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Technical Report on Groundwater Associated Aquatic Ecosystems

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Technical Report on Groundwater Associated Aquatic Ecosystems

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LIST OF ABBREVIATIONS

CIS – Common Implementation Strategy for the Water Framework Directive

CV – Criteria Value

DWS – Drinking Water Standards

GD – CIS Guidance Document

GWB – Groundwater body

GWAAE – Groundwater Associated Aquatic Ecosystem

GWD – Groundwater Directive (2006/118/EC)

GWDTE – Groundwater Dependent Terrestrial Ecosystem

RBMP – River Basin Management Plan (1: first cycle plan; 2 : second cycle plan)

SWB – Surface water body

TV – Threshold Value

WFD – Water Framework Directive (2000/60/EC)

WGGW – CIS Working Group on Groundwater

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EXECUTIVE SUMMARY

The achievement of good status in groundwater bodies involves meeting a series of conditions, which are defined in the Water Framework Directive (WFD) and, in the case of good chemical status, are given further detail in the Groundwater Directive (GWD). One of these conditions is to ensure that groundwater inputs to associated surface waters do not result in failure to meet the environmental objectives of those waters or result in significant diminution in status/ecological or chemical quality of those waters.

GWAAE (Groundwater Associated Aquatic Ecosystems) are those surface water bodies (SWBs), including rivers, standing waters and transitional waters where the surface water ecology and hydrology is dependent on contributions from groundwater in order to meet their environmental objectives under the WFD. These environmental objectives may vary, and therefore the associated environmental quality standards (EQS) or flow/level requirements of GWAAEs may differ between high status and good status SWBs.

As noted in the Blueprint for Water, analysis of the first River Basin Management Plans has shown that Member States (MS) have experienced difficulties in understanding the interactions between groundwater and surface water and undertaking the necessary status assessments. This was highlighted in a survey carried out by Working Group Groundwater (WGGW) in 2014/15, which indicated that only half of the MS had assessed quantitative interactions and very few had addressed chemical pressures, including the derivation of threshold values (TVs) that were appropriate to the WFD objectives for GWAAEs.

This report aims to further knowledge on what GWAAE are, how they are aligned to WFD processes, and support Member States to properly include the needs of these ecosystems in river basin management planning.

The report clarifies the categories of GWAAE and their relative dependence on groundwater and collates current available knowledge and experience via a number of examples and case studies. Terminology and status assessment procedures are explained and pragmatic approaches are proposed which leave some flexibility for MS to adapt to their own specific needs. This technical report, which is not a "guidance document", makes use of and complements existing CIS documents, including existing technical reports on groundwater dependent terrestrial ecosystems (GWDTEs) and Guidance Document 18 (Guidance on Groundwater Status and Trend Assessment).

A number of recommendations for technical users of the report are highlighted in boxes in each Chapter. The common themes from these recommendations are collated in Chapter 8, as issues and questions to WGGW and MS in general. The key message from this is the need for closer interaction between scientific disciplines, practitioners and Working Groups in developing conceptual understanding for GWAAEs and implementation of WFD requirements, including identification of GWAAEs, their characterisation and monitoring, and adopting appropriate status assessment methodologies.

1 INTRODUCTION

This Technical Report is prepared by the Working Group on Groundwater (WGGW) under the Common Implementation Strategy of the WFD (CIS).

1.1 Why a technical report on Groundwater Associated Aquatic Ecosystems (GWAAE)?

Analysis of the first River Basin Management Plans as drawn up and implemented by Water managers across Europe (Blueprint for Water ; http://ec.europa.eu/environment/water/blueprint/index_en.htm) has shown that EU Member States have experienced difficulties in understanding the interaction between groundwater and surface water, from a quantitative or volume perspective and from a qualitative or chemical perspective.

Further evidence of these difficulties was apparent in a focussed survey amongst groundwater and surface water representatives of Member States, as carried out by WGGW in the winter of 2014/2015 (European Commission, 2015b). This survey showed that, whilst about half of the 21 Member States that responded had assessed the impacts of groundwater on the low flow conditions of rivers, only a few had assessed the impact of chemical pressures from groundwater on surface waters (mostly rivers). A few Member States had started to assess the impacts on Natura 2000 sites, but these assessments were at the early stages of development. Others indicated that they were planning to increase the consideration of Groundwater Associated Aquatic Ecosystems (GWAAE) in the development of their second river basin plans (RBMP2). This technical report aims to help this process.

The recent EU Technical Report (2015-086) on "Ecological flows in the implementation of the Water Framework Directive" (European Commission, 2015a) also highlighted the need to include groundwater considerations, especially where ecological flows were not attained. It particularly, it focussed on the often critical supply of groundwater during low river-flow situations and in sustaining river ecosystems that are directly dependent upon groundwater.

This report aims to further knowledge on what GWAAE are, and how they are aligned to WFD processes, and thus support Member States to properly include the need of these ecosystems in river basin management planning.

As highlighted in the 2015 WGGW survey, most Member States currently do not derive Threshold Values (TVs) for groundwater bodies (GWBs) based on the WFD objectives for GWAAEs, but simply use drinking water standards as TVs, probably due to lack of data. We hope that this report will help to improve the development of groundwater TVs based on the objectives for GWAAEs. This will be an important step in protecting the ecological status of Europe's surface water bodies (SWBs).

Figures 1.1 and 1.2 show the extent of surface waters across Europe that are adversely impacted by nutrients. The transport pathway from the pollution source to the SWB can include groundwater (one of the subjects of this report).

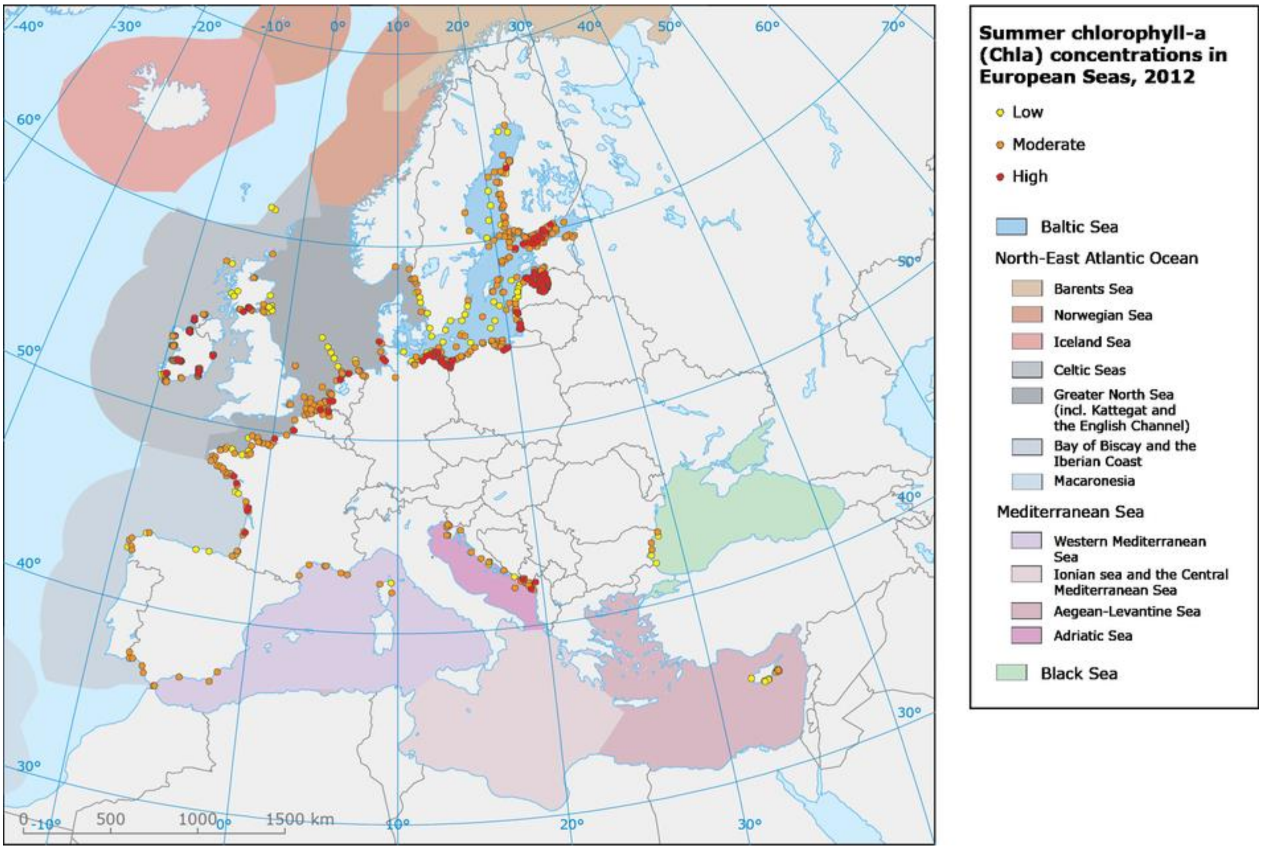

Figure 1.1: **EU overview of the eutrophication state of transitional and coastal waters.** Source:http://www.eea.europa.eu/data-and-maps/indicators/chlorophyll-in-transitional-coastal-and-2/assessment#toc-3. Note: Danish data is missing from this report. High summer chlorophyll-a concentrations and hypoxia frequently occur in Danish coastal waters.

