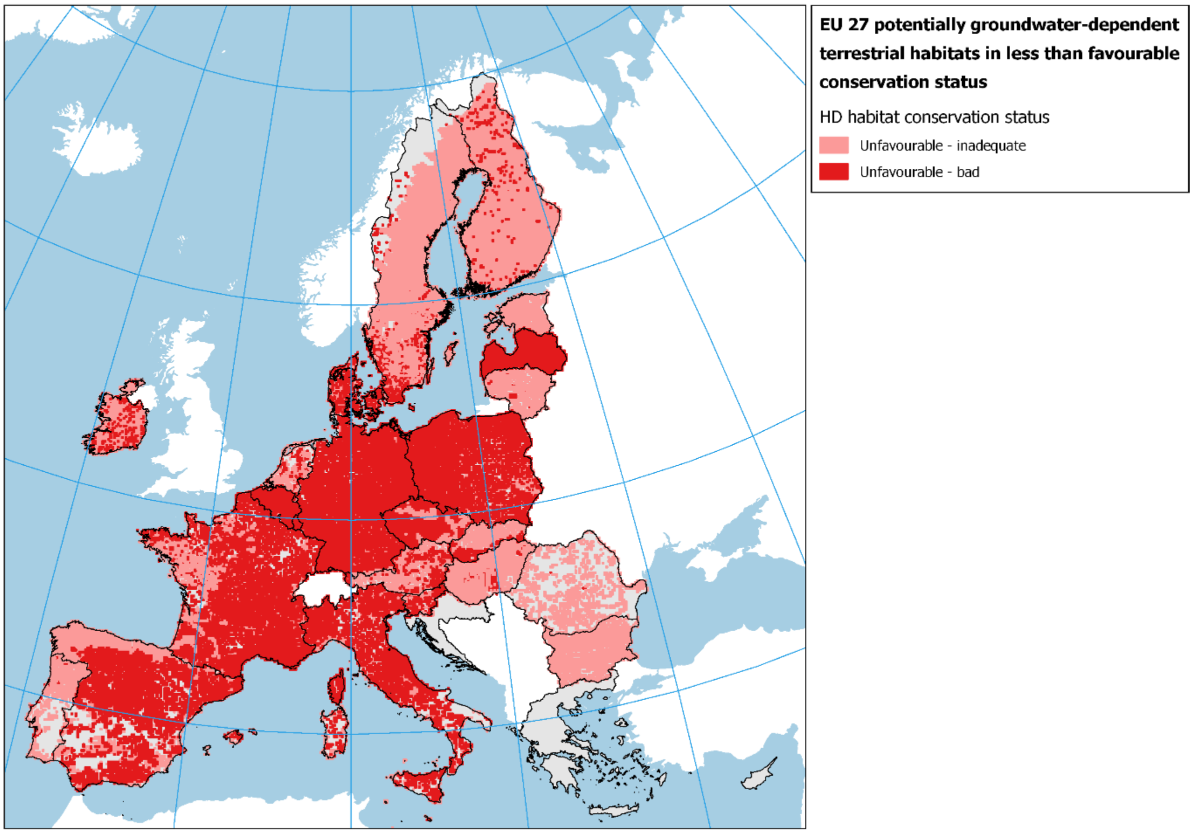
Map 3.1 EU 27 freshwater aquatic habitats in less than favourable conservation status.



Note: The term "freshwater aquatic habitats" includes all those HD Annex I habitat types which have been defined by Halada et al. (2020) under the ecogroup "4A – Freshwater aquatic habitats"; Please note that the reporting period of the HD data is (2007-2013) to match the reporting period of the latest WFD data (2009-2015) – less than favourable conservation status continues to be similarly extended across Europe in the latest HD Art. 17 reporting also (2014-2020) (see EEA, 2020a)

Source: Authors' compilation based on data from Habitats Directive – HD Art. 17 reporting (2007-2013) (EEA, 2020c)

Map 3.2 EU 27 potentially groundwater-dependent terrestrial habitats in less than favourable conservation status.



Note: The term "potentially groundwater-dependent terrestrial habitats" includes all those HD Annex I habitat types which have been defined by Halada et al. (2020) under the ecogroup "4E – Terrestrial habitats in need of high level of groundwater" and "4D - Freshwater riparian and alluvial habitats". Please note that the reporting period of the HD data is (2007-2013) to match the reporting period of the latest WFD data (2009-2015) - less than favourable conservation status continues to be similarly extended across Europe in the latest HD Art. 17 reporting also (2014-2020) (see EEA, 2020a)
Source: Authors' compilation based on data from Habitats Directive – HD Art. 17 reporting (2007-2013) (EEA, 2020c)

According to the latest EEA report on the State of Nature, there are various pressures which have caused less than favourable conservation status of habitats in a widespread area across Europe. In brief, the key pressures are those related to agriculture and forestry, as well as urbanisation. Other significant pressures are: invasive alien species; air, water and soil pollution; alterations in rivers due to abstraction, construction of barriers/dams and drainage; exploitation of species; and climate change, which is considered an increasing pressure (EEA, 2020a).

<u>The focus of this study is the pressures exerted on groundwater, which, in turn, may affect GWAAEs and GWDTEs through their interdependencies with groundwater</u>. Therefore, it is highlighted that it is out of the scope of this study to explore further the above pressures exerted on habitats.

3.2 Analysis of potential interdependencies between WFD groundwater status and HD habitat conservation status

As explained previously (see section 3.1), the conservation status of habitats in Europe is less than favourable over extended parts the continent. The same applies to potentially GWAAEs, as well as to GWDTEs (Maps 3.1 and 3.2). As habitats are affected by a wide range of pressures, it is difficult to apportion complex ecological problems, which are found in GWAAEs and GWDTEs, to the pressures related to groundwater only through a technical cross-walk analysis at the EU level.

