STUDY OF THE IMPACTS OF PRESSURES ON GROUNDWATER IN EUROPE

SERVICE CONTRACT No 3415/B2020/EEA.58185

Comparative study on quantitative and chemical status of groundwater bodies

Sub-study 1 - Final report

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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
DPSIR	Drivers-Pressures-State-Impacts-Responses
EU 27_2020	27 EU Member States by 2020, after exit of UK from the EU
GWAAE	Groundwater Associated Aquatic Ecosystems
GWB	Groundwater Body
GWDTE	Groundwater Dependent Terrestrial Ecosystems
HD	Habitats Directive
IED	Industrial Emissions Directive
RBMP	River Basin Management Plan
SWB	Surface Water Body
UWWTD	Urban Waste Water Treatment Directive
WFD	Water Framework Directive, Directive 2000/60/EC
WISE	Water Information System for Europe

Key findings

- Groundwater bodies (GWBs) in the EU 27 are under significant pollution and abstraction pressures, as 27% of the total GWB area was either in poor quantitative or chemical status in the 2nd River Basin Management Plans. The GWB area having poor chemical status was significantly larger, than the area having poor quantitative status.

- Porous, fissured and karstic aquifers are more likely to be in less than good groundwater status, compared to fractured and insignificant aquifers, as they are the most widespread and exposed to pressures from socio-economic development and climate change. The aquifer size, thickness, composition, and mechanisms for groundwater flow and pollutant transport also affect the vulnerability of aquifers. Furthermore, shallow aquifers, linked with surface water bodies, are more likely to be polluted or over-exploited.

- Agriculture is a key driver of pressures that lead to less than good groundwater status, with 20% of the EU 27 GWB area being affected by agricultural diffuse source pollution and 7% by agricultural abstraction. Other significant pressures include the supply of water to the public (7%), discharges from scattered dwellings non-connected to sewerage networks (5%), point source pollution from abandoned industrial or contaminated sites (4%), point source pollution from industrial plants regulated under the Industrial Emissions Directive (4%).

- Many GWBs are affected simultaneously by multiple drivers and pressures, which can be related both to water quantity and quality. GWBs in less than good status are also associated with multiple impacts. The most widespread impacts are chemical and nutrient pollution, water imbalances, as well as impacts on groundwater associated surface waters and groundwater dependent terrestrial ecosystems. Managing the trade-offs between different types of drivers and pressures, and their combined impacts on groundwater status, will be key for restoring GWBs in less than good status and reversing negative impacts.

- The quantitative and chemical status of GWBs can be strongly interdependent. Tackling over-abstraction may prevent salinisation of groundwater in coastal or inland areas, while reducing agricultural pollution can support the delivery of safe and affordable drinking water. This is particularly relevant for southern EU 27 Member States, where GWBs were twice more likely to be in both poor quantitative and chemical status (8%), compared to the EU 27 average (4%), in the 2nd River Basin Management Plans.

- Adaptation to the impacts of climate change will be a major challenge, as groundwater recharge is expected to decrease further in southern Europe, and parts of western and central Europe, where many aquifers are already over-exploited. In northern and north-eastern Europe, earlier snow melting is expected to change groundwater infiltration patterns, decreasing summer baseflow further, and making shallow aquifers more vulnerable to pollution. Saline intrusion will be more likely to affect coastal aquifers, where more frequent droughts may increase current abstraction and the average sea level is expected to rise. Maintaining and achieving good groundwater status can increase the climate resilience of European society and economy.

1. Introduction

1.1 Over-exploitation and pollution of groundwater and cases of interdependency

Groundwater is a finite resource which needs protection from over-exploitation and pollution to ensure the long-term sustainability of its use for human activities, as well as the conservation of ecosystems depending significantly on groundwater quantity and quality. Compared to surface waters, groundwaters tend to be less exposed to climate variability, droughts, floods and pollution with anthropogenically produced chemical substances. Therefore, sustaining sufficient and clean water in aquifers enhances societal resilience to the negative impacts of climate change and human development. As a result, groundwater resources have a strategic role in overall river basin management.

However, once a GWB is over-exploited or polluted, the natural processes of recharge and attenuation, as well as the artificial efforts to increase recharge and treat pollution, can take years or decades to lead to the recovery of groundwater levels and/or quality. Furthermore, the cost of the necessary technical measures can make water supply from the specific GWB unaffordable for water utilities and water users. Limited availability of groundwater of sufficient quantity and/or quality can distort the human activities which rely on the groundwater resources for water supply (e.g. cuts in drinking water supply, failure of irrigated crops). In addition, reduced availability may result in low flows and contamination of associated streams and rivers, and degradation of the relevant aquatic or terrestrial ecosystems (e.g. marshes, wet forests, wetlands and peatlands).

Groundwater quantity and quality issues are often interdependent: pollution can make a GWB no longer safe for its intended use regardless of the available volume, whilst lowering water tables can trigger processes which lead to the pollution of clean groundwater.

Indicative **examples** of such situations include the following cases:

- Unsustainable abstraction of groundwater may reduce the available groundwater storage and, subsequently, lead to degradation of groundwater quality. This happens because there is less groundwater volume for the dilution of pollutants present in the depleted aquifer. Such pollutants may include anthropogenic pollutants that leach from the soil surface to deeper aquifers, as well naturally occurring pollutants which originate from the chemical composition of the rock/soil minerals of the aquifer. Conversely, improving the local groundwater balance (e.g. through artificial groundwater recharge, natural water retention measures, and retrofitting permeable areas into urban land) may benefit both groundwater storage and groundwater quality, because the dilution of such pollutants will be higher and their concentrations will decrease.
- Unsustainable abstraction of groundwater may distort the hydraulic gradient and alter the typical direction of flows between adjacent groundwater bodies or between surface and groundwater bodies. This may cause the inflow of impaired surface waters or groundwaters, and their mixture with groundwaters of good quality. For instance, over-abstraction may change the normal flows in the area and cause the influx of polluted groundwater or surface water from neighbouring water bodies. Furthermore, over-abstraction may cause upwelling of deeper salt waters (e.g. deeper layers of brines from “ancient seas” or dissolved evaporitic formations in sedimentary basins) and their mixture with clean groundwater in upper layers. Over-abstraction may also cause mobilisation of highly mineralised connate water, which is trapped in the rock matrix during its formation.
- Over-exploitation of coastal aquifers may decrease their groundwater tables critically, allowing denser sea water to intrude into coastal aquifers. This results in the salinisation of coastal

groundwater. Furthermore, where hydraulic connections are present, saline intrusion into the coastal groundwater may lead to damages to associated surface waters and dependent terrestrial ecosystems.

- Deterioration of groundwater quality may lead to the closure of wells and boreholes, which serve water users with specific water quality requirements (e.g. for drinking, irrigation-agricultural, and industrial purposes). This can redirect the demand for groundwater supply to other available and clean water sources. Such alternative water sources may include nearby GWBs with good water quality. The additional pressure on these GWBs, due to the relocation of water abstraction, could potentially lead to the distortion of the water balance in these GWBs, unless measures are taken to control overall abstraction in the area.
- The phasing out of long-term dewatering operations, which are necessary for the safety of surface and sub-surface mining activities, can lead to the ingress or rebound of impaired groundwaters in the mining site. This can occur at historically abandoned mines or at contemporary managed mine abandonment. When pumping of groundwater ceases, then the groundwater table rises and groundwater flushes back through the fractured mined rocks, which were once dewatered. The mineral hosting rocks usually contain highly oxidisable metal sulphides (e.g. pyrite), which have oxidised when the water table was lowered during dewatering. The cessation of pumping and rebound of groundwater flushes out the soluble metal oxides leading to poor quality groundwater with low pH and a high concentration of dissolved metals. The groundwater is known as acid mine or rock drainage and may collect in the disused mine galleys and tunnels and discharge to the surface from “adits” (i.e. openings of the mining site). Mine water rebound is a potential source of pollution for receiving rivers and adjacent groundwaters. Some examples of the impacts of acid mine drainage include the blanketing of river and stream beds in “metal ochres”, which effectively destroy invertebrate life, pollution from low pH discharges with high dissolved metal concentrations and the abandonment of drinking water abstractions. Furthermore, surface and groundwater pollution with acid mine drainage may originate from rain falling upon unmanaged (e.g. uncapped) heaps of mine waste, or from leachates from detention ponds with mine residual slurries (Tayebi-Khorami et al., 2019; Briere and Turrell, 2012).

1.2 Scope and outline of this report

This report presents a **comparative analysis of the quantitative and chemical status of groundwater bodies** (GWBs) in the 27 EU Member States (EU 27_2020)[1], focusing on **interdependencies** that may explain failures of both groundwater quantitative and chemical status within the same river basin. The analysis is conducted taking the GWB area as a key measure for monitoring progress and making comparisons.

The report is structured around the key components of the Drivers-Pressures-State-Impacts-Responses (DPSIR) model. It starts with the **State** of GWBs (i.e. current quantitative and chemical status, and trends), analysing the possible connections between poor quantitative or chemical status where they occur in the same GWB. In addition, it explores how status conditions are differentiated for various groundwater characteristics, such as groundwater horizon depth, linkage to surface waters and hydrogeological conditions. Subsequently, the report describes the main environmental **Impacts** resulting from poor status, the **Pressures** causing them and the **Drivers** behind the pressures (e.g. sectors/activities), as reported by the EU 27 under the Water Framework Directive (WFD). The report

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[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

also illustrates various cases across the EU 27 where the quantitative status or the chemical status or both were reported as poor in the 2nd RBMPs.

1.3 Methodology: Key conventions and definitions for this study

Definition of “groundwater”, “aquifer” and ”groundwater body” in the study

This study adopts the following definitions for “groundwater”, “aquifer” and groundwater body” (Box 1.1).

Box 1.1 Definition of “groundwater”, “aquifer” and “groundwater body”

“*Groundwater*” means “*all water, which is below the surface of the ground in the saturated zone and in direct context with the ground or subsoil*” - Article 2, WFD (EU, 2000).

“*Aquifer*” is defined as “*a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater*” (EU, 2000)

“*Groundwater body*” is a term introduced in the WFD to describe one or more aquifers (or sub-divisions of extensive aquifers), which are addressed together for management purposes, as they have significant capacity to supply groundwater, and/or the absence of management may pose significant risks to ecosystems, due to unsustainable abstraction and transport of pollutants. Therefore, reported groundwater bodies under the WFD do not represent all groundwaters, but only those for which WFD objectives (i.e. achieving and maintaining good quantitative and chemical status) are assessed as meaningful by EU Member States (CIS, 2003; 2004)

For further read see *Annex 1*.

Furthermore, the analysis of the reported data from the EU 27 illustrates that there are significant differences in the assignment of horizons to GWBs. Those differences are assumed to be a combination of different physical realities, national practices predating the WFD and/or reporting choices as part of WFD implementation.

In general, the complex physical reality of hydrogeological structures has been simplified for WFD reporting purposes. As a result, the 3-dimensional geometry of aquifers and their overlay are modelled in less detail than they appear in nature. However, the modelling has sufficient accuracy to support the understanding of their properties and relationships, and to serve the management purposes of EU water policy. As part of this process, groundwater horizons have been assigned to GWBs with varying depth, starting from the surface and moving to greater depths; Horizon 1 is the shallowest and nearest to the groundwater surface, while Horizons 2, 3, etc. are deeper horizons.

Box 1.2 Understanding the delineation of groundwater bodies

A groundwater body may be identified (a) as a single group of geological layers/strata within one aquifer or multiple aquifers (single GWB with multiple horizons) (b) as separate geological layers/strata within one aquifer or multiple aquifers overlying each other in the vertical plane (multiple GWBs with single horizons). There is no fixed methodology for GWB delineation, but it is recommended that Member States implement hierarchical criteria to identify aquifers, geological boundaries, groundwater levels, etc. (CIS, 2003) (For further read see *Annex 2*).

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

According to the WFD, a GWB is assessed for both its quantitative and chemical status. For definitions of these terms, please read further *Annex 1*.

In addition, for the purposes of this report, the potential combinations of the quantitative and chemical status of GWBs 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 separately failures due to poor quantitative status or due to poor chemical status or due to both. The reader is reminded that, according to the "one-out-all-out principle", the overall status assessment of a water body in the 1st and 2nd River Basin Management Plans (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 corresponds to failure of the good quantitative status or chemical status or both.

Table 1.1 Conventions for labelling groundwater 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

2 Analysis of quantitative and chemical status of groundwater bodies at EU 27 and country level

EU-level overview

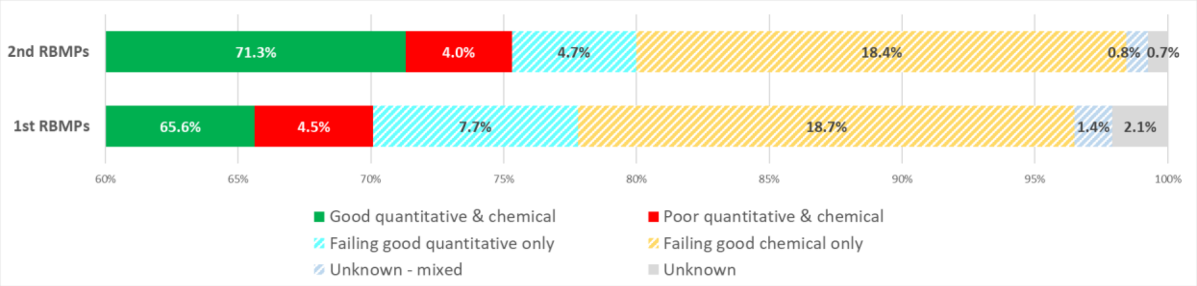
Since the adoption of the WFD, EU Member States have made great efforts to characterise, monitor and assess GWBs, and implement basic and supplementary measures, where required, to maintain or achieve good groundwater status (see Box 2.1). The overall implementation efforts have contributed to an improvement of groundwater status (especially quantitative status) and filling of existing knowledge gaps. However, relevant progress may be characterised as slow, considering that the WFD required that all water bodies would have achieved good status by the end of the 2015, when the 2nd RBMPs would be published.