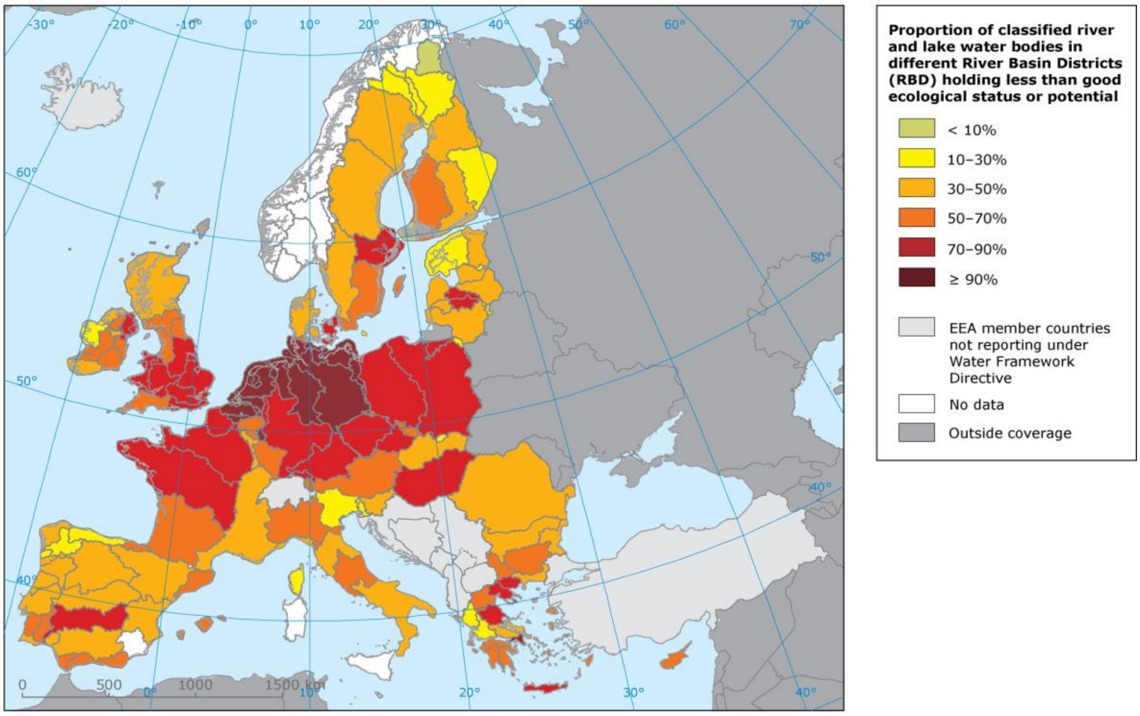

Figure 1.2: EU overview of the proportion of river and lake water bodies in less than good ecological status or good ecological potential. Source: [WISE WFD Database.]

1.2 Scope of this technical report

Anthropogenic alterations to groundwater levels or pollutant concentrations in the GWB can affect surface water aquatic ecosystems that are directly dependent on this groundwater (GWAAE) to such a degree that the GWB fails to achieve good status. This report aims to:

- clarify the categories of GWAAE and their relative dependence on groundwater;
- collate current available knowledge and experience;
- contribute to clarification of terms, making use of existing CIS documents; and
- suggest pragmatic solutions for the implementation of the provisions regarding the interaction of GWBs with associated and dependent aquatic ecosystems but leave flexibility for Member States according to their specific needs.

This technical report, which is not a "guidance document", complements the two existing technical reports on groundwater dependent terrestrial ecosystems (GWDTEs) (EC, 2012 and 2014); therefore GWDTE such as wetlands are not the subject of this report. In particular, the report provides complementary technical information to Guidance Document No. 18 "Guidance on Groundwater Status and Trend Assessment" (GD18; EC, 2009). The general procedures as outlined in GD18 in chapter 4.4.4 "Test: Significant diminution of associated surface water chemistry and ecology due to transfer of pollutants" and 5.3.2 "Test: Surface Water Flow" are still regarded as valid.

Similarly, there are clear linkages between the topic of this report and work that has been undertaken in parallel by the other WFD CIS Working Groups, in particular the working group that developed the guidance document on environmental flows (EU Technical Report 2015-086).

Finally, we note that ecosystems that are within the groundwater itself (Groundwater Ecosystems) can be important in their own right. However, they are outside the scope of this report, as they are not included in the WFD objectives and compliance regimes.

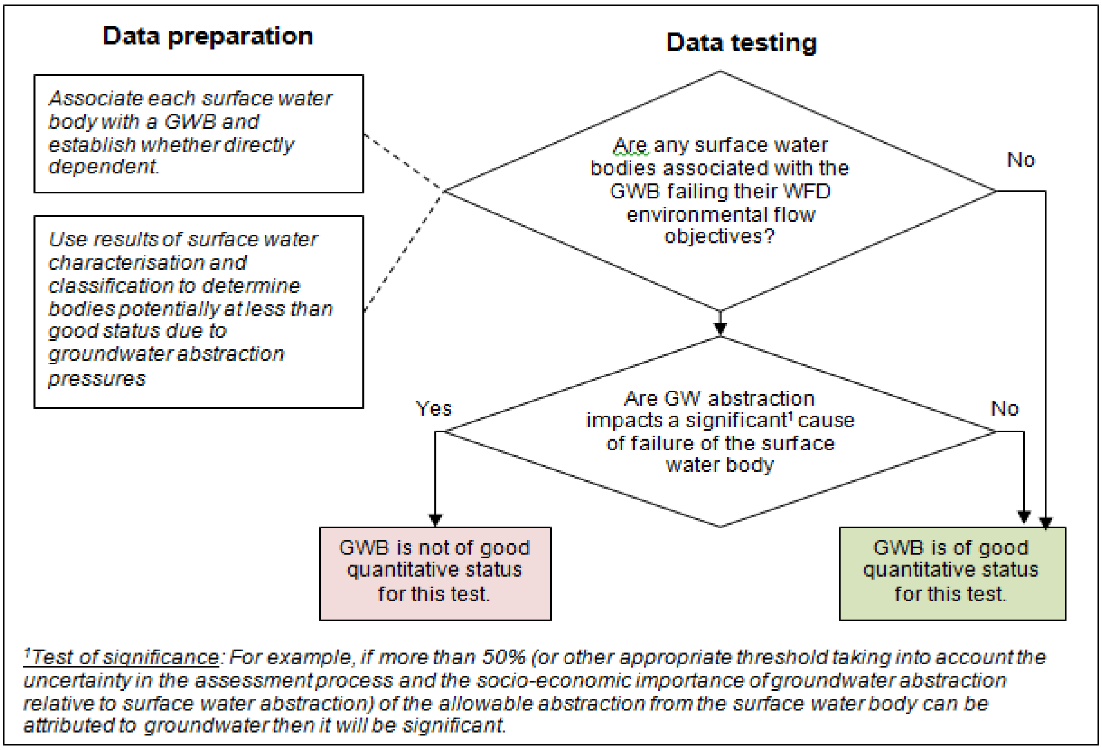

Figure 1.3: CIS Guidance Document No.18, Fig.12 (Outline of procedure for the surface water element of quantitative status assessment).