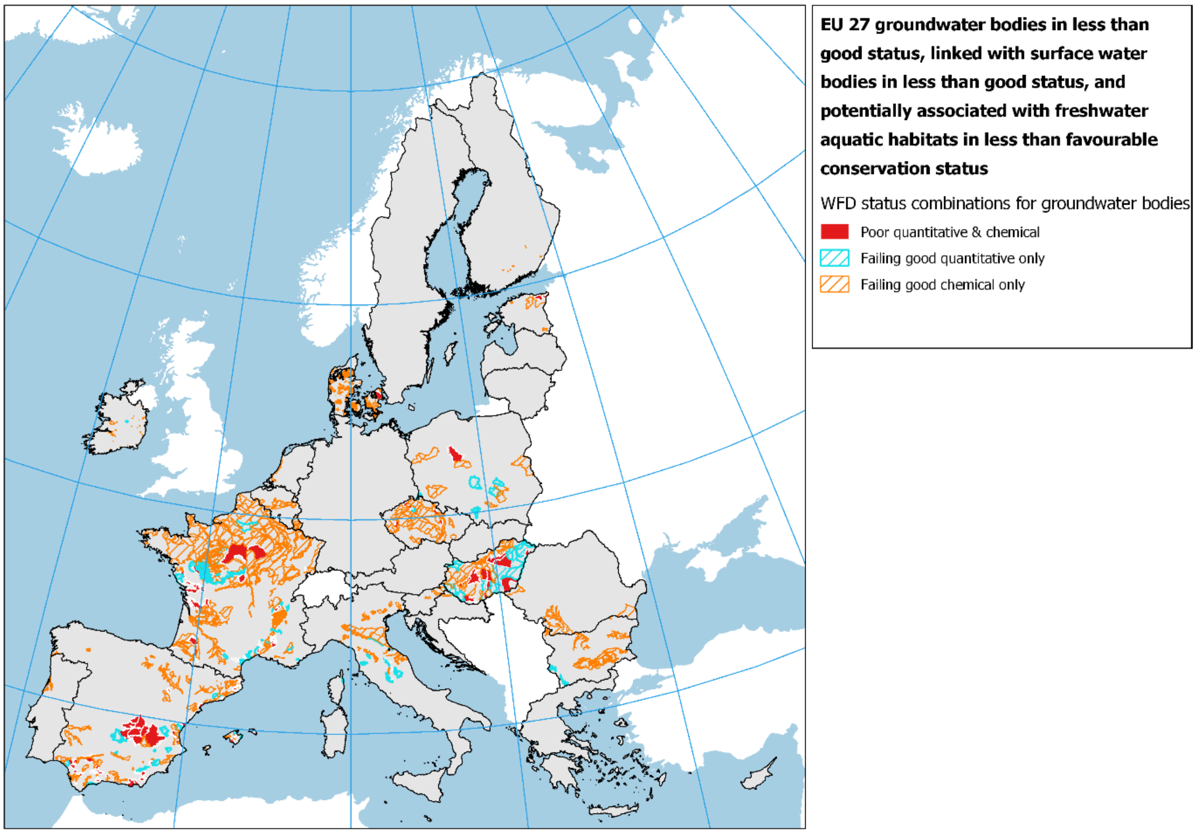
Therefore, this section of the study (section 3.2) will only attempt to identify and map those cases where less than good WFD groundwater status and less than favourable HD habitat conservation status are more likely to be interdependent, based on reported data in the 2^{nd} RBMPs and Art. 17 of the HD. Furthermore, section 3.3 of this study provides additional insights into the key drivers and pressures affecting GWBs linked with GWAAEs and GWDTEs. In addition, it complements the cross-walk analysis with specific local examples from across the EU 27.

Maps 3.3 and 3.4 support the above objective, as they show the GWBs which are linked with either GWAAEs or GWDTEs in the EU 27, taking into account only those GWBs which had poor WFD quantitative or chemical status in the 2^{nd} RBMPs, the GWAAEs which had less than good WFD ecological or chemical status and less than favourable HD conservation status, as well as the GWDTEs which had less than favourable HD conservation status.

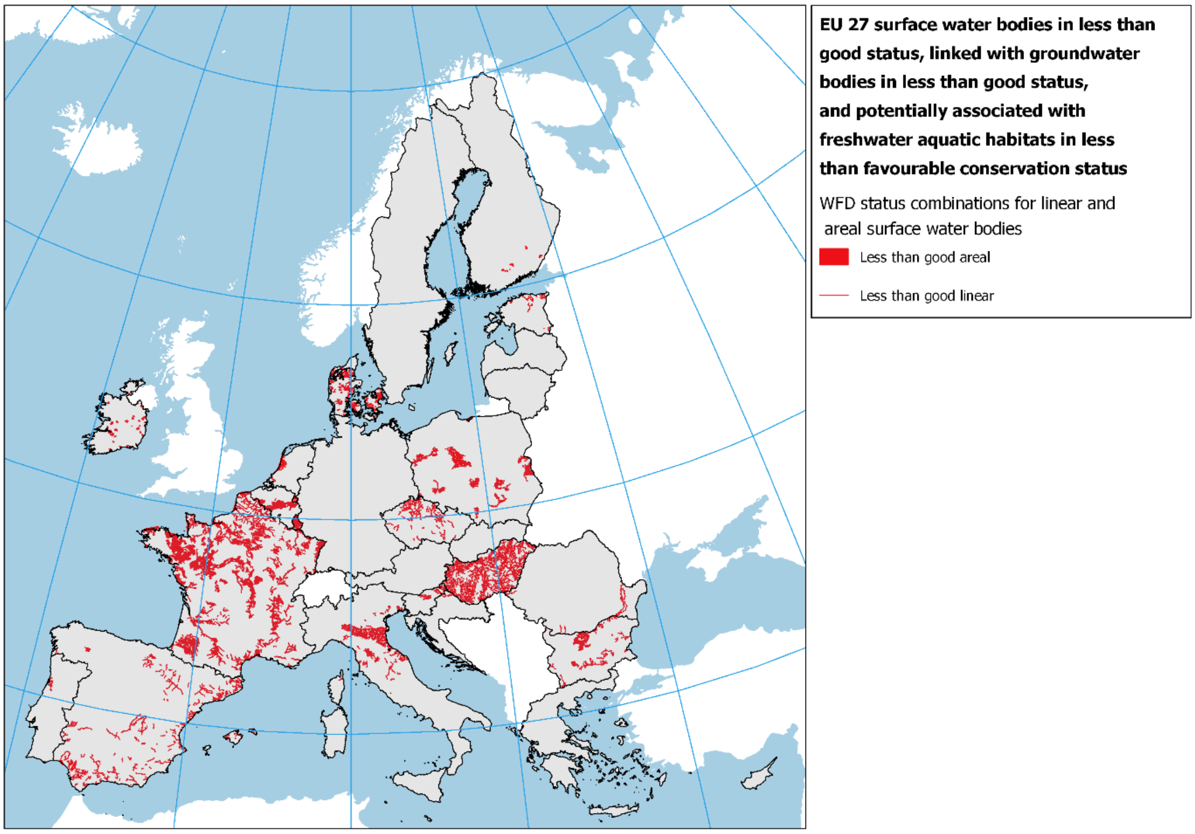
Around 5% of the total GWB area in the EU 27 (685 GWBs) had poor quantitative or chemical status, and it is also linked with GWAAEs having less than good ecological or chemical and less than favourable habitat conservation status (Map 3.3). Similarly, 7% of the total GWB area had poor quantitative or chemical status, and it was also linked with GWDTEs having less than favourable habitat conservation status.(928 GWBs) (Map 3.4). Box 3.1 presents the main areas across the EU 27, where such interdependencies between GWBs and GWAAEs or GWDTEs are highly likely.

Map 3.3 EU 27 areas where less than good status of GWBs and less than favourable conservation status of GWAAEs could be interdependent.