In the 2nd RBMPs, 71% of the total GWB area in the EU 27 was reported in good quantitative and chemical status. However, almost 23% of the total GWB area was affected by poor chemical status, and 9% by poor quantitative status. In 4% of the total GWB area, groundwater was in both poor quantitative and chemical status (see Figure 2.1).

A comparison of the reported data from the 1st RBMPs and the 2nd RBMPs[2] shows that the proportion of the GWB area in both good quantitative and chemical status has increased from 66% to 71%. In addition, the GWB area with unknown status has decreased from 2.1% to 0.7% (see Figure 2.1). Nevertheless, the share of the GWB area either in poor quantitative or chemical status remains high.

Although the above aggregate trends (Fig. 2.1) show an improvement in groundwater status, there are some uncertainties which limit confidence in the extent of this improvement. Caution is needed when comparing reported data from the 1st and 2nd RBMPs, because various EU Member States modified the boundaries of reported GWBs (e.g. re-delineation, merging, splitting, etc.) to better target those considered at risk (EC, 2019a). Thus, only 46% of the GWB area in the 2nd RBMPs remained identical to that in the 1st RBMPs, whereas the rest of the GWB area underwent some sort of modification (For further information see *Annex 3*).

Figure 2.1 Trends in groundwater status in the EU 27 between the 1st and 2nd RBMPs (in % of total EU 27 GWB area).



Source: Authors' compilation based on data from WISE Water Framework Directive Database – 1st and 2nd RBMPs (EEA, 2020)

Slow progress towards achieving the environmental objectives for GWBs can be partly explained by the different starting points and speeds in WFD implementation across EU Member States. This delayed the launch of practical measures in various cases. Initially, there were delays from agreed deadlines due to the time needed for preparatory actions (e.g. legislative, administrative) and improvements in monitoring coverage (e.g. additional monitoring points and monitored parameters) (EC, 2007; 2009). Additional delays were caused by: knowledge gaps and the time needed to prepare relevant field studies; technical feasibility problems; absence of secure funding; complexity of institutional set-up and other reasons (EC, 2012; 2015; 2019a; Buchanan et al., 2019). There are cases where local hydrogeological conditions have impeded the rapid recovery of GWBs from poor status, despite recent implementation of measures. Depending on the soil and rock type and the depth of the unsaturated zone, groundwater flow velocity can be slow. Therefore, there can be a lag time of years or decades before significant improvements are observed in water quality or groundwater levels following measures being put in place (see section 2.4). Furthermore, the absence of visible progress is not necessarily a result of a static, but rather a dynamic situation. The implementation of specific measures on site may target groundwater quantity and quality improvements. However, the impacts of concurrent climate change and socio-economic trends (e.g. population growth, land use change) may offset the delivery of expected improvements in practice, although these confounding factors should be taken into account during the design of the measures.

So far, EU Member States have used the WFD provisions under Article 4 (i.e. exemptions) to extend the applicable deadlines for the achievement of good groundwater status up to 2021 and 2027. For

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[2] 1st RBMPs were due to be developed between 2003-2009 and reported in 2010, while 2nd RBMPs were due to be developed between 2010-2015 and reported in 2016.

poor quantitative groundwater status, the deadline extensions were mainly justified on the grounds of technical infeasibility. For poor chemical groundwater status, the justification was based mainly on technical infeasibility or adverse natural conditions. There was also a smaller number of cases where less stringent environmental objectives, than those generally required, were applied and achieved by 2015[3]. The underlying justification for them was technical infeasibility and/or disproportionate costs. The Member States did not report any cases of temporary groundwater status deterioration, because of natural causes (e.g. prolonged droughts) or accidents (e.g. chemical pollution) (EC, 2019a).

Box 2.1 Definition of "basic measures" and "supplementary measures" in the WFD

"Basic measures" are defined in Article 11(3) and Annex VI (Part A) of the WFD, including measures such as: those foreseen under EU water legislation other than the WFD (e.g. Nitrates Directive, Urban Waste Water Treatment Directive); water pricing and cost recovery; water efficiency and sustainable water use; prior authorisation and control of water abstractions, impoundments, hydromorphological alterations, artificial recharge or groundwater augmentation, point or diffuse source emissions; and prohibition of direct discharges to groundwater; elimination of pollution from chemical substances, including priority substances; prevention of accidental pollution and losses of pollutants from technical installations (EU, 2000).

"Supplementary measures" are defined in Article 11(4) and Annex VI (Part B) of the WFD, including additional measures, beyond the basic measures, to ensure that environmental objectives for all water bodies can be reached. They also include measures for additional protection or improvement of the water status required by the WFD, as in the case of international agreements (EU, 2000).

Country-level overview

In the 2nd RBMPs, an average of 27% of the total GWB area in the EU 27 was reported to be in poor quantitative or chemical status. This average extent of GWB area in poor quantitative or chemical status was exceeded in the following 12 EU Member States (see Figure 2.2):

- In Bulgaria, Czechia, Germany, Luxembourg and Slovakia, a very high proportion of the total GWB area failing to achieve good status was in poor chemical status.
- In France and Italy, the highest proportion of the total GWB area failing to achieve good status was in poor chemical status, while also a significant proportion of the GWB area was in poor quantitative status.
- In Belgium, Malta and Spain, a significant proportion of the GWB area was in both poor quantitative and chemical status (i.e. Spain 15%; Belgium 27%; Malta 80%).
- In Cyprus and Hungary, the highest proportion of the GWB area failing to achieve good status was in poor quantitative status, but the proportion of the GWB area in poor chemical status was also significant.

Southern European[4] Member States do not show a significant difference from the EU 27 average of 27% of total GWB area in poor quantitative or chemical status. However, they do have a proportionately larger GWB area in both poor quantitative and chemical status (i.e. Southern EU Member States: 8.4%; EU 27: 4.0%). Furthermore, Italy accounts for 44% of the total GWB area in the EU 27 with unknown status.

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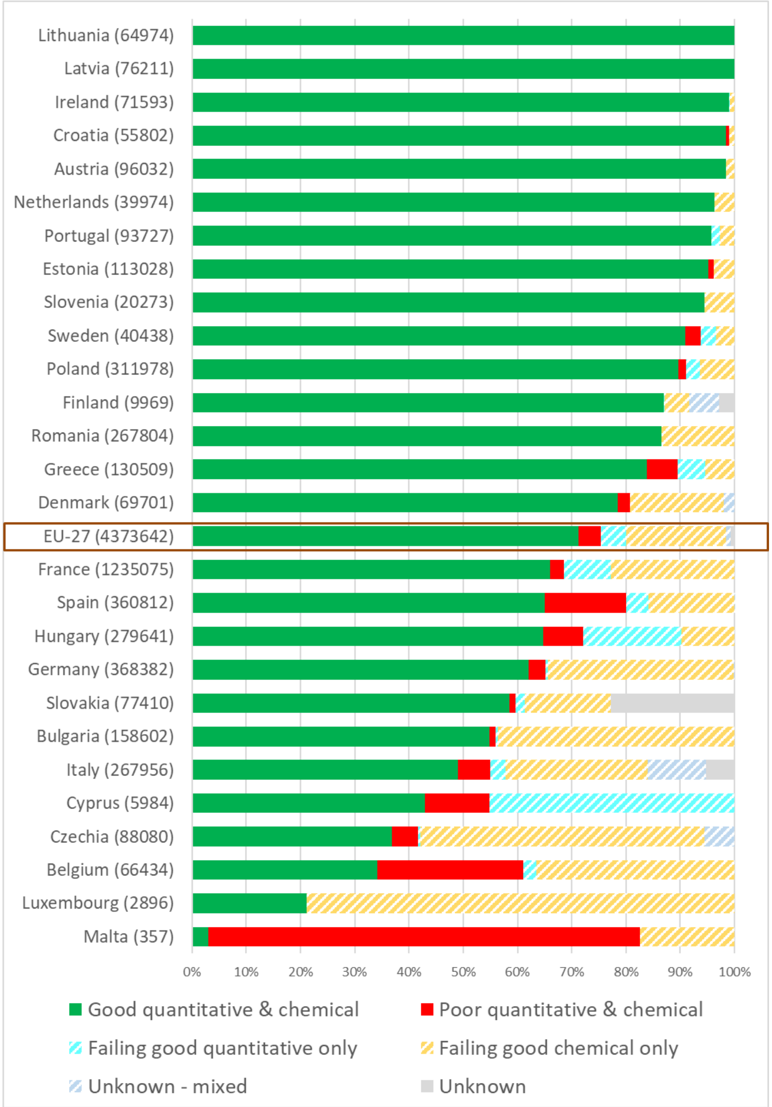
[3] For cases of poor groundwater quantitative status in Cyprus and Hungary, and cases of poor groundwater chemical status in Cyprus, Spain, Italy and Malta;
Note: less stringent environmental objectives are applied at the level of GWB for the quantitative status and at the level of quality element (pollutant) for the chemical status (EC, 2019a).

[4] Southern EU Member States are Cyprus, Greece, Croatia, Italy, Malta, Portugal, Slovenia, and Spain (adapted from UN Geoscheme M49 standard).

Figure 2.2 Distribution of groundwater status per EU 27 Member State in the 2nd RBMPs (in % of total national GWB area).



Note: The reported total national GWB area is given in brackets next to the country name (in km²)
Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020)

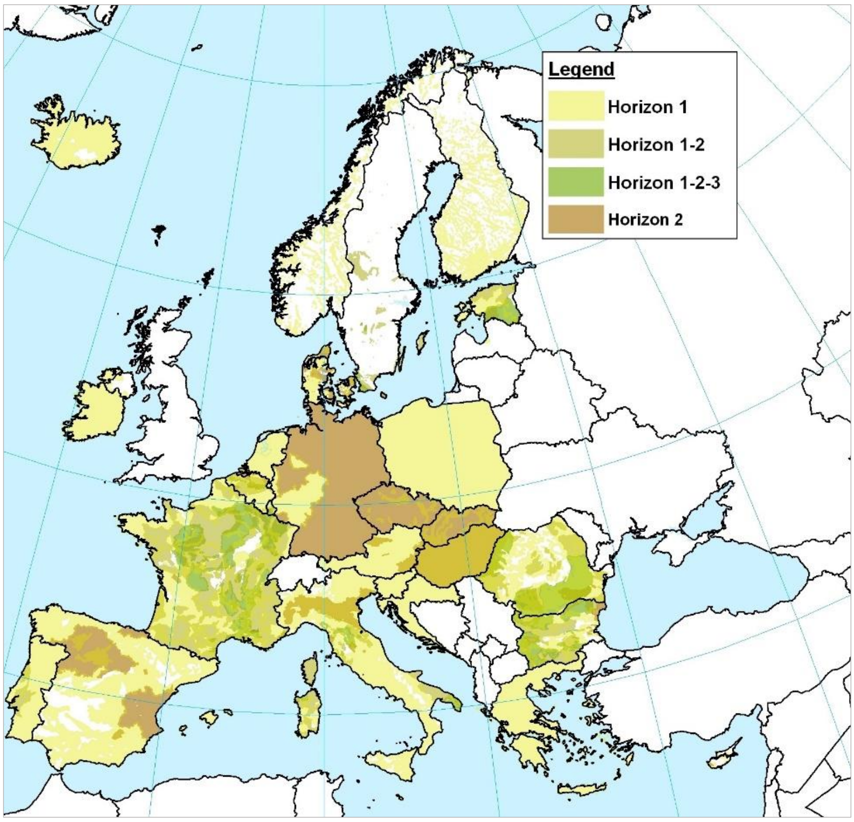
Box 2.2 GWB challenges and management in Malta

Malta is an arid Mediterranean island state, which depends heavily on groundwater for its water supply (e.g. drinking, tourism, and agricultural needs) (Zal et al., 2017). Water abstraction is a significant pressure for its GWBs, having caused severe issues with saline intrusion. Poor quantitative or chemical status is affecting 97% of the total national GWB area. Furthermore, a strong interdependence is observed between groundwater quantitative and chemical status, with 80% of the total GWB area having both poor quantitative and chemical status (EEA, 2020). Malta has made considerable efforts to diversify water supply sources, including intensive application of water reuse and desalination. However, the total volume of abstraction from groundwaters has actually increased in the past decades (Eurostat, 2021). In 2016, Malta reported to the European Commission that all national GWBs are expected to meet WFD environmental objectives by 2027 (EC, 2019a).

2.1 Impact of horizon depth on groundwater status

At the EU 27 level, almost 93% of the total GWB area is assigned to the uppermost groundwater horizons and other deeper horizons linked to them: Horizon 1 (42%), deeper horizons linked with Horizon 1 (32%), Horizon 2 (16%) and deeper horizons linked to Horizon 2 (3%). The remaining GWB area is assigned to deeper horizons than Horizon 3 and combinations of such deeper horizons (EEA, 2020). An overview of the reported horizon distribution in the EU 27 is shown in Map 2.1.
It should be noted that there are 7 EU Member States, representing 14% of the total GWB area in EU 27, which have reported all of their GWB area as assigned to Horizon 1 (i.e. Croatia, Finland, Greece, Ireland, Malta, Poland, Slovenia).

Map 2.1 Reported distribution of uppermost groundwater horizons in the EU 27 in the 2nd RBMPs .