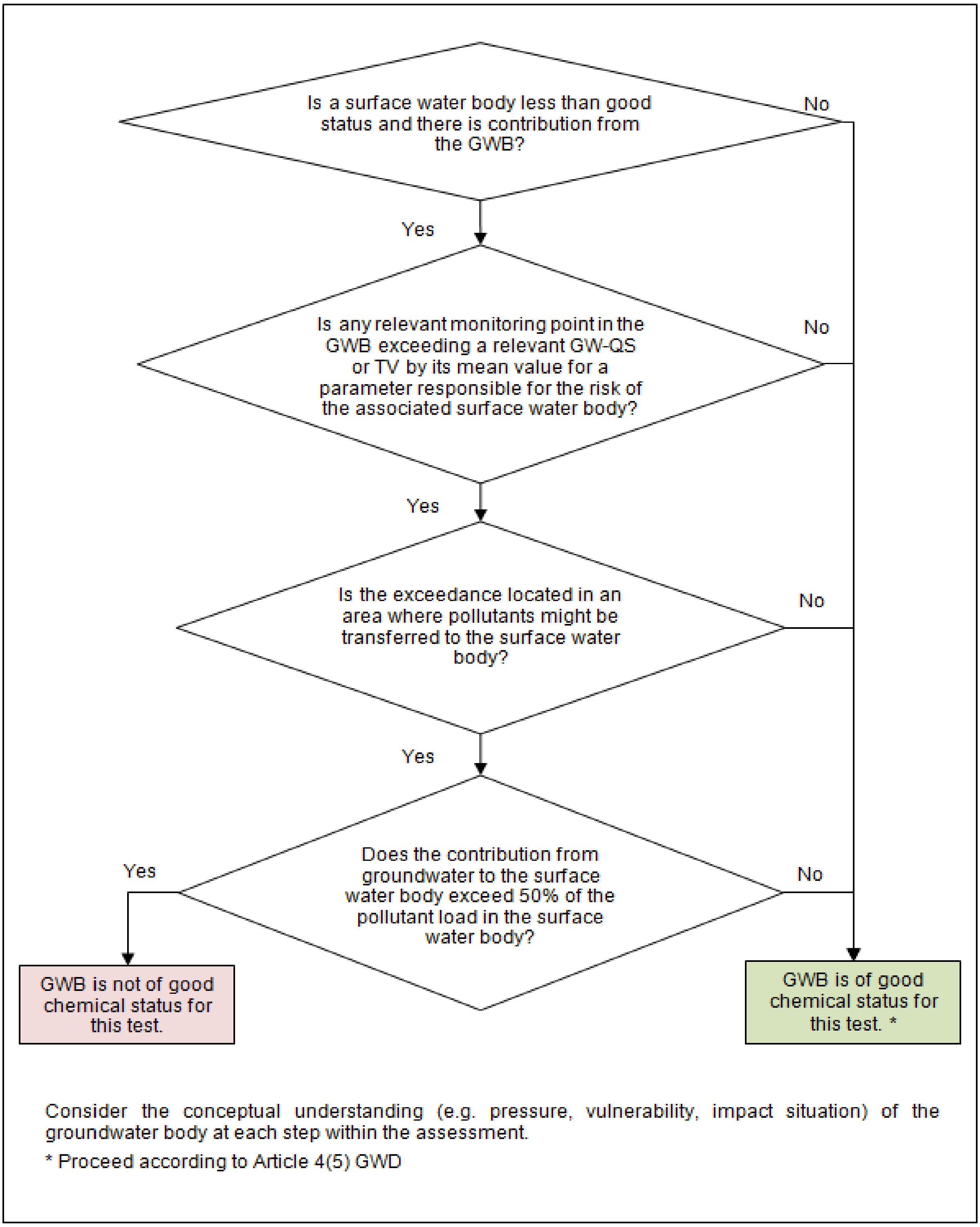

Figure 1.4: CIS Guidance document 18, Fig. 8 (Proposed procedure for test of significant diminution of the ecological or chemical quality of an associated SWB).

1.3 Groundwater associated aquatic ecosystems in the WFD and GWD

The Water Framework Directive (2000/60/EC) and Groundwater Directive (2006/118/EC), establish the framework for protecting Europe's water bodies and to reach good quantitative, chemical and ecological status by 2027. This ensures that a sufficient quantity of good quality water is available for people's needs, the economy and the environment throughout the EU (http://ec.europa.eu/environment/water/blueprint/index_en.htm).

1.3.1 Water Framework Directive (2000/60/EC)

The Water Framework Directive (WFD) aims to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. For groundwater, five environmental objectives are identified in Article 4. These objectives include the achievement of good groundwater status, which consists of good groundwater quantitative status and good groundwater chemical status. Definitions of these two terms are given in the WFD (Annex V).

With respect to **GWAAE**

- Article 1 states that: "*The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which: (a) prevents further deterioration and* ***protects and enhances the status of aquatic ecosystems*** *and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems…and thereby contribute to …. the protection of territorial and marine waters…..*"
- Recital 34 identifies that: "*For the purposes of environmental protection there is a need for a* ***greater integration of qualitative and quantitative aspects of both surface waters and groundwaters, taking into account the natural flow conditions of water within the hydrological cycle***" (EC 2000).
- Annex V establishes the criteria for the assessment of groundwater quantitative and chemical status e.g. based on **good status objectives for associated surface waters** and directly dependent terrestrial ecosystems.

Table 1.3.1: **Definition of good groundwater quantitative status** (reproduced from WFD Annex V, table 2.1.2)

Elements	Good status
Groundwater level	The level of groundwater in the groundwater body is such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction. Accordingly, the level of groundwater is not subject to anthropogenic alterations such as would result in: • **failure to achieve the environmental objectives specified under Article 4 for associated surface waters,** • **any significant diminution in the status of such waters**, • any significant damage to terrestrial ecosystems which depend directly on the groundwater body, and alterations to flow direction resulting from level changes may occur temporarily, or continuously in a spatially limited area, but such reversals do not cause saltwater or other intrusion, and do not indicate a sustained and clearly identified anthropogenically induced trend in flow direction likely to result in such intrusions.

Table 1.3.2: Definition of **good groundwater chemical status** according to the WFD (reproduced from WFD Annex V, table 2.3.2)

Elements	Good status
General	The chemical composition of the groundwater body is such that the concentrations of pollutants: • as specified below, do not exhibit the effects of saline or other intrusions • do not exceed the quality standards applicable under other relevant Community legislation in accordance with Article 17 • **are not such as would result in failure to achieve the environmental objectives specified under Article 4 for associated surface waters nor any significant diminution of the ecological or chemical quality of such bodies** nor in any significant damage to terrestrial ecosystems which depend directly on the groundwater body

Note: Poor chemical status does not reflect the impact of high concentrations of naturally occurring substances but **only the impact of human activities**.

1.3.2 Groundwater Directive (2006/118/EC)

The Groundwater Directive (GWD) aims to protect groundwater against pollution and deterioration.

With respect to GWAAE, the GWD focuses on assessments of groundwater chemical status for protection of groundwater dependent terrestrial and **associated aquatic ecosystems:**

- Article 3 specifies the criteria for assessing groundwater chemical status, which involves general quality standards for nitrates and pesticides as defined in Annex I and provides a minimum list of pollutants in Annex II of the GWD. These must be considered for derivation of threshold values for the protection of associated aquatic and dependent terrestrial ecosystems: "*The threshold values applicable to good chemical status shall be based on the protection of the body of groundwater in accordance with Part A, points 1, 2 and 3 of Annex II, having particular regard to its impact on, and interrelationship with, associated surface waters and directly dependent terrestrial ecosystems and wetlands and shall inter alia take into account human toxicology and ecotoxicology knowledge*".

- Annex I lists the general quality standards for nitrates and pesticides and includes the following: "*Where, for a given body of groundwater, it is considered that the groundwater quality standards could result in failure to achieve the environmental objectives specified in Article 4 of Directive 2000/60/EC for associated bodies of surface water, or in any significant diminution of the ecological or chemical quality of such bodies, or in any significant damage to terrestrial ecosystems which depend directly on the body of groundwater, more stringent threshold values will be established in accordance with Article 3 and Annex II to this Directive. Programmes and measures required in relation to such a threshold value will also apply to activities falling within the scope of Directive 91/676/EEC"*.

Consequently, the ecological or chemical quality of SWBs associated to groundwater (GWAAEs), or future deterioration in their ecological or chemical status, is a key driver when considering status assessments of GWBs.

Another key aspect is the nature of the dependency of the associated aquatic ecosystem on groundwater e.g. is the dependency on groundwater only critical at certain times of the year? Similarly, is the dependency related to groundwater chemistry? (for example, in the case where a particular surface water aquatic species is dependent on groundwater, or where relatively unpolluted groundwater is needed to maintain the ecology of a polluted SWB).

We recommend that a clear understanding of both the quantitative and chemical dependencies of a GWAAE is attained prior to undertaking any detailed WFD status assessments because these may have implications in the form of measures.

We also recommend that the understanding of the interactions between the GWB and the GWAAE are evaluated using a modelling approach. This could be a simple conceptual model (such as in presented at the end of chapter 2 (Fig 2.3) or could be a more detailed conceptual or numerical model. The modelling approach and level of detail required should be informed by the level of risk (or damage) to the GWAAE and the knowledge that the MS already has. CIS Guidance Document No.26: Risk assessment and conceptual models (Chapter 3.3; European Commission, 2010) provides further guidance on models, and the project GENESIS (output 5; GENESIS, 2015), described in Chapter 2, provides some examples and possible approaches.

Recommendation
1.1: A clear understanding of both the quantitative and chemical interactions of GWAAEs with GWBs should be attained prior to undertaking any detailed WFD status assessments so that these may inform any necessary measures. Conceptual and if necessary numerical modelling could be used to support this process, with the level of detail in proportion to the level of risk (or damage) to the GWAAE and the available data.

Example 1.1 – groundwater chemical status based on good status objective for an estuary (GWAAE)
The good ecological status of GWAAEs such as the Danish Horsens estuary (Hinsby et al., 2012) can be at risk from eutrophication resulting from excess loading of nutrients in river basin districts where intensive agriculture takes place. To protect the GWAAE and ensure good ecological status, freshwater and marine ecologists commonly compute the annual or seasonal acceptable total maximum loading of nutrients (typically N and/or P) to the ecosystem.

Monitoring data from groundwater (in oxic as well as the anoxic parts of the groundwater bodies) and streams (total water discharge and nutrient concentrations) are used to estimate the actual waterborne nutrient loading and the part of this loading that originates from groundwater, including shallow drainage water.

These data, together with the estimated maximum acceptable loading, were used to derive a groundwater total N concentration, which could be used as threshold value (TV) for total N ("nitrate") for the groundwater bodies in the catchment of the Horsens estuary in order to ensure and restore good ecological status of this GWAAE. For further information on this study see Example 5.2 and Section 6.2 in this report and (Hinsby et al., 2012).

Example 1.2 – Groundwater quantitative status based on good status objective for GWAAEs (A Swiss example)

The quantitative status of groundwater and the ecological status of GWAAEs are at risk locally and regionally in many parts of Europe due to groundwater abstraction for water supply, irrigation etc., as well as climate change. Climate change can affect both direct recharge by rainwater/melt water infiltration and indirect recharge via surface water bodies.

An example of groundwater – surface water (GWAAE) interactions in the context of anthropogenic use, climate change and ecosystems is the upper Emme Valley in Switzerland (Hunkeler, et al., 2015). The aquifer adjacent to the river supplies up to 40 % of the drinking water of the city of Berne. The ecological status of the river Emme is at risk due to the combined effect of groundwater abstraction for water supply and climate change causing e.g. summer droughts. Discharges in the summer are being reduced by earlier snow melt and disappearing glaciers. For example, in 2003 the pumping from the water supply wells had to be reduced in order to ensure the environmental flow (European Commission, 2015) and good ecological status of the river. Such reductions in the abstraction will occur more frequently in the future due to the longer and drier summers consistently projected by current climate models.