(a) GWBs linked with GWAAEs

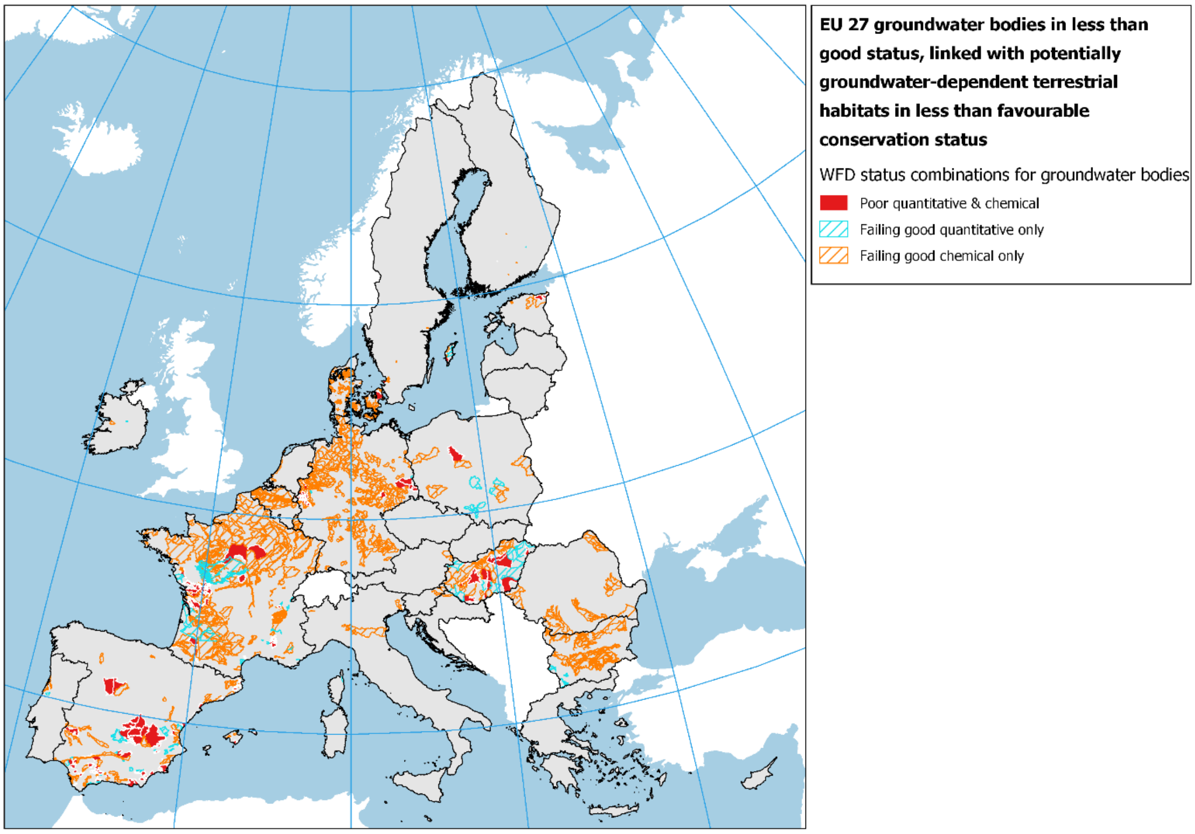


(b) GWAAEs linked with GWBs



Note: EU 27 GWBs in poor quantitative or chemical status, linked with GWAAEs in poor chemical or ecological status and less than favourable conservation status;
Germany is blank because no links between GWBs and SWBs are reported. Lithuania and Slovakia are blank because there is no reporting on links between GWBs and SWBs. The maps do not include linked GWBs and SWBs from the whole territory of Sweden and from part of the territory of Italy, although such linkages are reported to exist, because the specific codes of the SWBs, which are linked with GWBs, are not provided.
Source: Authors' compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020b) and from Habitats Directive – HD Art. 17 reporting (2007-2013) (EEA, 2020c)

Map 3.4 EU 27 areas where less than good status of GWBs and less than favourable conservation status of GWDTEs could be interdependent.



Note: EU 27 GWBs in poor quantitative or chemical status, linked with GWDTEs in less than favourable conservation status;
Czechia is blank because no links between GWBs and GWDTEs are reported. Lithuania and Slovakia are blank because there is no reporting on links between GWBs and SWBs.
Source: Authors' compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020b) and from Habitats Directive – HD Art. 17 reporting (2007-2013) (EEA, 202c)

Box 3.1 EU 27 areas where less than good status of GWBs and less than favourable habitat conservation status of GWAAEs or GWDTEs could be interdependent.

Highly likely interdependencies between the status of GWBs and GWAAEs have been found in various areas in Belgium, the Bulgarian-Romanian cross-border Danube region, Czechia, Denmark, Estonia (northern part), France (especially the northern and western part), Hungary, Ireland, Italy (central part and Po river basin), Luxembourg, Poland, Slovenia (northern part), and Spain (Ebro and Guadalquivir river basins and Mediterranean coasts).

Highly likely interdependencies between the status of GWBs and GWDTEs have been found in various areas in Belgium, the Bulgaria-Romania cross-border Danube region, Denmark, Estonia (northern part), France (especially the northern and western part), Germany, Hungary, Italy (Po river basin), Luxembourg, Poland, Slovenia (northern part), and Spain (Baleares, Guadalquivir river basin, La Mancha aquifers, and Mediterranean coasts).

The analysis conducted for this study also showed that pollution pressures are those most commonly affecting GWBs linked with GWAAEs or GWDTEs. In specific, the most frequent type of failure of good status for GWBs linked with GWAAEs was the following combination: a GWB in poor chemical status, linked with a GWAAE having less than good ecological or chemical status and less than favourable habitat conservation status. As already shown (see sub-study 1; Psomas et al., 2021), individual failures of good status of GWBs or SWBs are most frequently related to poor water quality, and significant pressures related to water quality are much more extended than those related to water quantity (e.g. agricultural and mining diffuse source pollution, industrial point source pollution). Other types of failure of good status of GWBs linked with GWAAEs or GWDTEs were related to poor water quantity. For this type of failure, the most frequent case was a GWB in poor quantitative status, linked with a GWAAE having less than good ecological and less than favourable habitat conservation status. The cases of GWBs in poor quantitative status linked with GWAAEs having poor chemical status and less than favourable habitat conservation status were rare. Similar conclusions to the above were observed for GWBs linked with GWDTEs.