Note: Map illustration includes Horizons 1, 1-2, 1-2-3, 2; Upper horizons (e.g. Horizon 1) may hide deeper horizons on the same location because of their vertical overlay.
Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020)

Box 2.3 Understanding the spatial extent of different horizon categories (see Map 2.1)

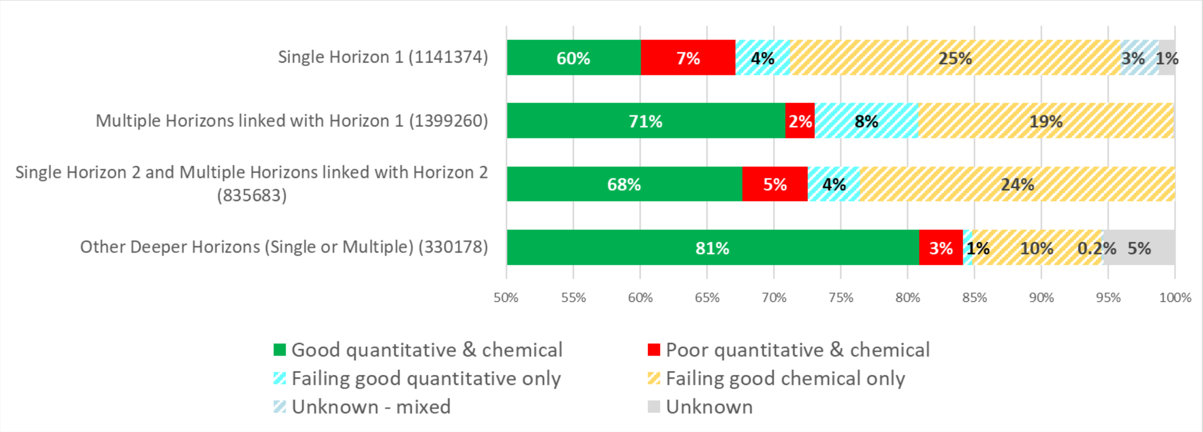
GWBs assigned to Horizon 1 represent 42% of the total GWB area in the EU 27. However, Czechia, Latvia, Germany, Slovakia and Sweden do not report any or only a few of those. These Horizon 1 GWBs often follow large rivers, representing aquifers linked to the floodplains of these surface water bodies.

GWBs assigned to Horizons 1-2 **and** ***Horizons 1-2-3*** represent 13% and 6%, respectively, of the total GWB area in the EU 27. They are typically located in Belgium, Bulgaria, Estonia, France, and Romania, and to a lower degree in Italy, Portugal and Sweden.

GWBs assigned to Horizon 2 represent 16% of the total GWB area in the EU 27. They are located mainly in central Europe (Czechia, Germany, Hungary and Slovakia), and to a lower degree in Austria, Denmark, Italy and Spain.

The analysis shows that poor quantitative or chemical groundwater status is more likely for horizons closer to the ground surface or with links to these horizons (e.g. Horizon 1 or 2, and horizons linked to them), compared to much deeper horizons (see Figure 2.3). This is expected because upper geological layers are more likely to be exposed to different types of pollution or they are more easily exploited. It is also more likely that over-abstraction and pollution problems exist concurrently and interact with each other. However, deeper horizons tend to be more protected from pollution. The transport of pollutants to deeper geological layers is a slow process and depends on the depth of the unsaturated zone, soil porosity, geometry and density of rock fractures, and general groundwater flow characteristics. In addition, the transport of pollutants may be intercepted by the existence of impermeable geological layers ("aquitards"), which confine overlaying aquifers. The concentration of pollutants can be significantly decreased during groundwater transport due to microbial breakdown, changing geochemical conditions and chemical reactions with the rock/soil minerals found within the aquifers.

Figure 2.3 Groundwater status by horizon depth in the EU 27 in the 2nd RBMPs (in % of total GWB area by horizon).



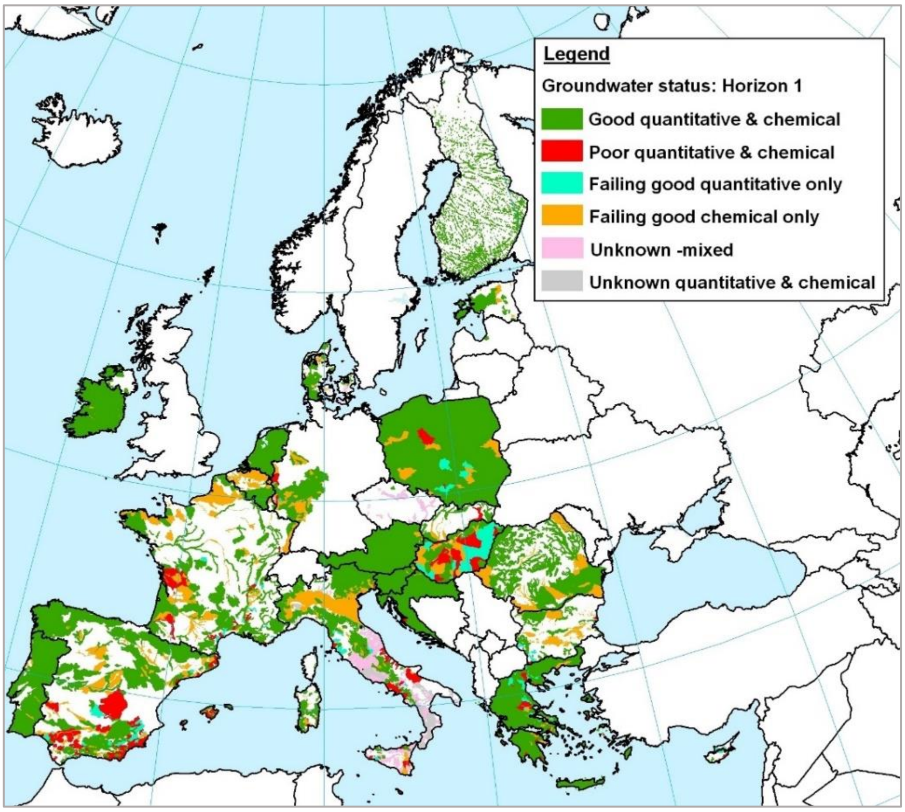
Note: The reported total GWB area per horizon category is given in brackets (in km^2); Analysis includes the following countries: Austria, Belgium, Bulgaria, Cyprus, Czechia, Denmark, Estonia, France, Germany, Hungary, Italy, Latvia, Luxembourg, Netherlands, Portugal, Romania, Slovakia, Spain, Sweden; Countries excluded because all GWBs assigned to Horizon 1: Croatia, Finland, Greece, Ireland, Malta, Poland, Slovenia; No reported data from Lithuania.

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

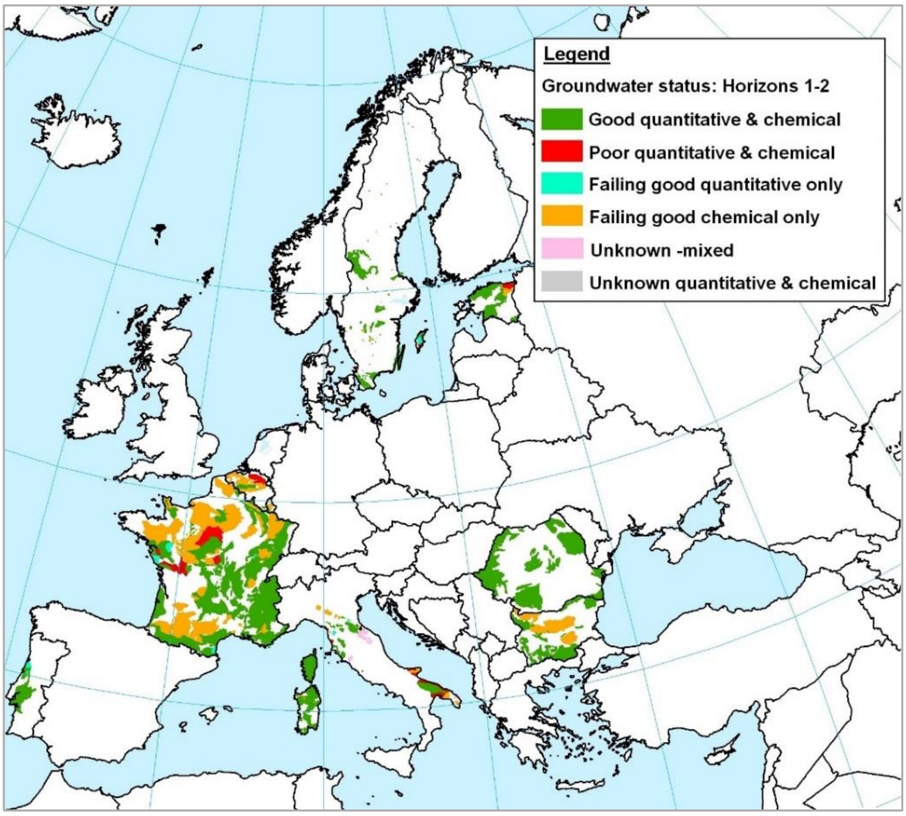
Map 2.2 shows the spatial extent of poor quantitative or chemical groundwater status across the EU 27, differentiated by depth of groundwater horizon, and for the uppermost horizons (i.e. Horizons 1, 1-2, 1-2-3 and 2). The uppermost horizons were selected as they are closer to the ground surface and they are more vulnerable to pollution and over-exploitation. Moreover, they are more likely to interact with surface water bodies (SWBs), groundwater associated aquatic ecosystems (GWAAEs) and groundwater dependent terrestrial ecosystems (GWDTEs). These four horizon categories represent nearly 77% of the total GWB area reported under the WFD, whereas the rest of the GWB area is covered by 35 less significant (combinations of) horizon categories (EEA, 2020). Mapping different horizon depths is necessary to show the status of different GWBs found at different depths of the same location.

Map 2.2 Quantitative and chemical status of GWBs assigned to the uppermost groundwater horizons in the EU 27 in the 2nd RBMPs .

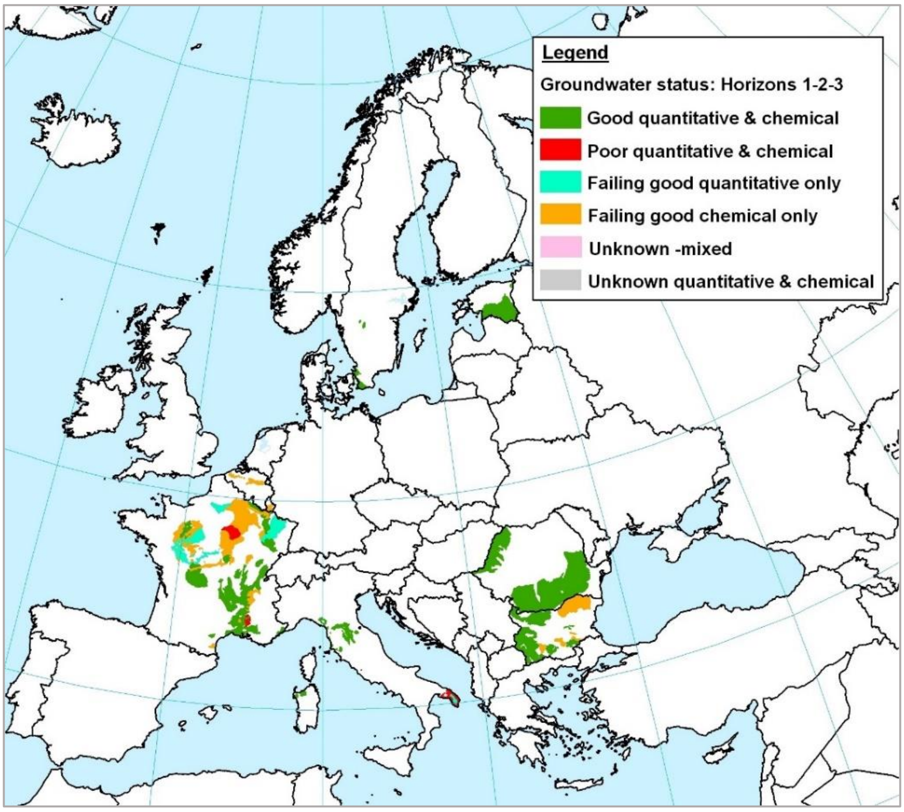
(a) Horizon 1



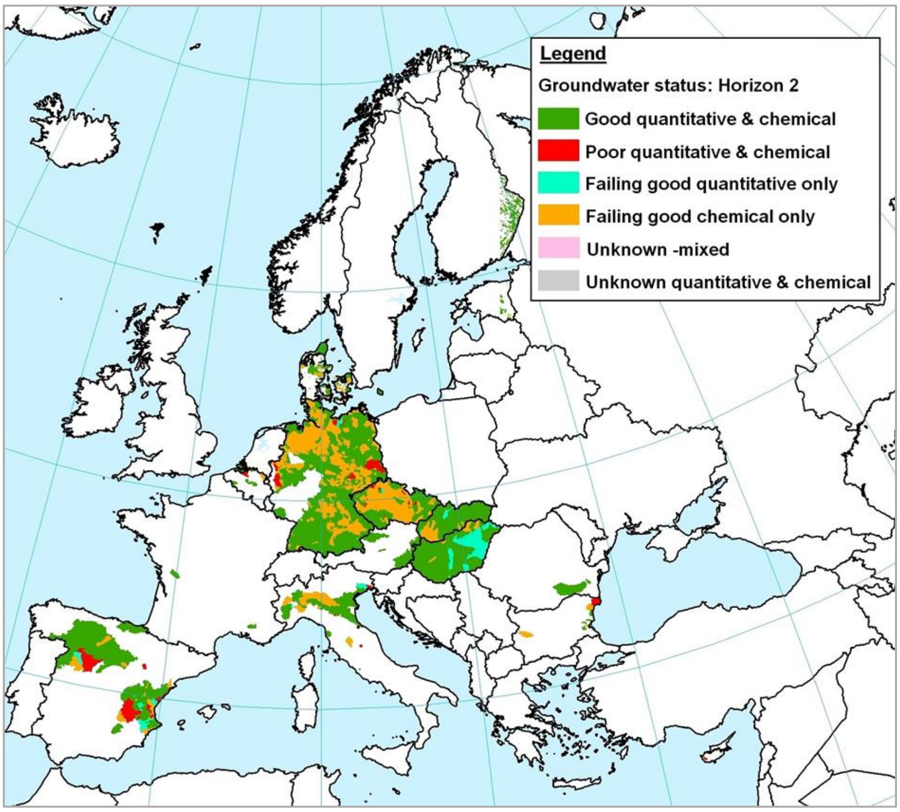
(b) Horizons 1-2



(c) Horizons 1-2-3



(d) Horizon 2



Note: Map illustrations include (a) groundwater status of Horizon 1 GWBs; (b) groundwater status of Horizon 1-2 GWBs; (c) groundwater status of Horizon 1-2-3 GWBs; (d) groundwater status of Horizon 2 GWBs.
Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020)

Box 2.4 EU 27 GWBs in poor quantitative or chemical status or both in the 2nd RBMPs (see Map 2.2)

GWBs in poor quantitative and chemical status

The GWBs from the uppermost horizons, which have both poor quantitative and chemical status, are frequently located across coastal areas, where potential over-exploitation can lead to saline intrusion. Furthermore, they are commonly found in inland areas, where critical combinations of abstraction and pollution pressures occur, as a result of different socio-economic activities (e.g. agriculture, public water supply, industry and mining).
Spain, France and Hungary have reported large GWB areas in poor quantitative and chemical status:
- Spain: many GWBs in central and southern regions (e.g. Western and Eastern Mancha aquifer, Lower Guadalquivir), coastal regions of Andalucia and Murcia and Balearic Islands.
- France: GWBs in southwestern parts (e.g. Charente and Adour-Garonne basins), and the Beauce aquifer south of Paris.
- Hungary: GWBs covering large parts of the Pannonian plain.