The interactions between groundwater and surface water bodies/ecosystems have been evaluated in the Swiss research project GW- TREND: Groundwater shortage due to climate change? (Hunkeler et al., 2015) and in an ongoing PhD project at the University of Neuchâtel. The project group uses distributed, fully coupled, groundwater-surface water models to assess climate change impacts on the river Emme in the upper Emme Valley. The developed modelling tool was applied to assess how the seasonal trends of groundwater levels and spring discharges may vary due to climate change. The influence of groundwater abstraction under changing climatic conditions can also be evaluated. In this context, the largest possible abstraction rates that guarantee minimal in-stream flow rates (the environmental flows required by law) can be calculated. In the ongoing PhD project a control system is being developed that allows optimization of the pumping scheme, taking into account the discharge into the river as well as the hydraulic conditions in the aquifer in real time.

The knowledge gained from the projects forms the basis of quantitative assessments of the importance of different factors in relation to the impacts of climate change on recharge, surface water - groundwater interactions and anthropogenic forcing. Using the results, aquifers and GWAAEs that respond particularly sensitively to climate change can be identified, appropriate measures can be taken in good time and targeted monitoring programmes can be implemented.

References:
European Commission, 2015: Ecological flows in the implementation of the Water Framework Directive. Technical reports, Guidance document No. 31

2 KEY CONCEPTS AND DEFINITIONS

2.1 What are GWAAE and associated surface waters?

Taking note of the WFD (Annex 5) and GWD (Article 3) requirements set out in section 1.3 above, the following definition is proposed:

***Definition* of a GWAAE:**

An ecosystem that is contained within one or more surface water bodies (rivers, lakes, transitional or coastal WB), the status (ecological or chemical) or environmental objectives of which could be affected by alterations of groundwater level or pollutant concentrations that are transmitted through groundwater (see Figures 2.1 and 2.2).

Damaged GWAAE that impact on the status of the SWB could also result in poor status of the GWB that supplies the essential water. The level of groundwater dependency of the GWAAEs will likely vary between years and seasons but the critical dependency of the ecosystem on groundwater is key. to its definition and protection.

Groundwater contributes flow to the majority of SWBs. The groundwater contribution will vary depending on the hydrogeology and physical setting; the groundwater component of the flow may fluctuate significantly throughout the year. The importance of the groundwater input to the ecological or chemical status of the SWB will vary significantly, but as a general rule it increases as the contribution of groundwater to the total water supply to the SWB increases. However, in some cases relatively small groundwater contributions may be ecologically significant when assessed on a seasonal rather than an annual basis. As a result, even in the less productive aquifers the groundwater contribution to a SWB can be significant e.g. during periods of low flow. In contrast, there are SWBs, such as groundwater dependent lakes (with no inflowing streams) or certain river stretches that are almost completely dependent on groundwater.

The GENESIS project (GENESIS, 2015) has provided interesting guidance on flow path characterisation and development of conceptual models. We have used this information to underpin the development of this report, but for further detailed information especially on conceptual GWAAE frameworks and more importantly on how to manage situations where the GWAAE is damaged, please refer to the GENESIS web site: http://www.bioforsk.no/ikbViewer/page/prosjekt/hovedtema?p_dimension_id=16858&p_menu_id=16904&p_sub_id=16859&p_dim2=16860

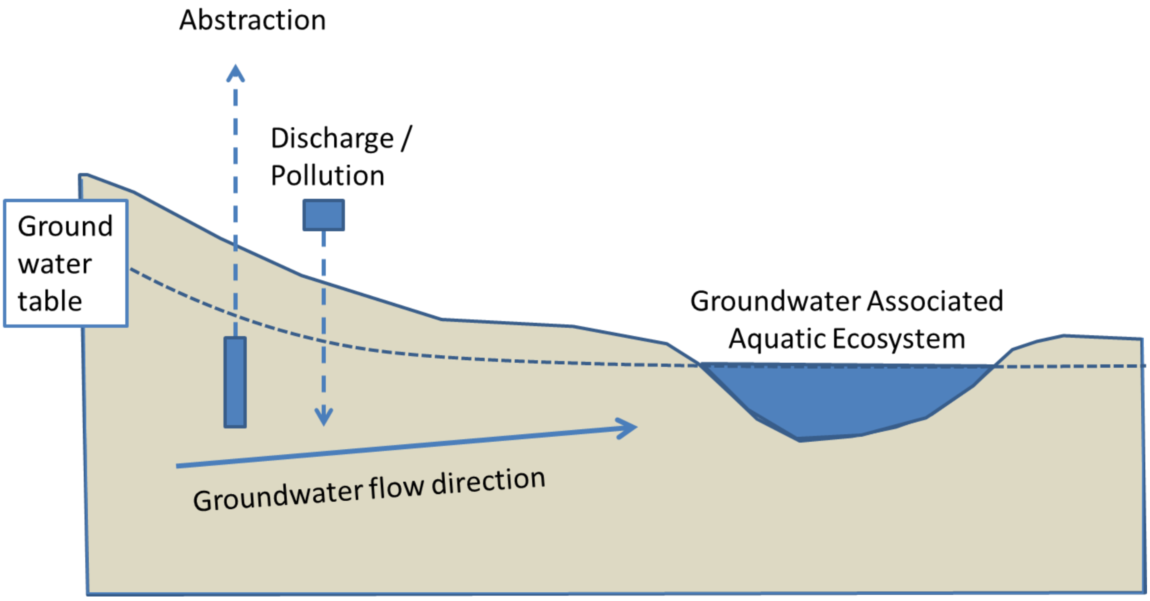

Figure 2.1: Conceptual model of a GWAAE with links to GWB and groundwater pressures.

This figure will be used as a basis for the rest of the report.

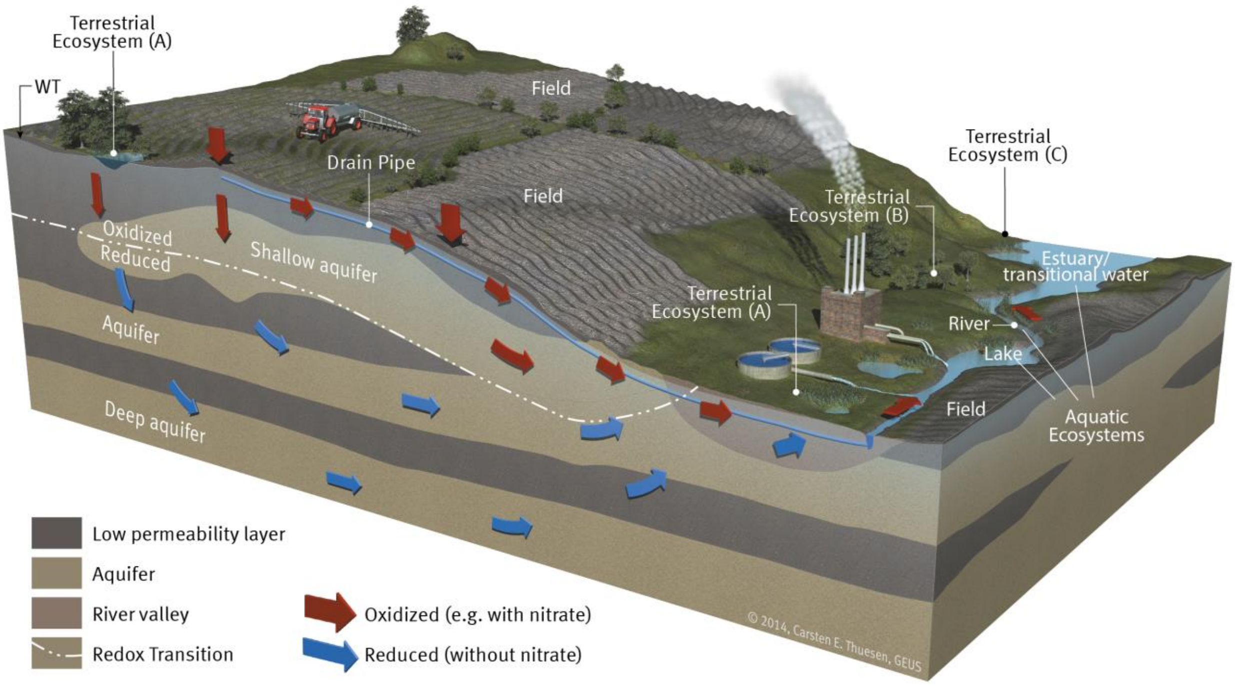

Figure 2.2: Danish example of groundwater associated aquatic ecosystems and the linkage to activities in the catchment (Modified from Hinsby et al., 2008, 2012).

Example 2.1: Turloughs are priority Annex I Natura 2000 habitats that predominantly occur on karstified limestone areas in Ireland. The Turloughs are transient lakes, which form as a result of a combination of high rainfall and accordingly high groundwater levels in topographic depressions in karst. Turlough flooding shows a continuum of hydrological behaviour ranging from short to long duration flooding.

A multidisciplinary Turlough conservation project titled *Assessing the Conservation Status of Turloughs* has been undertaken by the National Parks and Wildlife Service and Trinity College Dublin. Ecological impact assessments focused on the assessment of key habitat species and included algal communities, vegetation communities, and the presence of individual species of vascular plants and aquatic invertebrates. Water quality assessments focused on the identification of the key drivers causing variation in floodwater nutrient concentrations across the Turloughs.