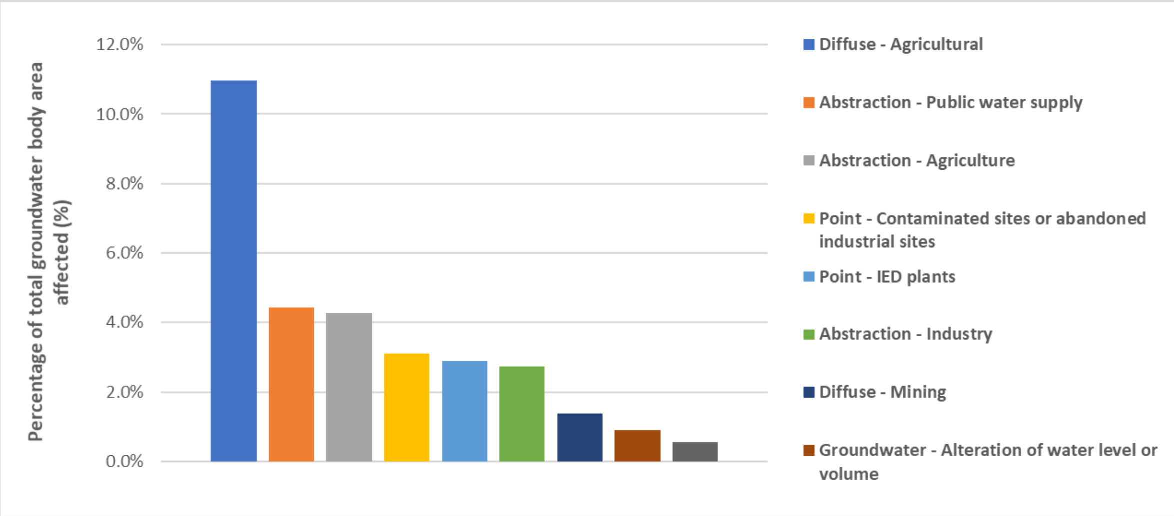
3.3 Pressures causing less than good status in GWBs linked with GWAAEs or GWDTEs

The status of GWBs linked with GWAAEs or GWDTEs is affected by a variety of human-induced pressures, as well as by climate change, which is an over-arching driver. Most commonly, linked GWBs are affected by pollution pressures. Over-abstraction also plays a significant role, either alone or in conjunction with the pollution pressures. Furthermore, increased frequency and intensity of droughts, due to climate change, may exacerbate the existing pressures. Figures 3.1 and 3.2 focus on the key human-induced drivers and pressures that affect significantly GWBs linked with GWAAEs and GWDTEs, respectively.

For further read on the interdependencies between the quantitative and chemical status of GWBs, and the impact of multiple pressures related to water quantity and quality, please see sub-study 1 form this series of studies (Psomas et al., 2021).

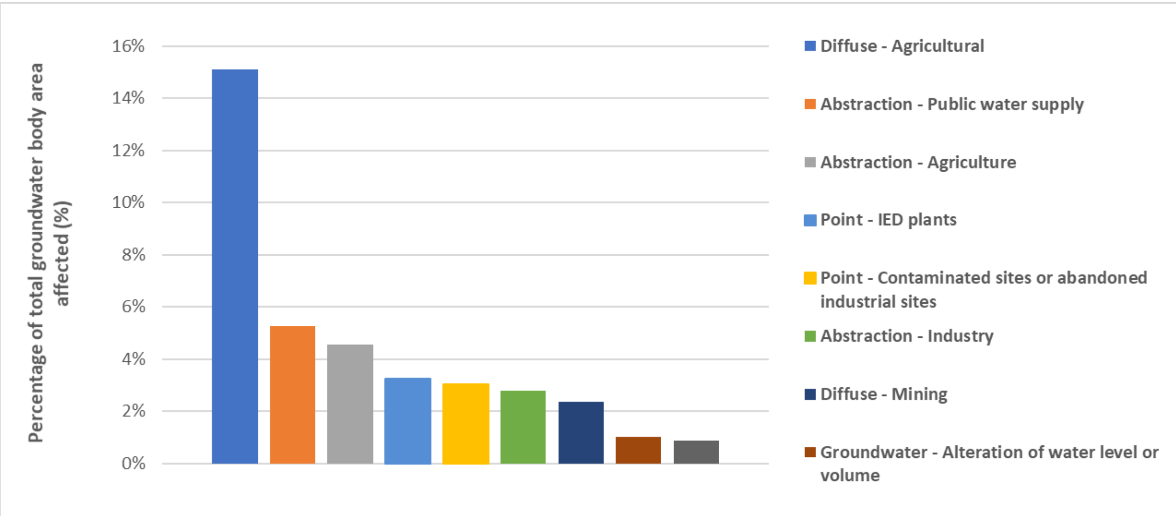
For a storyline delivering a wider synthesis of the interdependencies between groundwaters, associated surface waters and dependent terrestrial ecosystems affected by key pressures related to water quantity and quality, please see sub-study 3 form this series of studies (Rouillard et al., 2021).

Figure 3.1 Key drivers and pressures affecting significantly GWBs linked with GWAAEs.



Note: Key drivers and pressures causing poor quantitative or chemical status in GWBs linked with GWAAEs.
Source: Authors' compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020b) and from Habitats Directive – HD Art. 17 reporting (2007-2013) (EEA, 2020c)

Figure 3.2 Key drivers and pressures affecting significantly GWBs linked with GWDTEs.



Note: Key drivers and pressures causing poor quantitative or chemical status in GWBs linked with GWDTEs.
Source: Authors' compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020b) and from Habitats Directive – HD Art. 17 reporting (2007-2013) (EEA, 2020c)

Pressures by Agricultural production

In GWBs linked with GWAAEs or GWDTEs, the most common driver of pressures causing less than good groundwater status is agriculture. Agriculture is also the most significant driver affecting EU 27 GWBs in general (see sub-study 1, Psomas et al., 2021). About 11% and 15% of the total GWB area in the EU 27, linked with GWAAEs and GWDTEs respectively, has less than good groundwater status due to diffuse source agricultural pollution. Similarly, another 4% and 5% of the GWBs is linked with GWAAEs and GWDTEs, and its groundwater status is less than good due to agricultural abstraction (Figures 3.1, 3.2).

Agricultural pressures most commonly affect porous aquifers, according to the analysis of this study. This may happen because these types of aquifers are most commonly linked with GWAAEs and GWDTEs (see sections 2.1 and 2.2) and they are commonly found in agricultural plains. Their natural properties, such as thickness, storage capacity and flow velocity also play a significant role in their vulnerability against pressures.

Agricultural pollution, including legacy pollution with banned herbicides, as well as over-abstraction, have been reported to affect GWAAEs and GWDTEs in various cases in the EU 27 (Box 3.2, Box 3.3).