Additional cases are also found in Belgium, Bulgaria, Cyprus, Estonia, Germany, Greece, Italy (e.g. Campania, Puglia, eastern Adriatic and coastal aquifers in Sicily and Sardinia), Malta and central Poland.

GWBs in poor quantitative status only

The GWBs from the uppermost horizons, which have poor quantitative status only, are commonly located in inland areas across Europe. There are different socio-economic activities, which contribute to the total abstraction pressure causing over-exploitation of these GWBs. However, agriculture and public water supply are the most frequent drivers.
In Hungary, there are large GWB areas in poor quantitative status only (e.g. the Tisza river plains). Additional cases are also found in France (e.g. Beauce Aquifers, Moselle, Plaine du Roussillon), Italy (e.g. Puglia, Venice),

Poland, Portugal (e.g. Aveiro), Spain (e.g. around Valencia, Murcia, Leon and Castille), Sweden (e.g. Island of Gotland).

GWBs in poor chemical status only

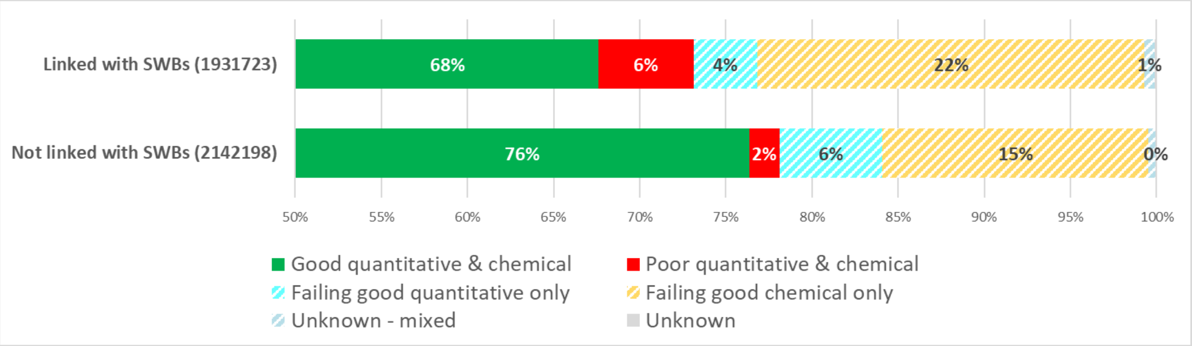
The GWBs from the uppermost horizons, which have poor chemical status only, are widespread in inland areas of western and eastern Europe, as well as in northern Italy and central Spain. In parallel, the good quantitative status of these GWBs may be a result of hydrogeological conditions favouring fast recharge or absence of over-exploitation or both.

Large areas of GWBs in poor chemical status only are found in Belgium, Bulgaria (e.g. Danube plains, Maritsa plains), Czechia, northern and south-western France, Germany, Hungary, Italy (e.g. Pô valley), Poland, Slovakia, Spain, Romania (e.g. Danube plains, Moldavian plains).

2.2 Impact of linkage with surface waters on groundwater status

In the EU 27, nearly 44% of the total GWB area is reported to be linked to SWBs. The analysis shows that the GWBs linked to SWBs are more likely to be in either poor quantitative or chemical status (linked GWBs: 32%; not linked GWBs: 23%). It should be noted that the difference is not significant between the poor quantitative status of linked GWBs and not linked GWBs, but there is a remarkable difference mainly in the poor chemical status (linked GWBs: 22%; not linked GWBs: 15%). (see Figure 2.4).

Figure 2.4 Groundwater status for linked and non-linked GWBs with SWBs in the EU 27 in the 2nd RBMPs (in % of total GWB area by category of linkage).



Note: The reported total GWB area per category of linkage is given in brackets (in km^2)

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

In general, GWBs closer to the ground surface (i.e. in uppermost horizons) are more likely to be linked with a SWB, compared to deeper GWBs. As shown in section 2.1, these GWBs are more likely to have poor quantitative and chemical status, because they are more vulnerable to pollution and over-exploitation. These pressures can not only affect them directly, but also indirectly through the linked SWB. For instance, an aquifer made up of coarse sediments which follows a river channel will be in hydraulic connection with the river itself and it is likely to contribute a significant proportion of the base flow. Lower flows in rivers (e.g. due to over-abstraction, diversions, upstream dam construction, drought events) can lead to lower recharges into the connected aquifer and groundwater levels may fall locally. Furthermore, if the river water is polluted by upstream activities (e.g. pesticides leaching from riparian agricultural fields, insufficiently treated waste water discharging from neighbouring households and small communities) this will also affect the quality of groundwater in the aquifer. Depending on local hydrogeological conditions, impacts from the interaction of surface and groundwaters may appear either more rapidly or more slowly (see section 2.4).

2.3 Impact of hydrogeological conditions on groundwater status

The groundwater quantity and quality are partly controlled by the local hydrogeological conditions, such as the dominant geological formation in the aquifer and the average aquifer productivity. These parameters control:

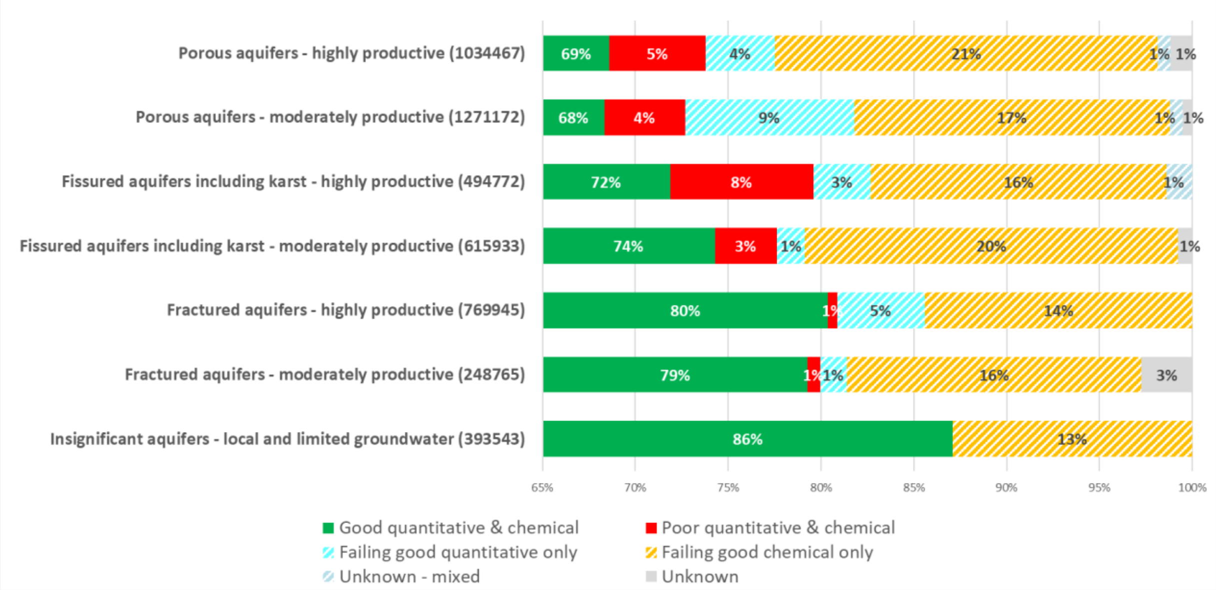
- how fast an aquifer is recharged (based on the flow mechanisms);
- how vulnerable an aquifer is to pollution;
- how fast the impacts of over-abstraction and pollution, as well as the impacts of natural attenuation and man-made measures, appear in the aquifer;
- if part of the pollution is caused naturally, due to the chemical composition of the rock/soil minerals found in the aquifers;

The analysis of the reported data under the WFD (see Figure 2.5) leads to the following conclusions:

- *For all types of aquifers, the most common problem is poor chemical status.* Poor chemical status is the prevailing problem for GWBs in the EU 27, as already presented above in section 2.0.
- *A combination of both good quantitative and chemical groundwater status is less common in porous aquifers, compared to other aquifer types*: A wide range of porous aquifers can be found across Europe, including river flood plain deposits (e.g. sands, silts and gravels), glacial drift (e.g. sands and gravels in thick continuous aquifers or isolated eskers), and consolidated sedimentary rocks (e.g. sandstones, conglomerates, siltstones). Unconsolidated sand and gravel porous aquifers are the most vulnerable to pollution and over-abstraction, because they are located closer to the ground surface, they are frequently linked to SWBs (see sections 2.2 and 2.3) and they are typically small with shallow thickness, leading to low storage capacity. Porous sandstones and conglomerates have a large storage capacity and, therefore, tend to respond slowly to over-abstraction and pollution. Once over-exploited or polluted, though, they recover very slowly also (e.g. over time scales of decades / centuries). Porous aquifers are the most common type of GWBs and they are typically exploited in river flood plain areas where water demand is often higher due to multiple water users (e.g. urban centres, agriculture, industries). Therefore, they are more likely to be exposed to significant pressures from human development.
- *Poor quantitative status is more pronounced in porous aquifers of moderate productivity*: Poor quantitative status occurs more frequently in porous aquifers of moderate productivity (e.g. sandstones), because they are exposed to significant pressures from human development as most porous aquifers (see first point), but their recovery rate is also slower compared to porous aquifers of high productivity.
- *Fissured aquifers of high productivity, including karstic aquifers, are more likely to have both poor quantitative and chemical status*: Fissured aquifers of high productivity (e.g. limestone, chalk and other carbonate rocks having dual porosity or karsts) are vulnerable to pollution, because they allow rapid flow-paths through their mass, which spread the pollutants rapidly. Although rapid fissure transport allows groundwater levels to recover quickly (e.g. over the time scale of weeks / months), the existing matrix of pore spaces can trap particles of pollutants through diffusion, and they can be released slowly over a longer period of time (e.g. over the time scale of decades). When the aquifer is also over-exploited, because the long-term abstraction rate exceeds the recharge rate, then the aquifer is likely be in both poor quantitative and chemical status.
- *Fractured aquifers of moderate and high productivity and insignificant aquifers are less vulnerable to pollution*: Crystalline basement rocks, volcanic rocks, schists and shales have limited matrix porosity. Thus, they have very low storage capacity of pore water and insignificant flow-paths through their mass, compared to fissured rocks with dual porosity or karsts. In this case, they form low-yield aquifers. Their storage capacity and productivity

increases, though, where the degree of their fracturing is higher. However, unlike fissured aquifers with dual porosity and karsts, increased productivity of fractured aquifers facilitates rapid flushing out of pollutants. Therefore, they are also less vulnerable to pollution. Furthermore, clays, marls and mudstones form low permeability layers or aquitards, which retard water flow. Localised bands of coarser sediments such as sandstone or gravel lenses within such layers can form small pockets of groundwater. Although these are unsuitable for large scale abstraction, they can provide small potable sources for isolated dwellings. In general, they are also less vulnerable to pollution from the surface. However, retarded water flow conditions can significantly slow down their recovery from over-exploitation or pollution, where such incidents occur.

Figure 2.5 Groundwater status by type of hydrogeological conditions in the EU 27 in the 2nd RBMPs (in % of total GWB area by category of geological formation and productivity).



Note: The reported total GWB area per category of hydrogeological conditions is given in brackets (in km^2)
Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020)

In the 2nd RBMPs, 56% of the reported GWB area under the WFD was reported as highly or moderately productive porous aquifers, covering an area of 2.3 million km^2. Highly or moderately productive fissured aquifers, including karstic formations, represented 27% of the GWB area, covering over 1.1 million km^2. Highly or moderately productive fractured aquifers accounted for 8% of the GWB area, covering around 0.3 km^2. The remaining 10% (or 0.4 km^2) was reported as insignificant local and limited aquifers (EEA, 2020).

Table 2.1 provides an overview of the geological, hydrological and chemical characteristics of different types of rocks/soils, categorised into the above types of geological formation/productivity followed in the WFD reporting.

Table 2.1 Geological, hydrological and chemical characteristics of different types of rocks/soils.

Type of rock/soil (lithology)	Type of geological formation/productivity (WFD)	Likely recovery rate after over-abstraction	Likely recovery rate after pollution	Potential pollution due to natural background conditions
Chalk	Fissured aquifers including karst - highly or moderately productive	Slow (matrix) – Very Fast (karst)	Slow (matrix) – Very Fast (karst)	Typically low levels, but deeper chalk groundwater may have naturally high anions (e.g. fluoride)
Evaporites	Fissured aquifers including karst - highly or moderately productive	Slow (matrix) – Fast (karst)	Fast and slow	High concentrations of naturally present evaporite salts (gypsum etc.)
Limestone	Fissured aquifers including karst - highly or moderately productive OR Fractured aquifers - moderately or highly productive	Slow (matrix) – Very Fast (karst)	Slow (matrix) – Very Fast (karst)	Mineralisation could lead to metals at elevated natural background concentrations
Crystalline Basement	Fractured aquifers - moderately or highly productive	Fast	Fast	Mineralisation could lead to metals, anions and radionuclides at elevated natural background concentrations
Shales and Schists	Fractured aquifers - moderately or highly productive	Fast	Fast	Mineralisation could lead to metals, anions and radionuclides at elevated natural background concentrations
Volcanic Rocks	Fractured aquifers - moderately or highly productive	Fast	Fast	Mineralisation could lead to metals, anions and radionuclides at elevated natural background concentrations
Sandstones (sedimentary rocks)	Porous aquifers - highly or moderately productive	Slow	Moderate to slow	Potential for poor natural quality due to sulphide oxidation
Unconsolidated Sands and Gravels	Porous aquifers - highly or moderately productive	Slow	Fast to Moderate	Potential for poor natural quality due to sulphide oxidation
Clays, marls and mudstones	Insignificant aquifers - unproductive	Very slow	Very slow	Potential for poor natural quality due to long residence time of water in matrix

Source: Author's compilation based on BRIDGE project outcomes (BRGM, 2006)

Box 2.5 Understanding the lag time in the response of an aquifer to over-abstraction, pollution or recovery.