All Turloughs studied were at risk from nutrient enrichment rather than quantitative issues, although conceptualisation and quantification of the groundwater – surface water interactions were critical to understanding the water quality issues.

Example 2.2: Nitrogen enriched groundwater discharges to a stream that flows into the Horsens Estuary (Denmark), a Natura 2000 site. The ecological damage (reduced extent of sea-grass and significant increase in filamentous algae) in the estuary (=associated SWB) is such that its WFD status is downgraded, and does not comply with the WFD good status objective. The groundwater threshold value for total-N is estimated to be 6.0 mg/l, equivalent to approx. 25 mg/l nitrate (Hinsby et al., 2012 and more detail is provided in Example 5.2).

Example 2.3: The nitrate enriched groundwater input (concentration about 35 mg/l as NO_3) to a directly dependent river water body in the Czech Republic caused the river water body to fail its chemical status test. The long-term base-flow index is about 0.7 and the boundary between good and moderate ecological status is 20 mg NO_3/l. Although the GWD Annex I groundwater quality standard (50 mg NO_3/l) was met, WFD good ecological status in the river (which is a GWAAE) is not met due to groundwater mediated pressures.

2.2 Categories of GWAAEs

In order to facilitate the implementation of the WFD and GWD a functional-based framework of categories is proposed that is pragmatic, practical and interlinked, where appropriate, with WFD surface water classes and Protected Area definitions. We recognise that Member States may develop their own categories reflecting the specific conditions in their country.

There are several ways to categorise GWAAEs (for example, Brown et al, 2007; GENESIS, 2015) and most include above ground ecosystems such as rivers, lakes and estuaries and some may include ecosystems within groundwater. This technical report only addresses the associated surface waters, not the groundwater ecosystem itself. GWDTEs are discussed in Technical Report No.6 (European Commission, 2012).

The level of groundwater dependency of an associated aquatic ecosystem can vary between those SWBs where the ecology is critically dependent upon groundwater, and thus may fail their WFD objectives when the quality or quantity of groundwater input deteriorates (thus also leading to a failure of the GWB to meet its chemical or quantitative status test), to those SWBs where the ecology or chemistry is able to withstand substantial changes in groundwater inputs, without resulting in a status change of the SWB.

Table 2.1: Framework of GWAAE categories and examples.

The framework below describes categories of GWAAE on basis of the associated SWB and the nature of this 'association' (temporary or permanent).

GWAAE category	Associated Water Body	Nature of groundwater dependency	Examples: protected sites (Natura 2000) and others
Temporary groundwater fed lakes	Lake	Critically dependent: Aquatic ecology in lake is critically dependent on the flow and chemical composition of groundwater as this is the dominant water source.	Turlochs in Ireland, Breckland Meres in UK,
Permanently groundwater fed lakes	Lake	Critically dependent: Groundwater is only source of water or contains chemicals that are critical for the ecology and are not supplied by other water sources.	Ohrid Lake (Macedonia, Albania)
Lake	Lake	Associated but not critically dependent. Lakes where a significant component of their water budget comes from direct groundwater inputs, but are not critically dependent on this flow or the chemistry.	Most lakes that also have river or stream inputs.
Temporary rivers or reaches of rivers primarily fed by groundwater	River	Critically dependent: Groundwater is only or dominant source of water and the river's ecology will be damaged if this source diminished significantly.	Winterbourne river sections / temporary headwater streams
Alkaline River – rivers with a high base flow index	River	Critically dependent: Groundwater is the dominant source of water that contains chemicals that are critical for the river's ecology.	River Itchen, UK
Permanent River	River	Associated but not critically dependent. Rivers where a significant component of their water budget (on an annual or seasonal basis) comes from direct groundwater inputs (for example, during	Most rivers that also have surface water inputs (for example, downstream from tributaries/ headwaters, where run-off is major water

		low-flow events), but where the river ecology is not critically dependent on the groundwater flow or chemistry.	source).
Temporary groundwater fed freshwater seeps on tidal flats	Transitional / coastal	Critically dependent: Groundwater is the dominant source of fresh water that is critical for the surface water ecology.	The ecology depends on freshwater input from groundwater (e.g. Sylt, Germany)
Estuaries, transitional and coastal waters that receive a permanent groundwater input either directly or via rivers	Transitional / coastal	Associated, but not critically dependent. Without the groundwater mediated pollution the estuary would be at good status.	Horsens estuary, Denmark Dalyan lagoon (GENESIS, 2015)
Small spaces in the sediment of rivers, lakes and estuaries	River, Lake or Estuary	Critically dependent: Oxic groundwater discharge through the river bed maintains the oxic and temperature conditions that are critical for the surface water ecology.	Hyporheic zone of rivers as spawning habitat for Salmon and refugia for salmon fry can be essential where Salmon is the Natura 2000 protected feature; Lule river, Sweden (GENESIS, 2015).
The aquatic ecology within a spring (Surface water), not the wetland ecology associated with the spring	River	Critically dependent. The ecology within the surface water is critically dependent on the groundwater outflow	Italy, Po valley; Pingo's, UK. One needs to be careful to distinguish the aquatic features from GWDTE spring and flush, which are focussed on the terrestrial ecology and discussed in European Commission, 2012)

2.3 How to determine whether an aquatic ecosystem is dependent on a GWB

Groundwater, surface water, precipitation and seawater all can provide water to the GWAAE. Determining when the aquatic ecology is critically dependent on groundwater (volume or chemistry) or when the aquatic ecology is associated with availability of groundwater is key to the protection of GWAAEs through the WFD and GWD. The dependency will also be further discussed in Chapter 3.

The dependency can be permanent (for example, in Turlochs) or temporary (for example, in hyporheic zone of rivers where these are essential for maintaining Natura 2000 habitat features for Salmon).

<u>Look out</u>

GWAAEs already receive protection under the WFD as they are integral components of surface water bodies (see section 2.5). Care should be taken in these situations to find out if the critical groundwater component is appropriately included in the SWB assessment methods; the groundwater component of the total surface water flow may provide essential services to a GWAAE which might not be considered by the SWB status assessment (for example, temperature stabilisation in a river hyporheic zone and stable low flow refugia which are essential for Natura 2000 Salmon habitat features).

2.4 Damage to a GWAAE

GWAAEs could be impacted by a change in the quantity or chemistry of the groundwater that it receives. This ecological change could (a) result in failure of the environmental objectives (including good status) for the associated SWB; or (b) is not yet so large that it results in such failure but, if this trend continues, results in failure within the foreseeable future.

Thus, there are two damage criteria:

a) **Failure to achieve the environmental objectives of associated bodies of surface water**: this occurs where the groundwater related pressure on the SWB (biology, hydromorphology or chemistry) results in a decrease in status class of this SWB or not achieving good or better ecological or chemical status of the SWB.

Example 2.4: Groundwater abstractions to irrigate agricultural crops during the dry summer months draw down the groundwater table. As a result, the groundwater component of the base flow of a dependent river drops to below the hydrological low flow standards. This results in a failure of the quantitative status test (see Chapter 7).

Example 2.5: Excessive fertilisation of agricultural crops on shallow and very permeable soils has resulted in significant leaching of nitrate to shallow groundwater. The outflow of this groundwater to the associated river has enriched the water such that the typical invertebrate community is replaced with one that is characteristic for nutrient enriched waters rather than the nutrient poor reference condition of the river. The failure of the ecological quality element of the SWB due to chemical pressures from the GWB results in a failure of the groundwater chemical status test (Chapter 7).

Example 2.6: Groundwater abstraction for drinking water purposes has lowered the groundwater level such that the quantity of alkaline groundwater that is discharged into the associated river is significantly reduced. The rest of the source of the river water is from run-off from higher areas in the catchment; however, this is not alkaline in nature. As a result, the alkalinity in the river drops significantly and causes the Natura 2000 river feature to become unfavourable in terms of conservation status. This decrease in condition of the protected site (on the protected site register) results in failure to meet a protected area objective and also in the reduction in status of the SWB. Therefore, the status of the GWB that is the source of this essential water is poor.

b) Significant diminution of the ecological quality of the associated water body. Significant diminution is not further defined in the WFD or GWD.

The definition of diminution is: *A reduction in the size, extent, or importance of something* (Oxford Dictionary online).

We define 'significant diminution of the ecological quality of the associated water body' as a trend in the reduction in the quality of the ecosystem that will ultimately (in the foreseeable future) cause this ecosystem to cease fulfilling its role within the associated water body (in terms of meeting either protected area or status objectives), but has not done so yet.

2.5 Terminology

The WFD defines **groundwater** as "all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil".

Threshold Values (TVs) are quality standards set by Member States that are one of the key criteria for assessing the chemical status of GWBs. In principle, exceedence of a TV triggers an investigation to confirm the status of the GWB

Criteria Values (CVs) are quality standards for pollutants that are set to protect a specific environmental receptor or use of water. They are sometimes referred to as receptor based standards, do not take into account the natural background level of the pollutant and may be derived from other legislation.

TVs and CVs and their usage in the assessment of good groundwater chemical status are described in more detail in Chapter 6.

Throughout this report, references to "status" are to the **status of whole water bodies**, as defined under the WFD. This is distinct from the **conservation status of habitats** under the Habitats Directive (92/43/EEC), which will be referred to as "conservation status". Natura 2000 sites designated under the Habitats Directive become Protected Areas under the WFD (Annex IV) and the objectives and standards for these sites become environmental objectives under the WFD. These again are distinct from the environmental objectives for surface waters and groundwater (as noted under WFD Article 4), which include achieving good status for water bodies.