Box 3.2 Impacts of agricultural pressures on EU 27 GWBs linked with GWAAEs and GWDTEs

Diffuse source agricultural pollution affects "turloughs", which are unique groundwater-fed lake ecosystems linked to karstic areas in Ireland (Skeffington et al., 2006). Furthermore, nitrate loading from groundwater into surface water discharging to the Horsens Estuary, Denmark, causes significant risk for the growth of filamentous algae and reduced sea-grass population (Hinsby et al., 2012).
In addition, over-abstraction has altered the flow regime of various Spanish rivers, turning normally perennial rivers into intermittent flow streams. Furthermore, in locations with high water abstraction fish populations were significantly affected (Benejam et al., 2010). In addition, in mountainous streams affected by over-abstraction, reductions were observed the breakdown of organic matter and the population of shredder insects (Arroita et al., 2015). The wetlands of Tablas de Daimiel, which are situated over the Western La Mancha aquifer, and Doñana, which takes up a coastal area in lower Guadalquivir, are indicative cases of affected ecosystems by over-abstraction in Spain (López-Gunn et al., 2013; Muñoz-Reinoso, 2001). The Marais Poitevin, which is the second largest wetland in France, is affected by various pressures, such as tourism, fisheries, and aquaculture. However, water abstraction by agriculture lowers the water table of the aquifers, which leads to seasonal reductions of baseflow to rivers, thereby impacting the fragile water balance sustaining the wetland (Rouillard, 2019). Impacts on GWAAEs and GWDTEs have also been observed in much northern and wetter climates. For instance, drainage for forestry activities over the Roqua aquifer in Finland is considered to be one reason having caused the decline of stages in unique oligotrophic "kettle" lakes (Rossi, 2014; Kløve et al.,2011).

Box 3.3 Legacy pollution from a banned herbicide

In the 2nd RBMPs, atrazine, which is a banned herbicide due to its persistence in groundwater, was reported to cause poor chemical status in a significant proportion of the total GWB area in the EU 27 (2%). In addition, it was reported to cause poor chemical status in a very small proportion of the total length of SWBs. However, the Member States did not report simultaneous failures of good status of GWBs linked with SWBs. Due to the official ban of the substance, it is assumed that the above cases represent a legacy pressure, with GWBs having been polluted in the past and still discharging atrazine.

Other commonly reported chemicals (not necessarily used in agriculture), which cause poor chemical status of either GWBs or SWBs are found in *Annex 6*.

Pressures by Public water supply

About 4% and 5% of the total GWB area in the EU 27, linked with GWAAEs and GWDTEs respectively, has less than good groundwater status due to abstraction for public water supply (Figures 3.1, 3.2).

This pressure affects most commonly porous aquifers, according to the analysis of this study. This may happen because these types of aquifers are most commonly linked with GWAAEs and GWDTEs (see sections 2.1 and 2.2). Furthermore, they are commonly exploited for the supply of drinking water to urban areas, settled in proximity of rivers and lakes. Their natural properties, such as thickness, storage capacity and flow velocity also play a significant role in their vulnerability against pressures.

Over-abstraction due to public water supply has been reported as a threat to GWAAEs and GWDTEs in various cases in the EU 27 (Box 3.4).

Box 3.4 Impacts of public water supply on EU 27 GWBs linked with GWAAEs and GWDTEs

Over-abstraction from coastal aquifers for the supply of drinking water is reported to have caused saline intrusion in coastal wetlands in the Apulia region, in southern Italy. The local wetlands are fed from local karstic aquifers, and they were impacted significantly by drinking water abstraction during drought events that occurred in past decades (Polemio et al., 2009; Fidelibus et al., 2011).

The Viinivaara esker in Finland discharges into a Natura 2000 peatland (fen) and several headwater streams. However, the city of Oulu planned to increase the drinking water abstraction from this GWB. Local concerns about impacts on streams, lakes, springs, local wells and groundwater-dependent peatlands led to an environmental impact assessment to identify such risks and recommend compensation measures (Klöve et al., 2011).

Pressures by Industrial development

About 3% of the total GWB area in the EU 27, linked with GWAAEs or GWDTEs, has less than good groundwater status due to pressures related to industrial development (e.g. point source pollution by contaminated sites or abandoned industrial sites, point source pollution by plants regulated under the Industrial Emissions Directive, industrial abstractions) (Figures 3.1, 3.2).

These pressures affect most commonly porous aquifers, according to the analysis of this study. This may happen because these types of aquifers are most commonly linked with GWAAEs and GWDTEs (see sections 2.1 and 2.2). In addition, they are commonly found in low-land areas, where industries are more likely to concentrate, compared to hilly and mountainous areas. Their natural properties, such as thickness, storage capacity and flow velocity also play a significant role in their vulnerability against pressures.

Chemicals in the environment can be a significant threat for GWAAEs and GWDTEs. However, the analysis conducted with the WFD data from the 2nd RBMPs did not conclude in significant and robust linkages between chemicals causing poor chemical status in GWBs and chemicals causing poor chemical status in SWBs in the EU 27 (Box 3.5).

Box 3.5 Exploration of chemicals causing poor chemical status in linked GWBs and SWBs

Based on the reporting from the 2nd RBMPs, this study has conducted an analysis of the most common pollutants causing poor chemical status in linked GWBs and SWBs[3]. The analysis concluded that *Benzo(a)pyrene* (CAS_50-32-8) is the only pollutant reported to cause simultaneously poor chemical status in GWBs and SWBs, which are linked together. *Benzo(a)pyrene* (CAS_50-32-8), which is a polycyclic aromatic hydrocarbon resulting from incomplete combustion and a reasonably anticipated human carcinogen

[3] *Nutrients* (e.g. nitrogen and phosphorus) are very common pollutants causing less than good groundwater status in various GWBs and SWBs in the EU 27. When they are found in excess in the environment they may result in eutrophication. This is a significant risk for wetlands, estuaries, and other ecosystems. However, since nutrients are associated to a high degree also with agricultural or waste water emissions to surface waters, apportioning the failures of good status only to nutrients from groundwater recharges would be difficult. Therefore, nutrients have not been considered in this analysis.

(PubChem, 2021), is identified in various cases in Czechia and France as the single pollutant causing poor chemical status in both the GWB and the SWB, where these are linked together.

Although no other pollutant was found to cause simultaneously poor chemical status in linked GWBs and SWBs, this does not necessarily mean that such cases do not exist. Monitoring limitations may be a reason for this gap. For example, a smaller number of parameters may be monitored for the SWB compared to the linked GWB.

Other commonly reported chemicals that cause poor chemical status of either GWBs or SWBs are found in *Annex 6*.

Pressures by Mining activities

About 1.5% and 2.5% of the total GWB area in the EU 27, linked with GWAAEs and GWDTEs respectively, has less than good groundwater status due to diffuse source pollution from mining. Alterations of groundwater levels/volumes (usually related to drainage of mining sites) affect approximately 1% of the GWB area, either linked with GWAAEs or GWADTEs (Figures 3.1, 3.2).

These pressures affect most commonly porous aquifers, according to the analysis of this study. This may happen because these types of aquifers are most commonly linked with GWAAEs and GWDTEs (see sections 2.1 and 2.2). Moreover, their natural properties, such as thickness, storage capacity and flow velocity, play a significant role in their vulnerability against pressures.