As groundwater flows through an aquifer, its velocity is controlled -*inter alia*- by the rate at which it is recharged and the size of the connected pores and voids in the relevant soil/rock formation. For instance, high recharge rates and bigger pores or voids (e.g. in porous, fissured-karstic and fractured aquifers of high productivity) may result in faster flow of groundwater through the aquifer mass, faster increase of groundwater tables in unconfined aquifers, shorter time for pollutants to infiltrate and pollute groundwater, shorter time for existing concentrations of pollutants to rise, but also shorter residence time and quick flush-out of pollutants from the aquifer (with the exception of fissured aquifers whose dual matrix porosity may trap pollutants and retard their flush-out).

The opposite applies for lower recharge rates and smaller pores or voids (e.g. in fissured and fractured aquifers with medium-low productivity, and insignificant aquifers in marls and clays). In this case, groundwater flow is slower, groundwater tables of unconfined aquifers respond to recharge with significant lag time, pollutants infiltrate slower and groundwater pollution is retarded, existing concentrations of pollutants rise more gradually, while pollutants have longer residence time in the aquifer and their flush-out is slowed down. However, a long residence time in the aquifer may also lead to significant microbial degradation of pollutants, where the geochemical conditions are suitable (e.g. in confined aquifers, where reduction of nitrate takes place). Furthermore, where groundwater flow is low, this can cause a lag time between the time of reduction of abstractions and the time of recovery of groundwater levels or, similarly, between the time of reduction of pollutant loads and the time of reduction in pollutant concentrations. Thus, the groundwater status could continue to deteriorate temporarily, in the early period after mitigation measures are taken, before status improvement could become observed.

Box 2.6 Understanding natural pollution due to background conditions.

Concentrations of pollutants, such as sulphides, fluorides, gypsum, metals, anions, radionuclides, can be naturally elevated, due to natural interactions between water and rocks/soils. Typically, these can be found in mineralised formations, evaporites, geothermal and connate waters. This can result in groundwater being of naturally poor quality which makes it unsuitable for potable or other human uses without treatment. In some cases, abstraction can lead to elevated metals, for example boreholes drilled into aquifers introduce oxygen which leads to oxidation of iron bearing minerals, and high iron and manganese in abstracted groundwater. This is a natural result of changing the geochemical conditions in the aquifer around the borehole.

GWBs cannot be assessed in poor chemical status under the WFD due to naturally elevated concentrations of naturally occurring pollutants. However, over-abstraction can lead to saline intrusion of connate waters or geothermal waters, leading to deterioration of naturally freshwater aquifers.

3 Key environmental impacts from less than good groundwater status

The main impacts affecting the GWB area in the EU 27 are associated with different types of pollution. In total, such impacts affect 34% of the GWB area: chemical pollution[5] (16%), nutrient pollution[6] (14%), organic pollution[7] (2%), saline intrusion (2%), other types of pollution (0.6%). In addition, other significant impacts include: water imbalances/lowering water tables (6%), impacts on GWAAEs (3%) and impacts on GWDTEs (3%) (EEA, 2020).

The above percentages do not add up to 100%, because multiple environmental impacts can affect the same area. Situations of two, three or more impacts are quite common. Furthermore, impacts related to groundwater quantity/hydrology and groundwater quality/pollution frequently coincide,

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[5] "*chemical pollution*": metals, hydrocarbons, biocides, pharmaceuticals, etc.

[6] "*nutrient pollution*": nitrogen, phosphorous

[7] "*organic pollution*": organic matter

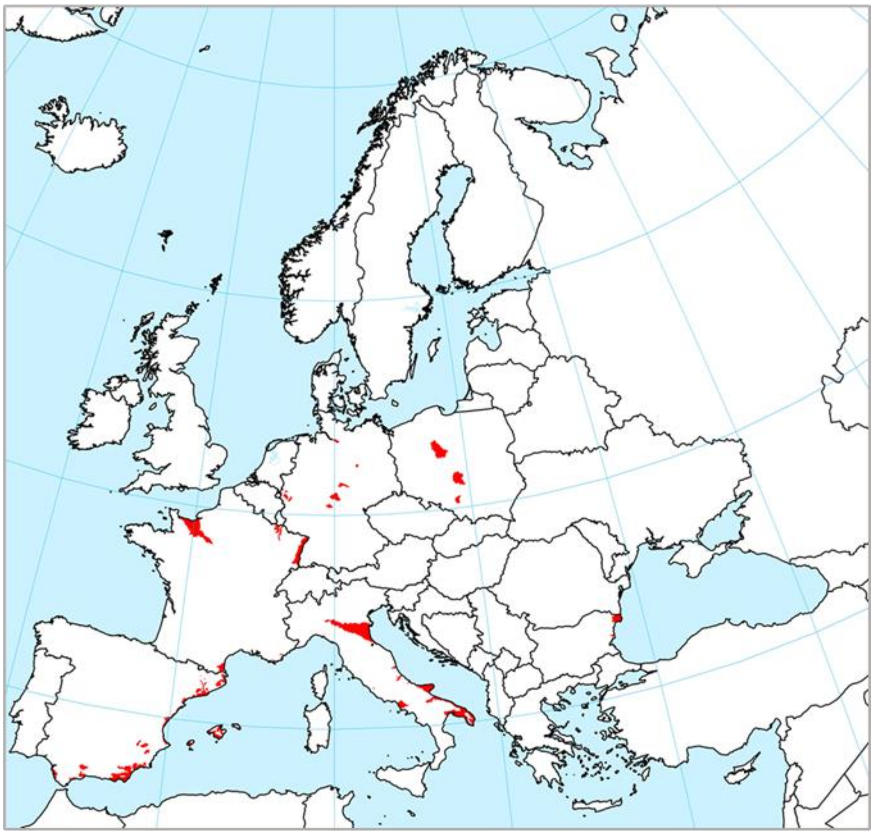
highlighting the interdependencies that exist and the complex reality that water managers have to tackle in practice.

The analysis of the reported data under WFD RBMPs shows that the GWBs having only poor quantitative status are more frequently associated with the following impacts: water imbalances/lowering water tables; impacts on GWDTEs; impacts on GWAAEs; saline intrusion. Moreover, those GWBs having only poor chemical status are most frequently associated with the following impacts: chemical pollution; nutrient pollution; organic pollution; impacts on GWAAEs; impacts on GWDTEs (EEA, 2020). Finally, those GWBs in both poor quantitative and chemical status are associated with combined impacts found in the above cases. For instance, it is estimated that 47% of the GWB area in poor quantitative and chemical status is affected by chemical pollution and water imbalances/lowering water tables, while 26% is affected by chemical pollution, nutrient pollution, saline intrusion and water imbalances/lowering water tables.

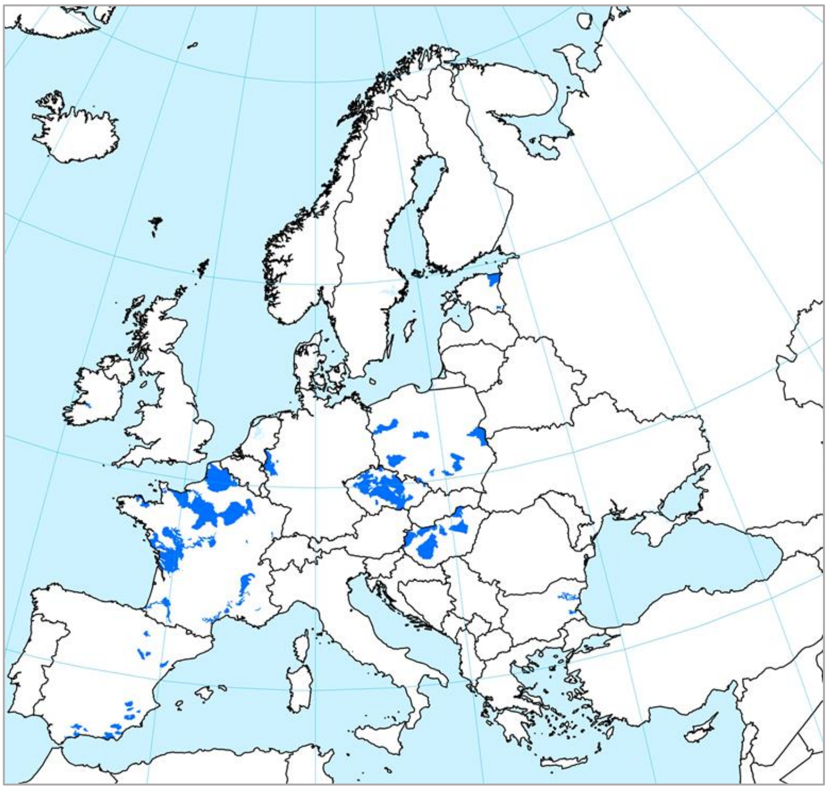
Map 3.1 illustrates a selection of three types of impacts (i.e. saline intrusion, impacts on GWAAEs and impacts on GWDTEs), and their reported distribution across the EU 27, taking into account only those GWBs on poor quantitative or chemical status or both.

Map 3.1 EU 27 GWBs in poor quantitative or chemical status affected by a) saline or other intrusion, b) impacts on GWAAES and c) impacts on GWDTEs in the 2nd RBMPs.

(a) saline or other intrusion



(b) impacts on GWAAEs



(c) impacts on GWDTEs

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

Box 3.1 EU 27 GWB areas with specific impacts in the 2nd RBMPs

Saline or other intrusion

The majority of the reported saline intrusions occur in coastal areas around the Mediterranean, the Black Sea and the Atlantic. However, many cases are also found in inland areas of the EU 27. Salinisation can be a result of direct influx of seawater into coastal aquifers or indirect influx through transitional water bodies, such as deltas. For instance, this occur along the Spanish coast, the Baleares, the Pô and the Seine delta, and the Italian Adriatic coast. However, saline intrusion may also be linked with the upwelling of deeper salt waters, such as deeper layers of brines from "ancient seas" or dissolved evaporitic formations in sedimentary basins. This is visible in the case of the Alsace valley between France and Germany, along the Rhine. In addition, saline intrusion can be caused by over-abstraction through mobilisation of highly mineralised connate water, which is trapped in the rock matrix during its formation. Moreover, increased salinity over inland areas can be a result of point source pollution due to mining activities (e.g. salt or potassium mines). Such examples can be found in salt mine areas of Poland.

Impacts on GWAAEs

Large areas with impacts on GWAAEs, due to reduced flow of groundwater or influx of polluted groundwater, are reported in Czechia, Estonia, France, Germany, Hungary, Poland and Spain.

Impacts on GWDTEs

Due to reduced flow of groundwater or influx of polluted groundwater, impacts on GWDTEs are commonly reported in France, Germany, Hungary, Italy, Poland and Spain. One such example is the Marais Poitevin wetland, which is situated along the Atlantic coast of France. It is the largest wetland in the country and is protected under the Birds and Habitats Directives (BD and HD).

4 Key drivers and pressures causing less than good groundwater status

Agriculture is the most significant driver causing less than good groundwater status in the EU 27, according to the 2nd RBMPs. The GWB areas, which are significantly affected by pressures related to agriculture, are reported to be the most widespread across the EU 27. In terms of GWB area affected, other significant drivers are public water supply and urban development, industry and mining.

Furthermore, less than good groundwater status is more frequently a result of pressures related to water quality (e.g. diffuse source pollution from agriculture and unconnected dwellings, point source pollution from abandoned industrial and contaminated sites, waste water discharges, industrial discharges, etc). Water quantity pressures (e.g. abstraction by agriculture, public water supply or industry) are relatively less widespread. Caution is needed because the intensity of water quantity pressures can be equally critical for the failure of good groundwater status, and, where they co-exist with water quality pressures, they may exacerbate them (see section 1.1). In general, many GWBs are in less than good status due to combinations of multiple pressures.

Overall, the most common types of aquifers affected by different pressures are the porous aquifers and the fissured (including karstic) aquifers. Porous and fissured (including karstic) aquifers take up nearly 83% of the total GWB area in the EU 27, which is reported under the WFD. Therefore, they are also the most common types of aquifers, for which management objectives have been set by EU Member States. As explained in Annex 1, the delineation of the WFD GWBs reflects a combination of criteria, such as hydrogeology, geochemistry, significance for water supply, exposure and vulnerability to over-exploitation and pollution, dependence of ecosystems upon them, administrational and management needs, etc. Therefore, the above types of aquifers are generally more exposed to major pressures from socio-economic development (e.g. agriculture, public water supply), as well as more vulnerable to such pressures, due to their size, thickness and composition, and mechanisms for groundwater flow and pollutant transport. Fractured and insignificant aquifers are less common in the EU 27, taking up nearly 18% of the total GWB area. Such aquifers are less impacted by major pressures, such as agricultural pollution and abstraction or public water supply and, normally, they are less susceptible to pollution; fractured aquifers because of quick flush-out of pollutants and insignificant aquifers because of slow flow conditions and retardation of pollutants.

For further details on management challenges for different aquifer types, see section 2.3.

The sections below provide a brief overview of the main combinations of drivers and pressures causing less than good groundwater status in the EU 27, presenting with maps the spatial extent of such GWBs having either poor quantitative or chemical status.

For further analysis of sectorial pressures, see sub-study 3 of this series of studies (Rouillard et al., 2021).

Pressures by Agricultural production

Over the past 70 years, the European agricultural sector has increased its production of food, feed and textiles to meet the rising demands of the population and markets in Europe and worldwide. EU is a global leader of agri-food exports, which reached 138 billion € in 2018 (DG AGRI, 2019). However, the demand for agricultural products is associated with significant pressures on groundwater.