Natura 2000 sites that are WFD Protected Areas may comprise part of, an entire, or more than one water body. Therefore, failure to meet conservation status at a Natura2000 site will result in failure to meet a WFD Protected Area objective and may or may not have an impact on the status of the water body in which the site is located. In this report wherever the **condition** of a GWAAE is referred to, this may be either the conservation status or the WFD status (where it comprises a whole water body).

In principle, a GWB with a GWAAE may not acheive its WFD status objectives if the GWAAE fails to meet protected area or surface water objectives due to impacts arising from anthropogenic pressures on the GWB.

When referring to future impacts based on current trends, the term "**foreseeable future**" is used. As a guide this may be taken to be within the planning horizon of the WFD (e.g. two RBMP cycles), but in practice the timescale appropriate to a specific case will be dependant on a wide range of factors such as confidence in the monitored trend, rate of change of environmental conditions etc.

3 DETERMINING THE QUALITY AND QUANTITY NEEDS OF GWAAEs

This is a rapidly evolving area of scientific understanding but the practical implementation of this knowledge is not straightforward. In this chapter, we aim to show how the GWAAE needs can be ascertained by examining the functional hydrological characteristics of the GWAAE, including, for example, the hydrogeological/hydrological linkage to the GWB.

Experience with WFD implementation during the first cycle of River Basin Management Plans (RBMP1), as noted in the recent WGGW questionnaire (European Commission, 2015b), has shown that Member States included the groundwater needs of the SWBs largely as quantitative flow needs during low river flows (i.e. base flow requirements). The chemical needs of the aquatic ecosystems or the needs of Protected Areas (Natura 2000) have largely not been included in RBMP1. However, many Member States indicated that they were trying to more fully include the needs of GWAAEs in RBMP2.

Recently (2014) the CIS working group on Eflows has finalised a report (European Commission, 2015a) on how to develop WFD focussed Eflow requirements of SWBs, in particular rivers. Groundwater can play an important role in providing water during low river flow situations (base-flow) and sometimes can provide ecologically important chemical environments in the river (such as elevated alkalinity, low nutrient concentrations, stabilised pH and temperature and a oxygenated river bed (e.g. hyporheic zone).

The EU 7th framework research projects GENESIS (GENESIS, 2015) and REFORM (REFORM, 2015) have increased our understanding of the interaction of groundwater and dependent ecosystems, and we have included the practical and conceptual knowledge of these projects in this technical report.

The groundwater needs of GWAAE have not yet been defined in a systematic way across the EU to date. Other than assessments of base-flow groundwater requirements, there have been no comparisons of methods to ascertain the groundwater requirements of GWAAE, let alone a comparison and alignment of the resulting standards.

Another route into this would be to understand the groundwater requirements of particular types of ecosystems, either based upon SWB category, or focussed around Natura 2000 categories. Research by EU countries that we are aware of has not provided clear numerical evidence of the groundwater need. For example, an alkaline river is critically dependent upon 'alkalinity' and this can only come from contact with the ground / geology, but how much alkalinity is needed and when (which season) is not defined in a systematic way (LIFE in UK Rivers, Natural England publications, 1999).

The recent WGGW TV questionnaire revealed that there are a small number of Natura 2000 site specific research projects underway that aim to develop standards or groundwater requirements for particular nature conservation sites, but no attempt has been made to systematically evaluate these and bring this work, if possible, into a pan-European environment, such as the ECOSTAT framework.

Recommendations

3.1 WGGW should work with surface water WGs (such as ECOSTAT) and with the EU DG ENV Nature conservation colleagues to develop a common framework for assessing the needs of individual GWAAEs, so that the outcomes of these assessments can be analysed in a coherent fashion and used across the EU. We recognise that the specific situations and needs of individual GWAAE will vary because of local conditions, such as hydrological variations, but consider that a common framework might assist consistent assessment and decision making.

3.2 Discussions should be held with surface water and groundwater ecologists and surface water managers to understand the location and groundwater needs of GWAAEs.

3.3 Where the GWAAE is part of a Natura 2000 site, there should be discussion with conservation ecologists.

4 CHARACTERISATION AND RISK ASSESSMENT

Chapters 1 and 2 outlined that GWAAEs are important receptors that may be impacted by groundwater from a GWB. Significant diminution of the ecological quality, or a deterioration in status class of the receiving SWB as a result of a changes in groundwater outflow or chemistry can result in poor status for the GWB.

The characterisation and risk assessment of the GWB therefore needs to appropriately include GWAAE as receptors. According to the WFD (Annex II) and Guidance Document No. 26 (GD 26: Risk assessment and the use of conceptual models for groundwater – EC2010), initial characterisation should identify GWBs for which there are directly dependent surface water ecosystems. Further characterisation, focused on GWBs at risk of failing their environmental objectives, should include an inventory of associated SWBs to which the GWB is dynamically linked.

The survey amongst Member States (EC, 2015b) showed that most Member States did not assess GWAAEs in the first RBMPs, but some followed GD18 and set specific threshold values (TVs) for GWBs with GWAAEs. In these cases, the TVs mainly reflected the EQS for surface water or base-flow contributions. A cut off for the groundwater contribution to the SWB pollutant load (50% of this load), as noted in GD18, was used in some cases. Under this approach, groundwater must be responsible for at least 50% of the pollutant load in the GWAAE for there to be poor groundwater chemical status.

The proposed schema (see below) is based on identification of potential GWAAEs in the initial characterisation process, the risk assessment and further characterisation where the risk is identified, and builds upon the limited experience from the Member States in RBMP1. The inclusion of an 'identification of the characteristics and any diminution of the GWAAE' in the initial characterisation is considered to be a reasonable expansion of GD26, though not explicitly mentioned in that guidance, and it would support the risk assessment.

Recommendation

4.1 The identification of GWAAEs, including the characteristics necessary to establish dependancy, should be considered within initial characterisation. The identification of specific characteristics and conditions (e.g. needs) of associated surface water bodies or parts of surface water bodies should be included within further characterisation.

Note: Discussions with surface water conservation ecologists are particularly important where the GWAAE is an interest feature of Habitats Directive protected sites (e.g. Natura 2000) and where changes to the groundwater flow to the GWAAE could result in significant impact on the WFD protected area or SWB objectives relevant to the site.

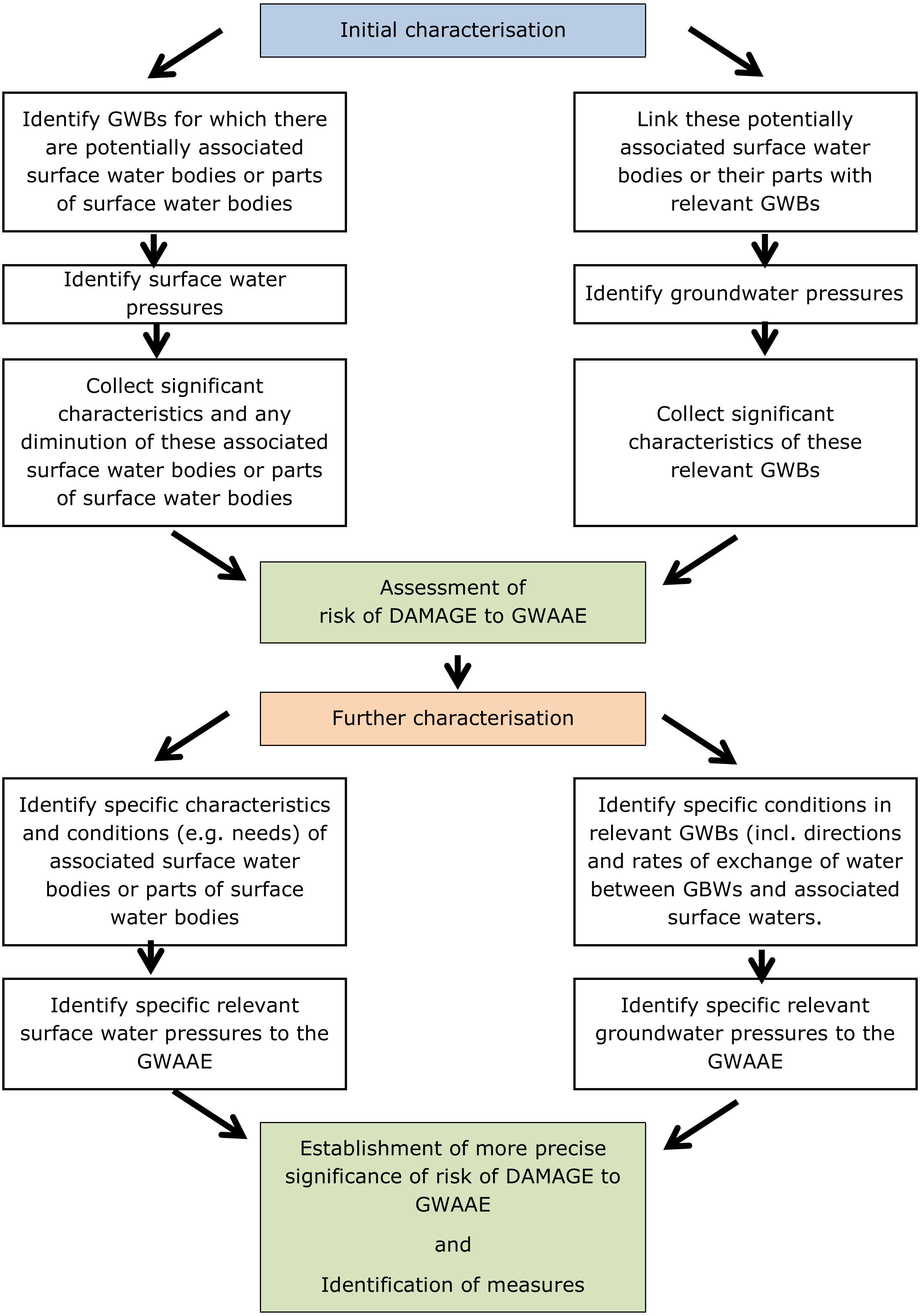

Figure 4.1: Flow chart of inclusion of GWAAE considerations in GWB characterisation and risk assessment.