In various cases, mining activities in the EU 27 have been reported as a significant driver of both current and legacy pressures exerted on GWBs, which are linked with GWAAEs and GWDTEs (Box 3.6).

Box 3.6 Impacts of mining activities on EU 27 GWBs linked with GWAAEs and GWDTEs

In Ireland, two GWBs are classified in poor quantitative status, including a GWB which is linked to the GWDTE of Clara bog. This GWB is in poor quantitative status, due to hydrological alterations resulting from drainage operations for safe peat cuttings. Drainage affects the hydrology of the bog, resulting in compaction, land subsidence and loss of soil carbon (Crushell et al., 2008).

Pressures by Climate change

According to the 2020 EEA report on the State of Nature, 5.4% of the habitats and 4.6% of the species are already affected by climate change. In particular, droughts and decreases in precipitation are identified as the most common climate-related pressure on species and habitats, representing nearly half of the reported climate-related cases. Other significant, but less common pressures include temperature changes, increases or changes to precipitation, sea-level and wave exposure (EEA, 2020d).

Rising temperatures and droughts affect significantly several types of species that dwell in GWAAEs (e.g. fishes, amphibians, molluscs, and waterbirds). In addition, they affect habitats which can be designated as GWDTEs (e.g. reedbeds and reedy ponds). Furthermore, decreases in precipitation affect significantly GWDTEs, such as bogs, mires and fens (EEA, 2020d). Between 2000 and 2016, water deficits due to severe droughts affected a considerable part of Iberia and south-western France. Areas in central Europe and the Balkans were also commonly affected. This caused a decline in the growth of natural vegetation (EEA, 2021 – forthcoming; EEA, 2020e).

Sea water intrusion, due to higher sea levels, storm surges and reduced recharge of coastal aquifers, can damage groundwater-fed transitional and coastal ecosystems, such as coastal karstic springs, spring-fed lagoons, and wet dune slacks. Coastal habitats in the Atlantic and the Boreal region have been found to be at higher risk of sea water intrusion due to climate change (EEA, 2020d). However, similar cases are also located in the Mediterranean (Box 3.7). Salinisation of transitional and coastal ecosystems can damage flora and fauna with low sensitivity to saline conditions.

Box 3.7 Impacts of climate change on EU 27 GWBs linked with GWAAEs and GWDTEs

The Gialova lagoon is a Natura 2000 site separated from the Navarino bay to the south and the Voidokoilia beach to the northwest by narrow wet dune slacks, which provide part of the groundwater flow to the lagoon. The lagoon is also fed with groundwater from artesian springs located to the eastern and south-eastern boundaries, where the lagoon meets with neighbouring wetlands. At least during the wet season, a portion of groundwater is recharged from an alluvial aquifer to the north. Both the lagoon and the wetlands are also supplied with water from precipitation, local streams, as well as marine upwelling, especially during the dry period. The Gialova lagoon shows seasonal fluctuations in salinity, which is expected to increase significantly under climate change. It has been estimated that warmer climate conditions in the future will increase evaporation by 10% and salinity by 5%. The mitigation of further salinisation of the lagoon requires up to 50% increase in freshwater inputs (Manzoni et al., 2020).

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ANNEX 1 – DEFINITION OF WATER BODY STATUS IN THE WATER FRAMEWORK DIRECTIVE (WFD)

*"**Good ecological status of a surface water body**"* is achieved if the values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions. The assessment of the ecological status of the surface water body depends on three types of criteria: biological elements; hydromorphological elements supporting the biological elements; and general physico-chemical and chemical elements (i.e. specific pollutants) supporting the biological elements. It is noted that if there are only very minor anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements, and the values of the biological quality elements resemble those under undisturbed conditions, then ecological status is assessed as "high", which is a superior classification compared to good. Heavily modified or artificial surface water bodies represent cases, where the reference natural conditions have been significantly disturbed. Thus, depending on the level of this disturbance, they can be closer or more distant to the reference conditions. For such surface water bodies, the environmental objectives refer to the "good ecological potential" (EU, 2000).

*"**Good chemical status of a surface water body**"* is achieved if the concentrations of pollutants in the surface water comply with the environmental quality standards established for priority and other substances under relevant water legislation. Environmental quality standards are required to take into account both chronic and acute exposure to the above chemicals and they are set out for samples of water, sediments or aquatic biota (EU, 2000).

*"**Good chemical status of a groundwater body**"* is achieved if the concentrations of pollutants and changes in electrical conductivity of groundwater caused by human activities: a) meet the quality standards established under relevant water legislation, b) show no evidence of impacts from saline or other intrusion, c) do not cause significant degradation of the chemical or ecological quality of associated surface water bodies, or failure of relevant environmental objectives, and d) do not significantly harm terrestrial ecosystems directly dependent on the groundwater body. Elevated concentrations of naturally occurring substances should not lead to poor chemical status, as they are expected to be accounted for in threshold values for these substances (EU, 2000; CIS, 2017).

*"**Good quantitative status of a groundwater body**"* is achieved if the alteration of groundwater level due to human activities: a) does not cause significant diminution of groundwater, b) does not result in failure of relevant environmental objectives for associated surface water bodies, c) does not significantly harm terrestrial ecosystems directly dependent to the groundwater body. The groundwater level balance is maintained if the average volume of the annual abstraction does not exceed the average volume of groundwater recharge in the long term. Alterations to groundwater levels may cause changes in groundwater flow direction temporarily, or continuously in a spatially limited area, provided that saline or other intrusions are not triggered or likely to be triggered (EU, 2000; CIS, 2017).

Sources:

CIS, 2017, Natural Conditions in relation to WFD Exemptions - Document endorsed by EU Water Directors at their meeting in Tallinn on 4-5 December 2017, Common Implementation Strategy for the Water Framework Directive (2000/60/EC) (https://circabc.europa.eu/sd/a/49b021b3-5d8e-4b4d-946d-4754d1ae0573/NaturalConditionsinrelationtoWFDexemptions.pdf) accessed 09 April 2021.

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ANNEX 2 – DEFINITION OF SPECIES/HABITAT CONSERVATION STATUS IN THE HABITATS DIRECTIVE (HD)

The "***habitat***" of a species is a part of the environment defined by specific abiotic and biotic factors, in which the plant of animal species lives at any stage of its biological cycle (EU, 1992).

The ***"conservation status of a species"*** means the sum of the influences acting on the species concerned, which may affect the long-term distribution and abundance of its populations within the European territory of the EU Member States. ***"Favourable conservation status of a species"*** is achieved if*:*
a) population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats,
b) the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future,
c) there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis (EU, 1992).

The ***"conservation status of a habitat"*** represents the sum of the influences acting on a habitat and its typical species, which may affect its long-term natural distribution, structure and functions, as well as the long-term survival of its typical species, within the European territory of the EU Member States. ***"Favourable conservation status of a habitat"*** is achieved if:
a) its natural range, and areas it covers within that range, are stable or increasing,
b) the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future,
c) the conservation status of its typical species is also favourable (EU, 1992).