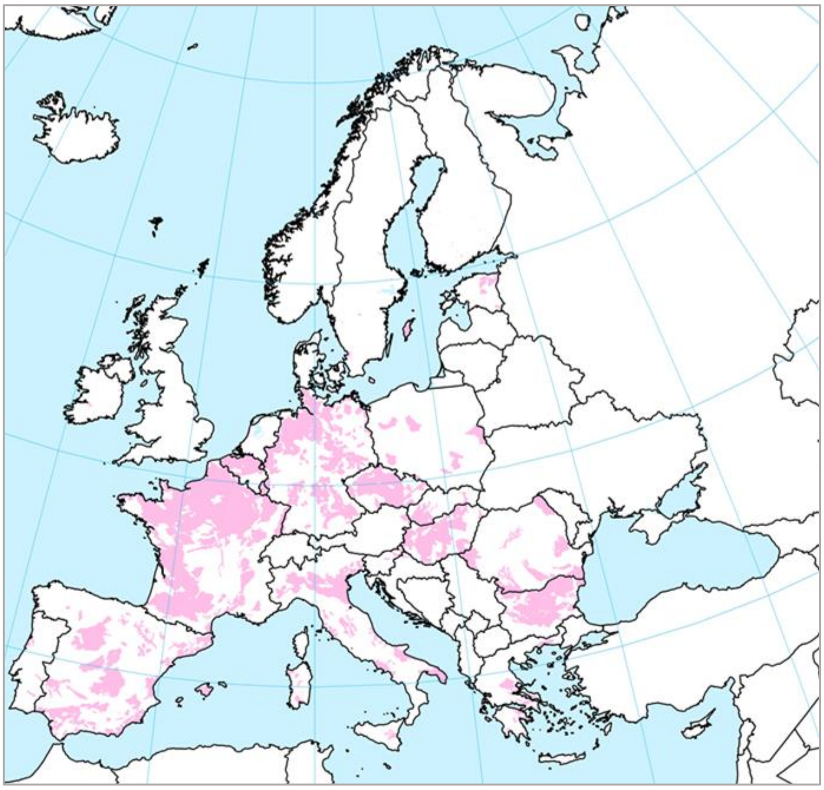
Diffuse source pollution from fertilisers, pesticides, and other chemicals used in agricultural production is the most common pressure causing less than good groundwater status in the EU 27 for all types of aquifers. It causes less than good groundwater status in 20% of the total GWB area, including 21% of the area with fissured and karstic aquifers, 20% of the area with porous aquifers, and around 13% of the area with fractured and insignificant aquifers (EEA, 2020).

In addition, water abstraction for irrigation and other agricultural activities causes less than good groundwater status in almost 7% of the total GWB area, including 9% of the area with porous aquifers area, 7% of the area with fissured and karstic aquifers, and lower shares for the areas with other aquifer types (EEA, 2020).

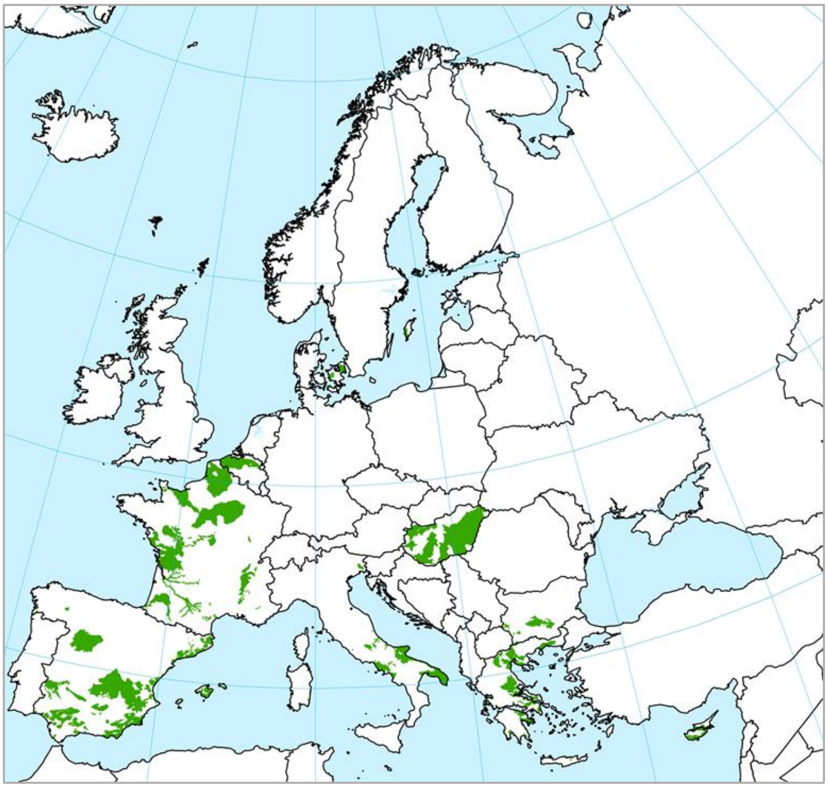
Map 4.1 illustrates the GWB area in the EU 27 affected significantly by the above pressures related to the agricultural sector, considering only those GWBs in poor quantitative or chemical status.

Map 4.1 EU 27 GWBs in poor quantitative or chemical status affected significantly by agricultural pressures in the 2nd RBMPs.

(a) diffuse source pollution from agriculture



(b) water abstraction for agriculture



Note: Map illustrations include EU 27 GWB areas in poor quantitative or chemical status in the 2nd RBMPs, affected significantly by the following agricultural pressures: a) diffuse source pollution from agriculture and b) water abstraction for agriculture

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

Box 4.1 EU 27 GWB areas in poor quantitative or chemical status in the 2nd RBMPs, affected significantly by specific pressures related to agriculture.

Diffuse source pollution from agricultural sources is a widespread pressure for GWBs in EU 27, leading to poor chemical status. The exception to this is Denmark, Ireland and the Netherlands, which report no GWBs affected by this pressure, although they also report intensive livestock or crop farming over their territory.

Furthermore, significant pressure from agricultural abstraction is reported in the Flanders region of Belgium, Cyprus, in France (e.g. northern and western parts and Rhone valley), northern and eastern Greece, Hungary, southern Italy, and across eastern, southern and central parts of Spain (e.g. La Mancha aquifers).

The combination of significant pressures from both agricultural water abstraction and diffuse source pollution leads to GWBs in both poor quantitative and chemical groundwater status in the Flanders region of Belgium, southern Bulgaria, France, central Greece, Hungary, southern Italy, Malta and many areas across Spain.

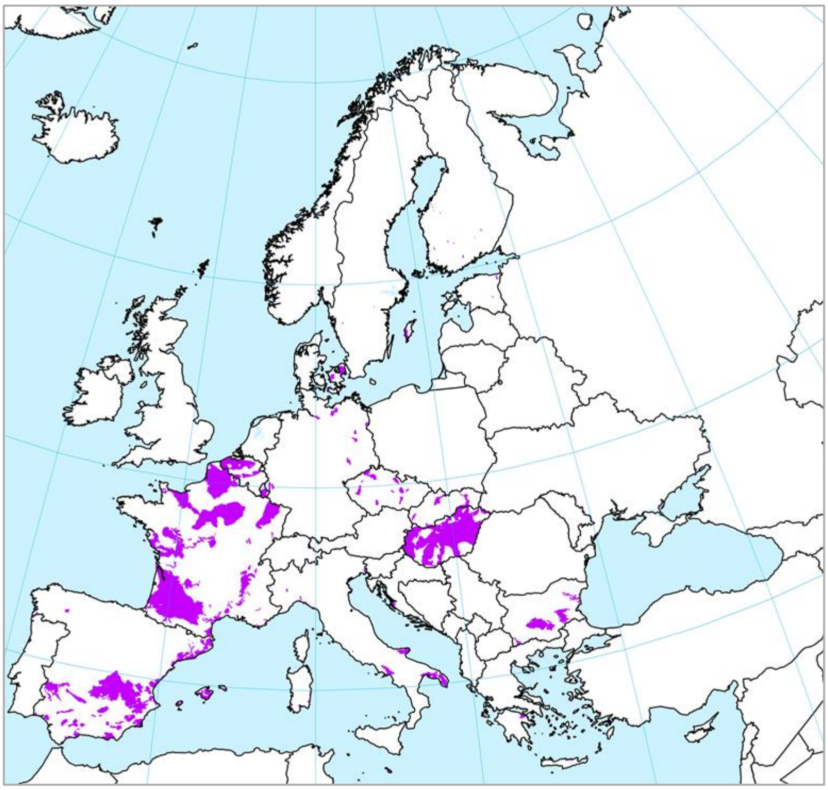
Pressures by Public water supply

The supply of high quality and sufficient water to the public is essential for domestic uses, such as drinking, food preparation, washing, cleaning and hygiene. The supply of water to the public for use in households, as well as in commercial and touristic areas, usually takes the form of tapped water produced by water utilities. Connection of the public to centralised water supply systems exceeds 80% in all EU 27 Member States, except for Romania (Eurostat, 2021). The supply of water to the public for tourism and recreation activities can be quite diverse, comprising of water used in hotels and other accommodation facilities, restaurants, bars, cafes, swimming pools, saunas, and spas, as well as water used for the irrigation of green spaces. There are also cases, where centralised water supply systems cover a part of the needs of the industry and agriculture.

Water abstraction for public water supply is one of the most significant pressures for GWBs in the EU 27, since it causes less than good groundwater status in approximately 7% of the total GWB area . In terms of aquifer types, water abstraction for public water supply affects 10% of the area with porous aquifers and 8% of the area with fissured and karstic aquifers (EEA, 2020).

Map 4.2 illustrates the GWB area in EU 27 affected significantly by water abstraction for public water supply, considering only those GWBs in poor quantitative or chemical status.

Map 4.2 EU 27 GWBs in poor quantitative or chemical status affected significantly by water abstraction for public water supply in the 2nd RBMPs.



Note: Map illustration includes EU 27 GWB areas in poor quantitative or chemical status in the 2nd RBMPs, affected significantly by the following pressure related to urban development: a) public water supply
Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020)

Box 4.2 EU 27 GWB areas in poor quantitative or chemical status in the 2nd RBMPs, affected significantly by water abstraction for public water supply.

Abstraction for public water supply is reported as a significant pressure in many areas of Europe. However, it affects proportionately larger areas in Hungary (78%), Luxembourg (33%), Spain (28%), Malta (27%), France (15%), and Belgium (14%). In other countries, such as Bulgaria, Croatia, Czechia, Denmark, Estonia, Germany, Greece, Italy and Slovakia, this pressure is more localised.

Pressures by Urban development

Pressures related to urban development include discharges from scattered dwellings non-connected to the sewerage network, urban waste water discharges, urban run-off, storm water overflows, and waste disposal sites.

Diffuse source pollution from scattered dwellings non-connected to sewerage networks and point source pollution from urban waste water cause less than good groundwater status in 5% and 2.5% of the total GWB area in the EU 27, respectively. Furthermore, diffuse source pollution from urban runoff and point source pollution from storm water overflows also affect 1.6% and 0.6% of the total GWB area (EEA, 2020). The implementation of, primarily, the Urban Waste Water Treatment Directive (UWWTD) and, supplementarily, the WFD has resulted in great improvements in the collection and treatment of urban waste water in Europe. However, not all aspects of waste water pollution are covered directly by the UWWTD (e.g. discharges from small agglomerations or scattered dwellings with loads below 2000 p.e.). In addition, some of the above aspects have not been addressed adequately yet, as they have come to the spotlight in more recent years (e.g. storm water overflows and urban runoff) (EC, 2019b).

Moreover, waste disposal sites are reported to cause less than good status in 2.4% of the total GWB area (EEA, 2020). Historically uncontrolled disposal in landfills or relevant landfill accidents, as well as cases of disposal in abandoned mining and quarrying sites, can lead to legacy groundwater pollution in current days.

Atmospheric deposition of nitrogen oxides, sulphur and heavy metals from combustion (e.g. car engines, thermal power plants) is not identified as a significant pressure for GWBs in the EU 27, as it affects only 0.6% of the total GWB area (EEA, 2020). However, it is considered a considerable problem for SWBs (e.g. where elevated metals impact ecosystems).

Regarding the types of aquifers which are most commonly affected by urban development pressures, no particular patterns can be observed. For example, discharges from scattered dwellings non-connected to sewerage networks affect more frequently porous and fractured aquifers (6.5% and 5.6% of their area, respectively). Urban waste water discharges affect mostly fractured aquifers (4% of their total area). Urban runoff and storm water overflows affect mostly porous aquifers (2.4% and 0.8% of their total area, respectively). In addition, waste disposal sites affect mostly fissured (including karstic) and porous aquifers (around 2.5% of their total area). Notably, atmospheric deposition affects insignificant aquifers more than any other aquifer type (4.9% of their total area) (EEA, 2020).

Pressures by Industrial development

Industry is associated with a variety of pressures asserted on GWBs, including both water quantity pressures (e.g. industrial water abstraction) and water quality pressures (e.g. point source pollution from industrial plants, and point or diffuse source pollution from abandoned industrial or contaminated sites).

Point source and diffuse source pollution from abandoned industrial or contaminated sites cause less than good groundwater status in 4.3% and 0.6% of the total GWB area in the EU 27, respectively. Furthermore, 3.8% of the total GWB area is affected significantly by point source pollution from plants regulated under the Industrial Emissions Directive (IED). Non-regulated industrial plants cause less than good status in 1.2% of the total GWB area (EEA, 2020). It should be noted that past industrial activity, as well as the historic use of chemicals which are now banned, can be a significant source of legacy pollution in many parts of Europe nowadays. Uncontrolled backfilling in contaminated industrial sites - a practice that was common in the past- is also a major source of groundwater and soil pollution (Boudjana et al., 2019). As a result, water authorities are required to deal with a driver which is no longer present, but whose impacts on the environment are still observed (Buchanan et al., 2019).