4.1 Step 1: Initial characterisation.

Identify GWBs, for which there are GWAAE and locate these ecosystems:

- Identify SWBs or their parts (such as Natura 2000 Protected Areas), whose status (ecological or chemical) or other environmental objectives could in principle be affected by groundwater;
- Link these SWBs or their parts with relevant GWBs;
- Ascertain the categories, significant characteristics and any diminution of the potential associated SWBs or their parts (is it a river, a lake, transitional and coastal water, specific Natura 2000) to enable risk assessment; and
- Collate relevant characteristics of related GWBs (or their parts) e.g. specific geological conditions, levels or quality of groundwater.

Identify all significant pressures to which the surface water bodies and the groundwater bodies are liable to be subject, to allow for appropriate risk assessment.

The result of initial characterisation is a list of potential GWAAEs and the link between surface water and groundwater. The results from integrated conceptual groundwater/surface water models could be used. All information is further used to assess the risk of damage to GWAAE and the risk of failing to achieve the environmental objectives of the WFD.

4.2 Step 2: Further characterisation.

- Provide an inventory of associated surface systems and bodies of surface waters with which the GWB is dynamically linked.
- Add specific characteristics of the potential GWAAEs, their dependency on GWBs and their specific (groundwater related) needs;
- Provide information on the estimations of the directions and flow rates of the exchanges of water between the GWB and associated surface systems;
- Identify and collect information on all significant specific anthropogenic pressures on the surface and GWBs that could result in a deterioration of status or failure of an environmental objective of the GWAAE.

a) **Where GWAAE are whole or part of river water bodies,** questions can be asked such as:
   - Is the dependency related to quantity or quality (or both)?
   - What proportion of the flow is derived from groundwater and how does this vary over the year? This is especially important during low flow (base-flow) conditions as decreasing base-flow has a significant impact on the hydro-morphological quality element of ecological status. NOTE: It is useful to include Eflow requirements as part of this consideration (EC, 2015a);
   - Are physico-chemical quality elements of the river critically dependent on the quality of the water that is derived from groundwater?

b) **Where GWAAEs are part of lake water bodies,** questions can be asked to ascertain if groundwater quality or quantity is essential for the GWAAE, such as:
   - Is there a specific geological condition that results in groundwater with a chemical make-up that is essential for the GWAAE? For example, Ohrid Lake (Macedonia, Albania) is a geotectonic depression and is karst; it is primarily fed by groundwater (about 50% of total inflow);

- Does the lake water body have other inflows (streams etc.)? If not, this is an indication that groundwater is essential. For example, Turlochs in Ireland, Groundwater fed lakes in UK; Groundwater fed lakes in Denmark.

c) **Where GWAAEs are part of coastal or transitional water bodies** questions can be asked such as:
   - Is groundwater outflow (either diffuse across mudflats, or as direct seepage) a significant proportion of the freshwater flow into the transitional or coastal water body?
   - Is the chemical load (pollution load such as nitrate) coming from this a risk to the status of the transitional or coastal water body?
   - And/or are there significant stream discharges containing a significant amount of groundwater baseflow or drain discharges?

d) **Where a GWAAE is also part of a Natura 2000 site** questions can be asked such as:
   - Are the conservation interest features (for example, an alkaline river or tufa forming stream) critically dependent on groundwater?
   - Are these features related to groundwater quality or quantity? (e.g. groundwater head regime, concentration of pollutants etc.). This will need interaction with surface water and conservation ecologists.

e) **For all categories of GWAAEs** additional information could be ascertained:
   - Identification of the groundwater quality and quantity requirements of the SWB and/or Natura 2000 protected area on a spatial (where) and temporal (when) basis, to identify critical groundwater dependencies that are associated with SWB status assessments or Natura 2000 assessments.
   - Assessment of GWB pressures that could impact on the outflow of groundwater (quality and quantity) such that the needs of the SWB or Natura 2000 are not met and the SWB status would deteriorate / fail its classification tests or the Natura 2000 would turn into unfavourable conservation status.

4.3 Step 3: Assessment of the risk of damage to GWAAE.

Is there a risk that the pressures coming from the GWB are adversely impacting on the GWAAE?

GD18 on groundwater status and trend assessment describes significant diminution of associated surface water chemistry and ecology due to transfer of pollutants from the GWB, the setting of specific threshold values and explains the quantitative status test.

<u>This technical report aims to provide a more detailed approach for risk assessment of GWAAEs.</u>

There are two potential ways of doing risk assessment:

a) receptor (GWAAE or Natura 2000) based -GD18 focusses on this approach- or

b) groundwater based.

Each of these can have value when carrying out a risk assessment on a GWAAE and are described below.

a) Receptor as starting point:

- Identify SWBs that are in less than good status or that are trending to become less than good status in the foreseeable future; or part of SWBs that fail environmental objectives;
- Identify aquatic Natura 2000 sites that are in unfavourable conservation status.

b) Groundwater as starting point:

- **Consider all identified specific anthropogenic pressures on the GWB** that can cause a significant change to the groundwater volume or chemistry that is discharged to the GWAAE. For example:
    - Quantitative impact: is the base-flow index (BFI) of the river greater than the relevant SWB standard?
    - Are there significant abstractions on the GWB that could impact on the discharged volume at the GWAAE?
- **Consider all identified specific anthropogenic pressures on the SWB** that can cause a significant change to the volume or chemistry of surface water that flows through the GWAAE. For example:
    - Are there significant abstractions or reservoirs upstream from the river water body GWAAE that will significantly change the quantity of water that flows through the GWAAE and thus changes the relative contribution of groundwater and surface water to that flow?
    - Are there significant discharges (e.g. Sewage treatment works or intensive agriculture that could cause diffuse pollution) upstream from the transitional water body (GWAAE) that will significantly change the quality of water that flows through the GWAAE and thus change the relative requirements of groundwater and surface water to that flow?

Note: Only the impact of **anthropogenic pressures** should be assessed – not the natural characteristics of groundwater, although the natural aspects can be perceived to have negative influence – e.g. naturally decreasing of groundwater head during a dry period or increased concentrations of naturally occurring substances as heavy metals or ammonium in groundwater arising from natural events.

Recommendations

4.2 For GWAAE risk assessment, both receptor and groundwater based approaches are considered and utilised, as appropriate.

4.3 As clearly indicated by the characterisation and risk assessment, there needs to be direct discussion and joint working within Member States:

- **i. between surface and groundwater experts and scientists to assess the risk of whether changes to groundwater flow could result in significant impacts on GWAAEs; and**
- **ii. between groundwater scientists and surface water ecologists to identify the location and hydrological/hydrochemical requirements of GWAAEs.**

5 MONITORING

5.1 Collation of background data

Considerable information is already available on monitoring, including monitoring of interactions between groundwater and ecosystems, e.g. CIS GD7 (Monitoring) and GD15 (Groundwater monitoring), Technical Report no. 3 (Groundwater monitoring), CIS GD26 (Risk Assessment and Conceptual Models) and Technical Report No. 6 (Groundwater Dependent Terrestrial Ecosystems).

Obtaining a sufficient level of knowledge to effectively include GWAAE in WFD/GWD characterisation (Chapter 4) and status assessment (Chapter 6) can require monitoring information from:

- The GWB that supports the GWAAE, to ascertain the magnitude of current or future changes to the quantity or quality of this water;
- The associated SWB, to ascertain if the volumes and quality of groundwater that are essential to meet good status for this water body are met; and
- The GWAAE, to ascertain:
    - if the required volumes and quality of groundwater that are essential to prevent significant diminution of dependent ecosystem are met; and
    - if the condition of the associated ecosystem has changed to a level that can be described as 'significant diminution' or will change so in the foreseeable future if the trend continues.

The need to have information from all these three components depends on the level of risk (as identified from the steps in Chapter 4). Monitoring is carried out most effectively where there is integration of the information from each monitoring network. A conceptual scheme of monitoring activities is shown below.