Sources:

EU, 1992, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.07.1992, p.7–50) (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31992L0043) accessed 09 April 2021.

ANNEX 3 – ECOGROUPS OF FRESHWATER AQUATIC HABITATS FROM ANNEX I OF THE HABITATS DIRECTIVE (HD)

HD habitat code	Ecogroup and HD Annex I habitat name
4A: Running Freshwater[1]	
3210	Fennoscandian natural rivers
3220	Alpine rivers and the herbaceous vegetation along their banks
3230	Alpine rivers and their ligneous vegetation with Myricaria germanica
3240	Alpine rivers and their ligneous vegetation with Salix elaeagnos
3250	Constantly flowing Mediterranean rivers with Glaucium flavum
3260	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation
3270	Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation
3280	Constantly flowing Mediterranean rivers with Paspalo-Agrostidion species and hanging curtains of Salix and Populus alba
3290	Intermittently flowing Mediterranean rivers of the Paspalo-Agrostidion
32A0	Tufa cascades of karstic rivers in the Dinaric Alps
4A: Standing Freshwater[2]	
2190	Humid dune slacks
3110	Oligotrophic waters containing very few minerals of sandy plains (Littorelletalia uniflorae)
3120	Oligotrophic waters containing very few minerals generally on sandy soils of the West Mediterranean, with Isoetes spp.
3130	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea
3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.
3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition - type vegetation
3160	Natural dystrophic lakes and ponds
3190	Lakes of gypsum karst
7210	Calcareous fens with Cladium mariscus and species of the Caricion davallianae
31A0	Transylvanian hot-spring lotus beds
4A: Temporary Freshwater[3]	
3170	Mediterranean temporary ponds
3180	Turloughs

[1] **Running Freshwater** ("Rivers"): All permanent rivers and streams, including rivers, streams, brooks, rivulets, rills, torrents, waterfalls, cascades and rapids.

[2] **Standing Freshwater** ("Lakes"): Lakes, ponds and pools with fresh (non-saline) or slightly brackish water. Included are semi-natural, man-made freshwater bodies like artificially created lakes, reservoirs and canals.

[3] **Temporary Freshwater** ("Temporary streams and ponds"): Running or standing waters with non-permanent water column, drying seasonally (usually in summer).

Non-Mediterranean rivers and lakes are further distinguished (for higher resolution), based on their altitude (i.e. low-land, mid-altitude, highland), while Mediterranean rivers and lakes are separated from the rest surface water bodies of Europe, due to warmer and drier climate conditions.

Sources:

Halada, L., et al., 2020, Proposals of the ecological grouping of the Habitats Directive habitats and species, ETC Biodiversity report 2020, pp. 38.

Halada, L., et al., 2020, Proposals of the ecological grouping of the Habitats Directive habitats and species, Database accompanying the ETC Biodiversity report 2020.

Solheim, A.L., et al., 2019, A new broad typology for rivers and lakes in Europe: Development and application for large-scale environmental assessments, Science of the Total Environment, 697, 134043 (https://www.sciencedirect.com/science/article/pii/S0048969719340203#f0040) accessed 09 April 2021.

ANNEX 4 – ECOGROUPS OF GROUNDWATER-DEPENDENT TERRESTRIAL HABITATS FROM ANNEX I OF THE HABITATS DIRECTIVE (HD)

HD habitat code	Ecogroups and HD Annex I habitat name
4E: Terrestrial habitats in need of high level of groundwater[1]	
	Bogs and Mires
7110	Active raised bogs
7120	Degraded raised bogs still capable of natural regeneration
7140	Transition mires and quaking bogs
7150	Depressions on peat substrates of the Rhynchosporion
	Fens
7210	Calcareous fens with Cladium mariscus and species of the Caricion davallianae
7220	Petrifying springs with tufa formation (Cratoneurion)
7230	Alkaline fens
	Inland salt marshes
1310	Salicornia and other annuals colonizing mud and sand
1410	Mediterranean salt meadows (Juncetalia maritimi)
	Wet Forests
9190	Old acidophilous oak woods with Quercus robur on sandy plains
91E0	Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
91F0	Riparian mixed forests of Quercus robur, Ulmus laevis and Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers (Ulmenion minoris)
92A0	Salix alba and Populus alba galleries
	Wet Heaths and Scrub
1420	Mediterranean and thermo-Atlantic halophilous scrubs (Sarcocornetea fruticosi)
4080	Sub-Arctic Salix spp. scrub
	Wet Meadows
6510	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)
	Bogs and Mires / Fens / Wet Meadows
6410	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caeruleae)
	Bogs and Mires / Wet Forests
91D0	Bog woodland
	Fens / Wet Meadows
2190	Humid dune slacks
4D: Freshwater Riparian and Alluvial habitats[2]	
3130	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea
3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.
3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition - type vegetation
3220	Alpine rivers and the herbaceous vegetation along their banks
3260	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation

3270	Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation

[1] **Terrestrial habitats in need of high level of groundwater**: These habitats depend on high level of ground water: bogs, mires, marshes, fens, wet meadows. The following categories are distinguished:
• *Bogs and mires*. Bog and mire complexes, usually acid or neutral, including raised bogs, blanket bogs, acidic fens, transition mires, boreal marsh-fens, aapa, palsa and polygon mires.
• *Calcareous fens*. Wetlands mostly with peat or tufa soils permanently waterlogged, with base-rich, nutrient-poor, often calcareous water supply, and with the water table at, or slightly above or below, the substratum.
• *Wet meadows*. Managed or unmanaged grasslands on wet and humid stands.
• Inland salt marches. Habitats of sites submerged by high tides at some stage of the annual tidal cycle of oceans and their connected seas. Similar halophyte communities colonizing the fringes and emerged beds of inland permanent or temporary saline, hypersaline or brackish waterbodies, including lakes, pools, springs.
• *Wet forests*. Forest with permanently or temporary wet soils. Included are forests in alluvial and riparian positions, bog forest, forests of marshes and forests in other wetlands.
• *Wet heaths and shrubs*. Heaths and scrub habitats of wetlands. Included are scrubby habitats in alluvial and riparian sites, scrubs on periphery of water bodies, scrub habitats in bogs, marches, and other wetlands.

[2] **Freshwater Riparian and Alluvial habitats**: These habitats stretch along streams and rivers and depend on (frequent) inundation or high water level in the soil. This group of habitats is linked to hydrological regime of rivers and streams and it is classified under the category of wetland habitats. Wetland habitats are defined by WFD as "habitats, which depend on frequent inundation or on the level of groundwater (e.g. alluvial alder wood, blanket bog, fens)". It is possible to divide this group further to herb-, shrub- and tree-dominated habitats. It is noted that the freshwater bodies are excluded from this type of habitat.