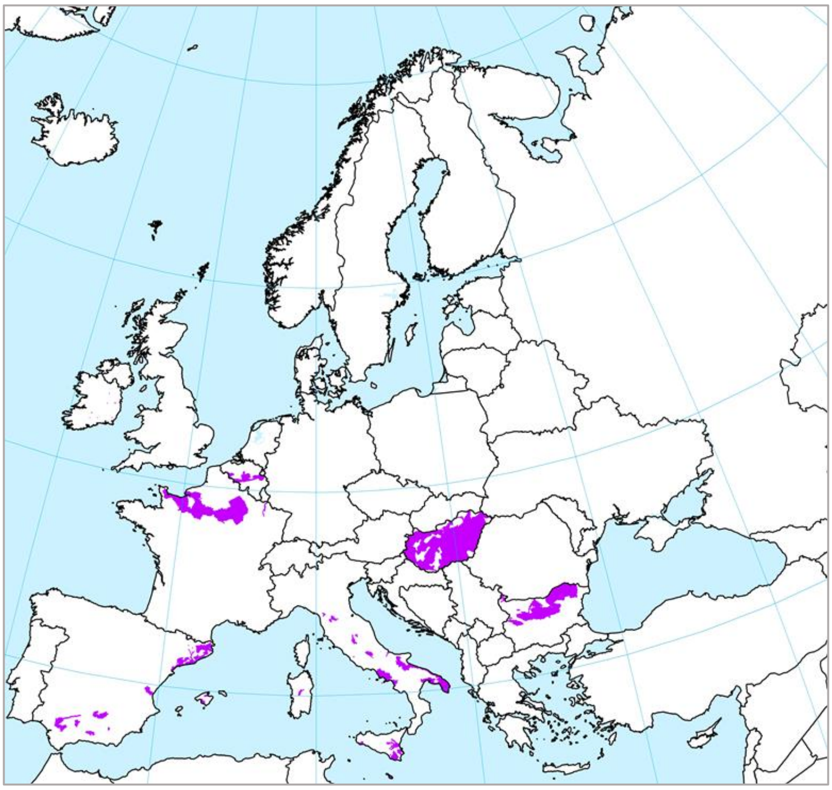
In addition, water abstraction for industrial purposes causes less than good groundwater status in 4.1% of the total GWB area (EEA, 2020). Over-abstraction is generally associated with local imbalances and other physical impacts.

In terms of aquifer types affected by industrial pressures, there are no particular patterns. For instance, all types of aquifers are affected to a similar proportion by point source pollution from abandoned industrial or contaminated sites. Furthermore, fractured aquifers, porous aquifers and fissured and karstic aquifers, are all similarly affected by point source pollution from plants regulated under the IED, and industrial water abstraction.

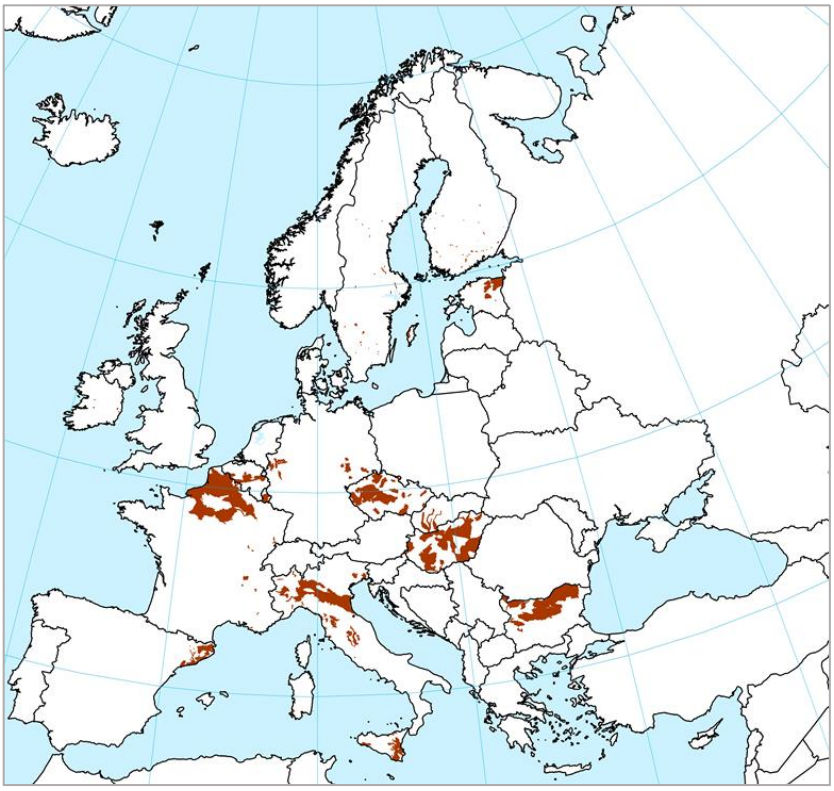
Map 4.3 illustrates the GWB area in the EU 27 affected significantly by selected pressures related to the industrial sector, considering only those GWBs in poor quantitative or chemical status.

Map 4.3 EU 27 GWBs in poor quantitative or chemical status affected significantly by industrial pressures in the 2nd RBMPs.

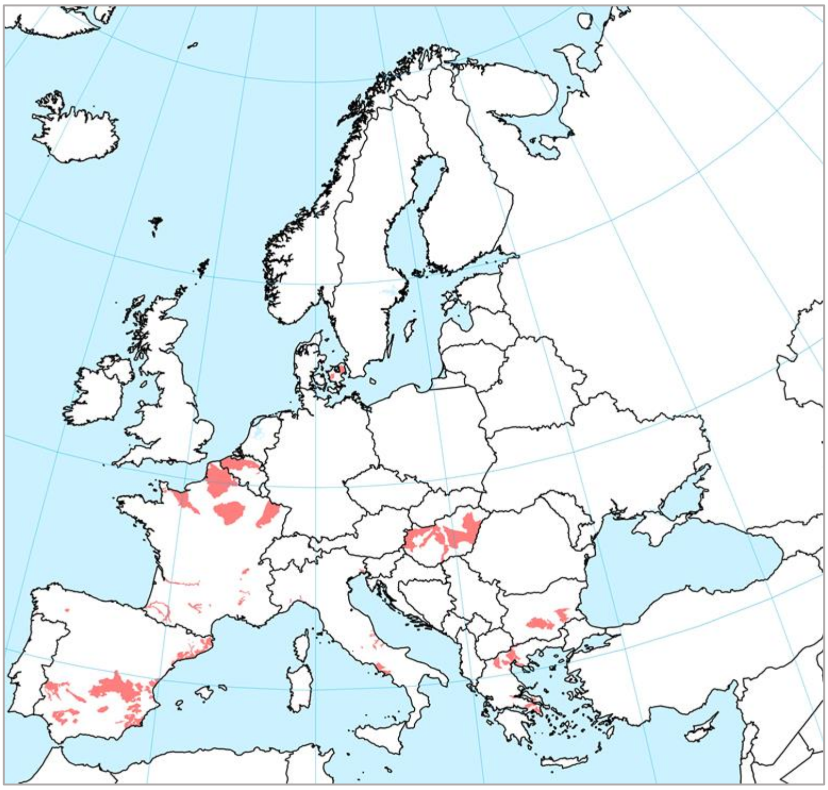
(a) point source pollution from IED plants



(b) point source pollution from abandoned industrial or contaminated sites



(c) water abstraction for industry



Note: Map illustrations include EU 27 GWB areas in poor quantitative or chemical status in the 2nd RBMPs, affected significantly by the following industrial pressures: a) point source pollution from IED plants, b) point source pollution from abandoned industrial or contaminated sites and c) water abstraction for industry
Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020)

Box 4.3 EU 27 GWB areas in poor quantitative or chemical status in the 2nd RBMPs, affected significantly by specific pressures related to industry.

The GWB areas in poor quantitative or chemical status, affected significantly by industrial pressures, are less common than those affected by agriculture or public water supply. Areas with significant industrial pressures are mainly found in specific EU Member States, including Belgium, Bulgaria, Czechia, northern Estonia, northern France, northern Germany, Hungary, many parts of Italy, and southern Spain.

Proportionately, the most common problems with industrial pressures are found in Hungary, where significant parts of the country have poor quantitative or chemical status and they are affected by overlaps between point source pollution from IED plants, point source pollution from abandoned industrial or contaminated sites, and industrial water abstraction. Other areas with similar problems are found in northern France and coastal areas of Catalonia in Spain.

Pressures by Mining activities

The operations of most modern mines are now strongly regulated, both during and after completion of the mining activities. However, until the second half of the 20th century, most mines would be abandoned without appropriate reclamation. Thus, reported pressures from mining sites may originate from either current activities or past activities, still impacting groundwaters. However, intervention at abandoned mines is more difficult to due to lack of liability.

According to the 2nd RBMPs, the pressures from mining activities are less widespread at the level of the EU 27. Notably, they can be more important for specific EU Member States and regions. Almost 3% of the total GWB area is in less good status and affected by diffuse source pollution from mining, 1.5% by point source pollution from mine waters, and another 1.3% by alteration of water levels/volumes, which is usually related to drainage of mining sites (EEA, 2020). Mining activities commonly affect all types of aquifers, with the exception of insignificant aquifers.

Map 4.4 illustrates the GWB area in the EU 27 affected significantly by selected pressures related to mining activities, considering only those GWBs in poor quantitative or chemical status.

Map 4.4 EU 27 GWBs in poor quantitative or chemical status affected significantly by mining pressures in the 2nd RBMPs.

(a) diffuse source pollution from mining

(b) water level /volume alteration from mining

Note: Map illustrations include EU 27 GWB areas in poor quantitative or chemical status in the 2nd RBMPs, affected significantly by the following mining pressures: a) diffuse source pollution from mining and b) water level /volume alteration from mining or other activities
Source: Author's compilation based on data from WISE Water Framework Directive Database – 2nd RBMPs (EEA, 2020)

Box 4.4 EU 27 GWB areas in poor quantitative or chemical status in the 2nd RBMPs, affected significantly by specific pressures related to mining.

GWBs in poor quantitative or chemical status, affected significantly by diffuse pollution from mining, are mainly reported over large parts of Bulgaria. Other areas, which are more localised, are found in northern Estonia, northern Germany, western Macedonia in Greece, western Hungary, central and southern Poland, western Slovakia and parts of Catalonia and Andalusia (e.g. Rio Tinto) in Spain.

Furthermore, GWBs in poor quantitative or chemical status, affected significantly by water level /volume alteration, which is usually linked with mining, are found in northern France and northern Germany, central Greece, eastern Hungary, central and southern Poland, and Catalonia in Spain.

The main overlaps between GWBs areas in poor quantitative or chemical status, affected by significantly by pressures related to mining, can be found in northern Germany (e.g. areas with strip mining of lignite), central and southern Poland, and Catalonia in Spain.

Pressures by Climate change

Climate change is a major over-arching driver, which is already putting direct and indirect pressures on GWBs. Some key points regarding its impact on groundwater quantity and quality and their interdependence are presented below (see further sub-study 3, Rouillard et al., 2021):

In southern Europe, as well as in parts of western, central and eastern Europe annual and summer precipitation have decreased, temperature and evapotranspiration have increased, and droughts have become more frequent and intense. Climate change is expected to aggravate these trends, especially if global temperature rises up to 3°C above the pre-industrial levels. As a follow-up, soil moisture and groundwater recharge show decreasing trends roughly over the same areas. Groundwater depletion may already be observed in various aquifers across Europe, especially in the Mediterranean and the Black Sea. Climate change contributes partly to the depletion, but it is over-abstraction that has the leading role in this development (although, in turn, can be affected by climate indirectly). In any case, reduced groundwater recharge and increased water abstraction, whether more climate-driven (e.g. increased irrigation needs due to higher evapotranspiration) or more human-induced (e.g. population increases and land use change) are expected to increase the stress on aquifers in the above areas (EEA, 2021 – forthcoming; Bisselink et al., 2020; Gelati et al., 2020; Taylor et al., 2013).

Climate change may also affect groundwater quality, through the interdependencies between pollution and over-abstraction. For example, concentrations of nutrients and chemicals may increase in groundwater, because of lower dilution capacity of pollutants in depleted aquifers. Lower groundwater levels may also lead to extreme low flows in surface waters, where pollutant concentrations (e.g. from waste water effluents) may also increase due to lower dilution in the available surface water. Furthermore, if groundwater table decreases significantly, leaving the associated SWB perched, then the SWB will start recharging the GWB. Polluted SWBs may also cause pollution to linked GWBs (Cantor et al., 2018). In water-stressed areas, groundwater pollution may also occur after over-abstraction (e.g. for drinking or agricultural purposes). Over-abstraction can lead to the ingress and mixture of impaired waters with clean groundwaters. As climate change is expected to cause the rise of the average sea level and increase storm surges, coastal areas across the EU 27 may be further impacted by sea water intrusion. Coastal aquifers, which are already over-exploited, may be particularly in danger (Clifton, 2010).

In northern and north-eastern Europe, GWBs are not expected to face additional water stress compared to nowadays. In these areas, groundwater recharge is projected to increase in the future, as a result of increased precipitation, and less frequent and intense droughts. (EEA, 2021 – forthcoming; Bisselink et al., 2020). However, increased precipitation and recharge may cause more frequent inundation due to rising groundwater tables. In urban areas, the rise of the groundwater tables can damage building basements and public infrastructures, such as sewer pipes. It may also increase the loading to waste water treatment works through infiltration of groundwater into the sewerage network.

Furthermore, in the colder climates of northern Europe, warmer winters may also lead to retreat of the permafrost and earlier start of snow melting. This might shift groundwater recharge with melted snow from spring currently, closer to winter in the future. Increased recharge in winter may also increase the seasonal groundwater levels and favour the leaching of pollutants to the groundwater, because the unsaturated zone will become more shallow (Ortmeyer et al., 2021). Furthermore, reduced spring recharge, combined with more frequent droughts during summer months, may increase water deficits in summer and autumn (Clifton, 2010; Klöve et al., 2014). For shallow aquifers linked with surface water bodies, lower groundwater levels will intensify the low flows in summer and autumn, thus impacting GWAAEs and GWDTEs during these periods.

Combinations of drivers and pressures

It should be highlighted that, in many cases, combinations of different drivers and pressures affect the same GWB areas, causing multi-stress conditions. Therefore, less than good groundwater status is not a result of a single pressure. Pressures affecting water quantity and pressures affecting water quality can act together and stress the GWB simultaneously. Such combinations of pressures can result in failures of GWBs to achieve overall good status, although individual pressures may not violate stipulated thresholds. This happens because of the cumulative effect from combinations of pressures. Moreover, different types of pollutants, when diluted and mixed together, may create chemical mixtures (“cocktails”). These may be hazardous for human health, ecosystems in associated surface waters and dependent terrestrial ecosystems, where polluted groundwaters reach the surface through existing hydraulic connections or abstractions.