Sources:

Halada, L., et al., 2020, Proposals of the ecological grouping of the Habitats Directive habitats and species, ETC Biodiversity report 2020, pp. 38.

Halada, L., et al., 2020, Proposals of the ecological grouping of the Habitats Directive habitats and species, Database accompanying the ETC Biodiversity report 2020.

Annex 5 – Key methodological challenges for Cross-Walk Analysis between the Water Framework Directive (WFD) and the Habitats Directive (HD)

While conducting the cross-walk analysis between the WFD and the HD, a series of methodological challenges emerged, including the following:

- **The "conceptual" cross-walk between the WFD and HD definitions was relatively easier than the "technical" cross-walk between the WFD and HD data**. Scientific publications rarely distinguish between "GWAAEs" and "GWDTEs" as clear as the WFD does, and they are both covered under the more general term "Groundwater Dependent Ecosystems", including also other types of ecosystems, such as stygofauna. However, recent work of the EEA and ETC BD (Halada et al., 2020) has allowed to identify ecogroups of HD Annex I habitats, which could be matched to the WFD definition of a GWAAE or GWDTE.

- **The national methodologies for the designation of habitats as GWAAEs/GWDTEs under the WFD are not well documented and readily available to the public and scientists for review**. For the purposes of this report our expert team analysed the relevant methodological approaches of France, Ireland and the UK. These were more easily accessible, than other national methodologies searched (e.g. relevant methodologies in the Danube region). A key conclusion was that there are significant differences in the criteria and the scoring system being used. Although this is not necessarily negative, and may show a focus on specificities of national conditions, different methodologies per country create significant burdens in cross-country exercises, due to comparability issues, misinterpretations, and conflicts in assessments for the same type of habitat.

- **Data from WFD and HD reporting differ greatly in terms of: a) spatial units for reporting and assessments; and b) timetables and periods for reporting.** The spatial scale used for the assessment of the conservation status of habitats is gridded and coarse, and it does not match the geometry of water bodies (e.g. lines for rivers, and polygons for groundwaters, lakes, transitional and coastal waters). In addition, any spatial overlaps between the vertical projections of the boundaries of GWBs upon the boundaries of river basins and habitats on the ground surface can be hardly studied visually. This task requires more sophisticated understanding and conceptual modelling. To add to this complexity, different horizons can be located on the same location in the vertical plane, making it strenuous to distinguish the exact GWB interacting with a SWBs or a GWAAE/GWDTE. As the reporting and assessment units are incompatible, the uncertainty on which water bodies are linked with which ecosystems becomes challenging. Under the WFD, Member States have to define GWAAEs and GWDTEs, and assess their condition. Furthermore, under Art.17 of the HD they have to report data on the conservation status of those types of habitats included in Annex I of the HD. However, potential GWAAEs and GWDTEs are not explicitly distinguished as a special category of the reporting of conservation status, making the review of relevant WFD assessments less transparent and straightforward. Moreover, the reporting obligations under the WFD and the HD have different timetables, which creates a gap when trying to compare data from exactly the same period. Although both Directives have 6-year cycles, there is a lag time of two years in the reporting periods.

- **Reporting choices and gaps create additional obstacles for a comprehensive cross-walk analysis between WFD and HD data**. For example, EU Member States are required to provide the code identifiers of all GWBs and SWBs which are linked together. However, in more than 20% of the linkages this was not done (i.e. 10,698 pairs of GWBs and SWBs with unknown SWB code – "null"). Therefore, our knowledge on the linked water bodies is only partial, although we know that a linkage is reported. For sound implementation of the overall methodology, those linkages where the SWB was unknown, were excluded from the analysis. Furthermore, the reported physical distance between GWBs and SWBs showed a wide range, even reaching up to 300 km. Those SWBs having a distance greater than 2 km (less than 1.5% of the total number of SWBs linked with GWBs) were also excluded from the analysis. Thus, our final sample of linked GWBs and SWB ended up including only 2,743 unique GWBs linked with 31,554 unique SWBs, having a distance between them less than 2 km.

References:

Halada, L., et al., 2020, Proposals of the ecological grouping of the Habitats Directive habitats and species, ETC Biodiversity report 2020, pp. 38.

ANNEX 6 – COMMON CHEMICALS CAUSING LESS THAN GOOD CHEMICAL STATUS IN GROUNDWATER BODIES (GWBS) OR SURFACE WATER BODIES (SWBS) IN EU 27

Common GWB pollutants causing poor chemical status of GWBs:

- EEA_34-01-5 - Pesticides (Active substances in pesticides- including their relevant metabolites- degradation and reaction products)
- CAS_67-66-3 - Trichloromethane
- CAS_127-18-4 - Tetrachloroethylene
- CAS_7440-02-0 - Nickel and its compounds
- CAS_7440-43-9 - Cadmium and its compounds
- CAS_205-99-2 - Benzo(b)fluoranthene
- EEA_33-56-7 - Total PAHs (Benzo(a)pyrene- Benzo(b)fluoranthene- Benzo(k)fluoranthene- Benzo(ghi)perylene- Indeno(1-2-3-cd)pyrene)
- CAS_1912-24-9 – Atrazine
- CAS_7439-92-1 - Lead and its compounds
- CAS_193-39-5 - Indeno(1-2-3-cd)pyrene
- CAS_191-24-2 - Benzo(g-h-i)perylene
- CAS_206-44-0 - Fluoranthene
- CAS_120-12-7 - Anthracene
- CAS_7439-97-6 - Mercury and its compounds
- CAS_87-68-3 - Hexachlorobutadiene
- CAS_608-73-1 - Hexachlorocyclohexane

Common SWB priority substances causing less than good status of SWBs:

- EEA_32-24-6 - Total Benzo(g-h-i)perylene (CAS_191-24-2) + Indeno(1-2-3-cd)pyrene (CAS_193-39-5)
- CAS_7439-97-6 - Mercury and its compounds
- CAS_206-44-0 - Fluoranthene
- EEA_32-23-5 - Total Benzo(b)fluor-anthene (CAS_205-99-2) + Benzo(k)fluor-anthene (CAS_207-08-9)
- CAS_67-66-3 - Trichloromethane
- CAS_7440-02-0 - Nickel and its compounds
- CAS_7439-92-1 - Lead and its compounds
- CAS_7440-43-9 - Cadmium and its compounds
- CAS_608-73-1 - Hexachlorocyclohexane
- CAS_87-68-3 - Hexachlorobutadiene
- CAS_127-18-4 - Tetrachloroethylene
- CAS_120-12-7 – Anthracene
- CAS_1912-24-9 – Atrazine

Note: Chemicals are sorted according to affected GWB area or SWB length.

Sources:

EEA, 2020, 'WISE Water Framework Directive Database', DAT-124-en, published 25 March 2020 (https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4) accessed 13 January 2021.