Box 4.5 Hungarian GWBs in both poor quantitative and chemical status due to multiple pressures

The main exploitable aquifers for public water supply and agriculture in Hungary are porous aquifers with coarse sandy and gravel layers at shallow depths and sandstone layers deeper than those. Such porous aquifers take up around 80% of the total GWB area. Karstic aquifers represent 11% of the total GWB area, and they are mainly found on hilly areas. The remaining 9% of the GWB area is mountainous rocky formations and other local and limited GWBs. Parts of the hilly areas have non-karstic rocks (e.g. crystalline, volcanic or sedimentary formations of lower yield). There are nearly 1,400 thermal springs in Hungary, supporting the spa industry, which is an important branch of the national tourism sector.

According to the 2nd RBMPs, 11 GWBs (covering 7% of the total GWB area) are in poor quantitative and chemical status in Hungary. They are all porous, sedimentary aquifers. They are situated, for instance, around Lake Balaton and the Duna Tisza region. They are affected by multiple co-existing pressures, including diffuse source pollution from agriculture and discharges from non-connected sewerage network (both affect 100% of the GWB area in less than good status), point source pollution from IED regulated plants (96%), agricultural abstraction (75%), point source pollution from abandoned industrial or contaminated sites (70%), abstraction by public water supply (68%), and diffuse source pollution from mining (43%).

Sources: ICPDR (2021); EEA (2020); MfE&W (2006); Deseo and Deak (1997)

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ANNEX 1 – DEFINITION OF GROUNDWATER BODIES AND THEIR STATUS IN THE WATER FRAMEWORK DIRECTIVE (WFD)

The WFD defines a "**groundwater body**" (GWB) as a "coherent sub-unit in the river basin (district) to which the environmental objectives of the WFD must apply" (EU, 2000).

Therefore, a GWB is a groundwater management unit identifying a body of groundwater which should be managed to ensure that the WFD objectives of good quantitative and chemical status are met and to mitigate the potential risks of not achieving these (CIS, 2003; 2004).

Common criteria which were used by EU Member States to define the GWBs included:
- Aquifer Yield (i.e. how much groundwater can be stored and extracted from the aquifer);
- Transport mechanisms (i.e. velocity of groundwater and, therefore, of groundwater pollutants moving through the aquifer);
- Water abstraction from the aquifer for various uses;
- Any support to surface ecosystems by flow from the GWB.

As some aquifers are at the lower limit of water productivity or they do not support ecosystems or they are not currently used for abstraction (note: although potential future use of groundwater must be protected), this volume of groundwater is not assigned to GWBs reported under the WFD.

Furthermore, extensive aquifers were subdivided into manageable GWBs based on: aquifer boundaries, groundwater divides, geochemical boundaries[1], local authority / national boundaries, rivers and confined / unconfined areas. The national groundwater management realities at the time of relevant WFD implementation also influenced the delineation process. Subsequent GWB characterisation identified the risk of failing to meet WFD objectives based on: pressures, groundwater vulnerability, and interaction with associated surface waters and terrestrial ecosystems.

The definition of "**good chemical status**" and "**good quantitative status**" of groundwater bodies, according to the WFD, is provided below:

"Good chemical status" of a groundwater body is achieved if the concentrations of pollutants and changes of conductivity in the groundwater due to 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 to the groundwater body. Naturally elevated concentrations of substances do not impact good chemical status, as they are expected to be accounted for in the 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

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[1] Including saline and freshwater boundaries, the presence of organic matter (e.g. coal / oil formations), thermal gradients, microbial population of the aquifer (potentially leading to biological and geochemical degradation of pollutants), as well as confinement (confined aquifers have lower levels of dissolved oxygen – "redox potential").

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, 2003, Guidance N°2 - Identification of water bodies, Common Implementation Strategy for the Water Framework Directive (2000/60/EC) (https://circabc.europa.eu/sd/a/655e3e31-3b5d-4053-be19-15bd22b15ba9/Guidance%20No%202%20-%20Identification%20of%20water%20bodies.pdf) accessed 13 January 2020.

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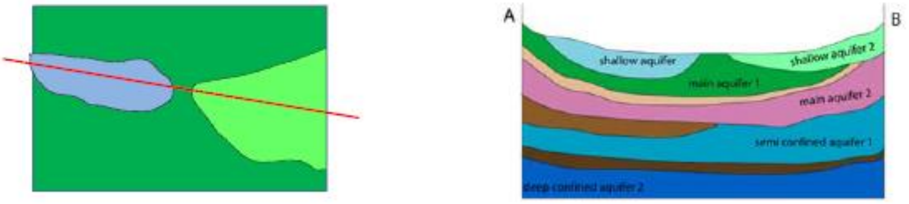
ANNEX 2 – EXAMPLE DELINEATION OF GROUNDWATER BODIES

The WFD Reporting Guidance 2016 (EC, 2016) includes - among others - the following two examples on groundwater delineation:

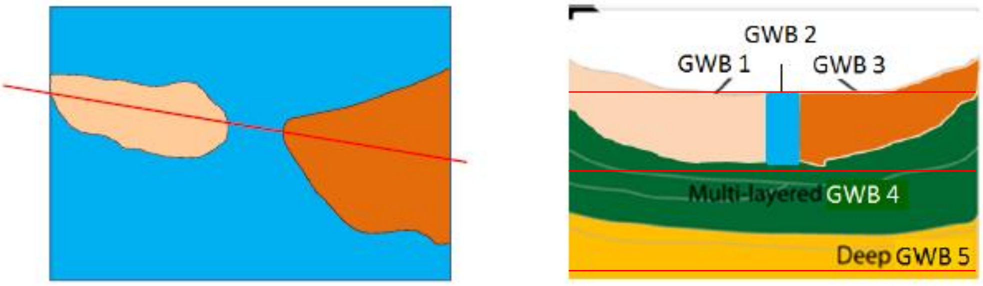
- Example 1: GWBs made up of multiple aquifer segments assigned to single horizons
- Example 2: GWBs made up of multiple aquifers assigned to single or multiple horizons

<u>Example 1</u>

Hydrogeological context – Map view and sectional view



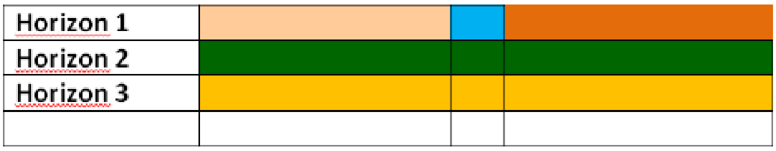
Delineated groundwater bodies



Example 1 – Map view

Example 1 – Sectional view

Horizon assignment – Vertical subsequential arrangement

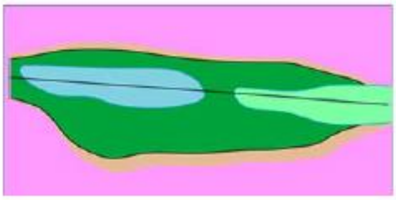


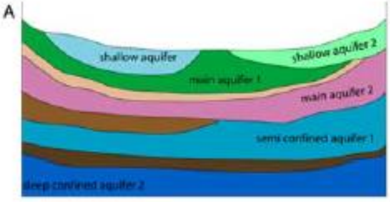
Indicative WISE WFD reporting for Horizon assignment to GWBs:

thematicIdIdentifier	horizons	
GWB1	1	
GWB2	1	
GWB3	1	
GWB4	2	
GWB5	3	

Example 2

Hydrogeological context – Map view and sectional view

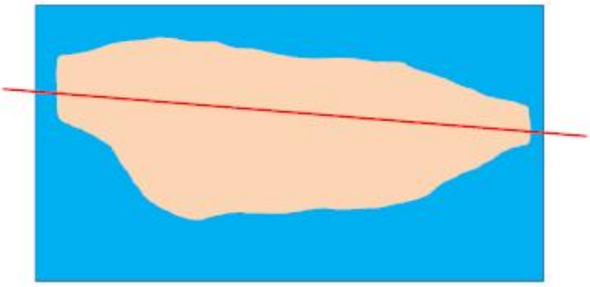


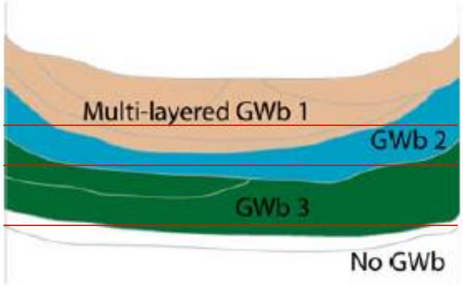


Delineated groundwater bodies

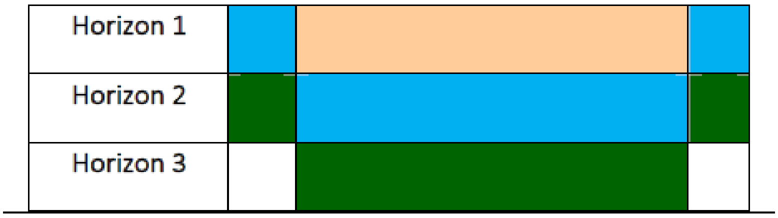
Example 2 – Map view

Example 2 – Sectional view





Horizon assignment – Vertical subsequential arrangement



Horizon 1	🟦	🟧	🟦
Horizon 2	🟩	🟦	🟩
Horizon 3	⬜	🟩	⬜

Indicative WISE WFD reporting for Horizon assignment to GWBs:

thematicIdIdentifier	**horizons**	
GWB1	1	
GWB2	1,2	
GWB3	2,3	

Source:
EC, 2016, WFD Reporting Guidance 2016, Final Draft 6.0.6, pp.347-350 (https://cdr.eionet.europa.eu/help/WFD/WFD_521_2016/Guidance/WFD_ReportingGuidance.pdf) accessed 13 January 2021

ANNEX 3 – POTENTIAL LIMITATIONS OF THE ANALYSIS

Groundwater characterisation: Delineation of groundwater bodies and their area

Although the delineation of GWBs is at the discretion of MS, some common principles to the delineation of GWBs have been developed. The homogeneity of natural characteristics, the concentrations of pollutants and alterations to groundwater levels should be considered, as well as the capacity to estimate with adequate precision quantitative and chemical status (CIS, 2003)[2].

According to the latest WFD reporting, the EU-27, Norway and the United Kingdom identified 15,930 GWBs in 2016, covering an area of 4.6 million km^2. The number and the average area of GWBs reported per country varies widely. For example, there are 6 GWBs in Luxembourg vs 3773 GWBs in Finland. The same Finnish GWBs cover and area less than 10 000 km^2, whilst France reports only 645 GWBs over an area of 1,2 million km^2. In Finland, GWBs are mainly made up of eskers (small isolated gravel deposits developed within post-glacial moraine), whilst in France the GWBs represent the wide extents of continual outcrop of highly productive aquifers.

Thus, the variation in numbers and extents of GWBs reported is likely to be a combination of the legacy of groundwater management by individual Member States prior to WFD implementation and the geology and hydrogeology of the aquifers. The pre-WFD era of groundwater management can be a strong influence on how GWBs have been identified. In some MS, some less productive aquifers with low population density, which historically not been managed, and achieve the criteria of providing >10 m^3/d or potable supply to a population of 50, may not have been classified as a GWB to reduce the administrative burden for what may be a low-risk scenario for groundwater.

The delineation of water bodies is an iterative process, refined over time to the extent needed to adequately assess and manage risks to the achievement of the WFD objectives (CIS, 2003). Hence, new GWBs may be identified, and existing ones may be re-characterised, split or merged. In total, the number of reported GWBs has increased between the two cycles, from 13,962 to 15,930 GWBs along with the area covered by GWBs (from 4,567 million km^2 to 4,608 km^2). According to reported data in 2010 and 2016:

- Only 6 countries have not changed the number of reported GWBs. They all have a small number of GWBs (i.e. Belgium, Hungary, Latvia, Lithuania, Malta, the Netherlands, Slovenia);
- 18 countries have increased the number of reported GWBs, usually by one or two GWBs (the largest increase being in Sweden, from 3023 to 3311 GWBs).
- Norway only reported information on GWBs in the 2016 reporting period.

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[2] Delineation should enable the accurate description of GWBs quantitative and chemical status. Thus, the boundaries of a GWB should, first and foremost, consider physical characteristics such as geological boundaries and hydrogeological features (CIS, 2004). But it may also take into account: major differences in groundwater status; the level of confidence and knowledge on geology and groundwater flows; protection needs; risk potential; economic importance; and water management aspects (e.g. administrative borders or the borders of the River Basin Districts) (CIS, 2004).

- There are no specific patterns between changes in the number of GWBs and changes in the total area covered by GWBs (i.e. some countries increasing the number of GWBs can see the area covered increase or decrease; and vice-versa).

Reporting choices for pressures and impacts

The detail of the reporting of pressures and impacts differs greatly among EU Member States, with some of them using a variety of pressure and impact types. For instance, Italy and Spain reported more than 20 pressure types. Belgium, Bulgaria, Germany, Greece, Finland, France, Hungary and Sweden reported more than 10 pressure types. Other coutries reported less than 10 pressure types.

In addition, only few cases of impacts on GWAAEs and GWDTEs are brought up in the reporting, although all EU Member States report that GWAAEs and GWDTEs are being considered in their status assessments.

Sources:

CIS, 2003, Guidance N°2 - Identification of water bodies, Common Implementation Strategy for the Water Framework Directive (2000/60/EC) (https://circabc.europa.eu/sd/a/655e3e31-3b5d-4053-be19-15bd22b15ba9/Guidance%20No%202%20-%20Identification%20of%20water%20bodies.pdf) accessed 13 January 2020.

CIS, 2004, Groundwater body characterisation - Technical report on groundwater body characterisation issues as discussed at the workshop of 13th October 2003, Common Implementation Strategy for the Water Framework Directive (2000/60/EC) (https://circabc.europa.eu/sd/a/157c2240-b988-417b-9137-a14e89db41d8/Groundwater%20characterisation%20report.pdf) accessed 13 January 2020