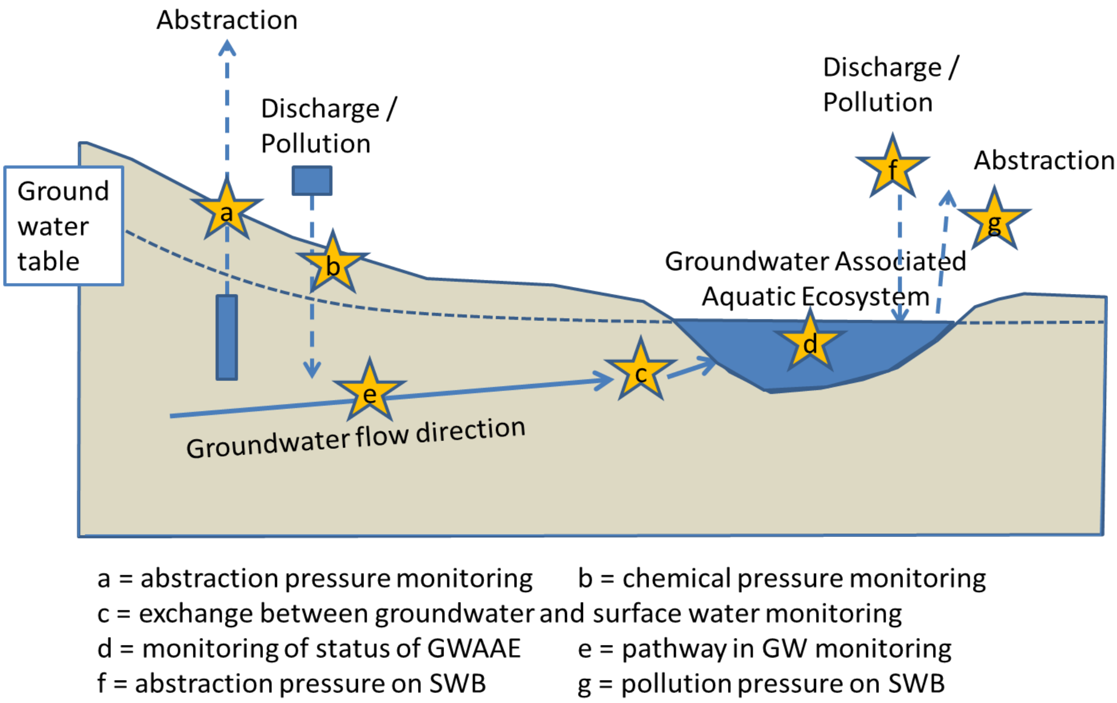

Figure 5.1: Schematised relationship between GWB and GWAAE, showing potential monitoring locations.

With reference to Figure 5.1, **Initial characterisation** (see Chapter 4) requires information on the:

- Location of the GWAAE and the state of the associated SWB; this might include ecological assessments (d);
- State of the GWB (e);
- Hydrogeological and hydrogeochemical requirements of the GWAAE (d); and
- Significant pressures which the surface water bodies and groundwater bodies may be subjected to.

Further characterisation requires information on the:

- Characteristics of the GWAAE (this might include ecological assessments (d);
- Specific pressures on the GWB that would affect the quality and quality of the groundwater discharging into the GWAAE (a and b);
- Specific pressures on the SWB that would affect the quality and quality of the water irrigating the GWAAE (f and g);
- Process understanding of the interlinkage between the GWB and the quantity and/or quality of groundwater that is available to the GWAAE, (i.e. estimations of the directions and flow rates of the exchanges of water between the GWB and associated surface systems) (c).

5.2 Monitoring in GWBs and associated SWBs

Data from monitoring networks include both quantity and quality characteristics and their trends. It is good practice that GWB monitoring is related to the corresponding conceptual model (see above and chapter 2.2) to ensure that monitoring points can adequately describe GWB status and the relationship with the GWAAE. In other words, the conceptual model of groundwater flow to the GWAAE that is developed as part of the characterisation and 'needs assessment' of the GWAAE will help to evaluate what monitoring points in the GWB are representative of the inputs to the GWAAE. These monitoring data could be analysed to check their influence on the condition of the GWAAE and the status of the SWB. If necessary, specific monitoring points could be considered for GWAAE evaluation, based on the conceptual model of groundwater and surface water flow.

GWB monitoring normally includes water table measurements and changes over time. These data can indicate the influence of the groundwater flow feeding into the GWAAE, potentially affecting GWAAE objectives/water body status or at least the dependence on groundwater. It is good practice that particular emphasis is given to water table oscillations. Similarly, where the GWAAE clearly depends on discharge from the GWB (as baseflow) into the SWB, flow monitoring can be useful.

Monitoring information from the associated SWBs, if necessary, can be used to evaluate possible influences on the GWAAE objectives and the water body status. Monitoring upstream and downstream from the GWAAE could be useful and, where required, could include both quantity and quality.

Is it recommended that monitoring networks and parameter lists for the quality characteristics of GWB associated with the GWAAE are representative of the GWAAE needs and condition (for example, if it is in favourable or unfavourable conservation status); this means that the parameter list can be defined in detail on the basis of a "GWAAE site-specific" approach. To understand the interactions between GWB, SWB and GWAAE it is recommended that those physico-chemical parameters and chemical substances conditioning/affecting the integrity and the functionality of the GWAAE are included in the monitoring.

Table 2.1 identified several degrees of dependencies (critical; dependent; and not, but can be influenced by pollution). Therefore, we propose that monitoring is focused according to the following three classes:

I. GWAAE that are critically dependent on GWB, e.g. fed by GWB and/or having physico-chemical requirements specific to the associated GWB ; in this case data from GWB monitoring are sufficient, if representative of the GWAAE needs and status/objectives;

II. GWAAE dependent on SWBs and GWBs, where both types of water bodies can influence the GWAAE conservation and associated water body status (e.g. permanent river in Table 2.1); in this case specific data from GWAAE monitoring, coupled with selected GWB and SWB data have to be considered;

III. GWAAE not critically dependent on GWBs (see Table 2.1) and having a limited interaction with them, but which can be negatively affected by pollutant transfers into the GWAAE. If such transfers are apparent, monitoring of the GWAAE is likely to be needed.

Monitoring activities can be tailored for each of the three general cases, and can show a decrease in parameters, monitoring points and frequency of sampling needed to be monitored in the GWB, moving from class I to class III.

Where there is a risk of significant diminution (i.e. a trend that will cause failure of the environmental objectives in the foreseeable future), we propose that not only values from specific monitoring could be considered but also longer term data series of GWAAE related parameters from GWB and SWB monitoring.

Example 5.1: GWB monitoring for GWAAE

GWB monitoring activities to identify impacts on a GWAAE have been performed for sites where the relationships are very clear and these have informed the anonymised example below:

- water level and/or discharge measurements were carried out in one location along the pathway between GWB and GWAAE (e in Figure 5.1) or in at least two monitoring points if they are not located along the pathway. A seasonal frequency was sufficient;

- chemical-physical parameter monitoring included a list approved for the GWB, with at least two samples per year. The monitoring points needed to be located along the groundwater flowpath towards the GWAAE, which meant that wells and springs intercepting groundwater flow that did not discharge into the GWAAE were excluded;

- it is possible that there were different flowpaths or hydrogeological conditions layered within one GWB and this would have an impact on the transport of pollutants (e.g. nitrates). In these cases a multilevel depth-discrete monitoring network was recommended along the main flowpath and one location was sufficient;

- the GWB monitoring parameter list of was informed by the sensitivity of the ecological receptors (GWAAE) and their indicators where they were known (e.g. for Natura 2000 network);

- monitoring of the GWAAE included parameters not considered for the GWB, and considered seasonal variations.

Recommendation
5.1 Monitoring to inform risk assessment and status assessment for GWAAE should include data from both the GWB and the SWB. Joint working between surface and groundwater scientists within Member States on monitoring needs and exchange of existing data and knowledge is essential.

Example 5.2: Monitoring data required for derivation of groundwater TVs to protect a GWAAE.

Lakes and estuaries may receive groundwater both from direct GWB discharges and from a groundwater component in river discharges. It is important to quantify the groundwater part of both the river discharge and the total discharge to the GWAAE in order to estimate its contribution to the total pollutant loading to the GWAAE and ultimately derive TVs for the assessment of GWB chemical status.

All relevant quality (concentrations) and quantity (runoff/stream discharge) parameters need to be monitored to facilitate the above. Both monitoring data and modelled groundwater-surface water interactions by calibrated numerical models are sometimes required for such assessments.

A further consideration is the geochemical environment in which the monitoring points are located. For instance, monitoring points located in the anoxic zone should not be included in the estimation of average nitrate concentrations, as the nitrate will have been reduced and should not be present in this zone. If all monitoring points were located in the anoxic zone the average concentration in the GWB would be 0 mg/l, even if shallow oxic groundwater with short travel times to streams (and the most vulnerable GWAAEs) contained >30 mg/l of nitrate and had a severe impact on the GWAAE. Such an example is provided by the case of Horsens estuary, Denmark, as shown in the Figure 5.2.

GWAAEs are typically more sensitive to total annual loadings of nutrients (mainly total N and P) than to maximum concentrations. Hence, the assessment of the nutrient impact on an aquatic ecosystem requires long term monitoring of seasonal variations in both quantity (runoff) and quality (e.g. nitrate concentrations) to be able to estimate flow weighted concentrations and annual nitrate or total N loadings to the ecosystem, and ultimately stream and groundwater threshold values to protect the ecosystem (Hinsby et al., 2008, 2012). The Horsens estuary case described above provides such an example.

Data from both monitoring and modelling will support each other and improve the understanding of groundwater – surface water interactions and data needs. Finally, they provide important data for climate change adaptation and assessment of climate change impacts on both groundwater and surface water quantity and quality.

Note

GD18 describes methods for deriving TVs that take account of natural background concentrations and the legitimate uses of groundwater. These would result in a TV for nitrate (expressed as N) that would be of a similar magnitude to that derived above to ensure (restore) good ecological status of the Horsens estuary. However, some lakes and/or GWDTEs in the catchment of Horsens estuary, or in other catchments, could be more vulnerable and therefore some GWBs would have even lower TVs for nitrate. Emerging evidence from the UK (UKTAG, 2012) shows a range of nitrate sensitivities for GWDTE starting as low as 4mg/l nitrate (NO_3).

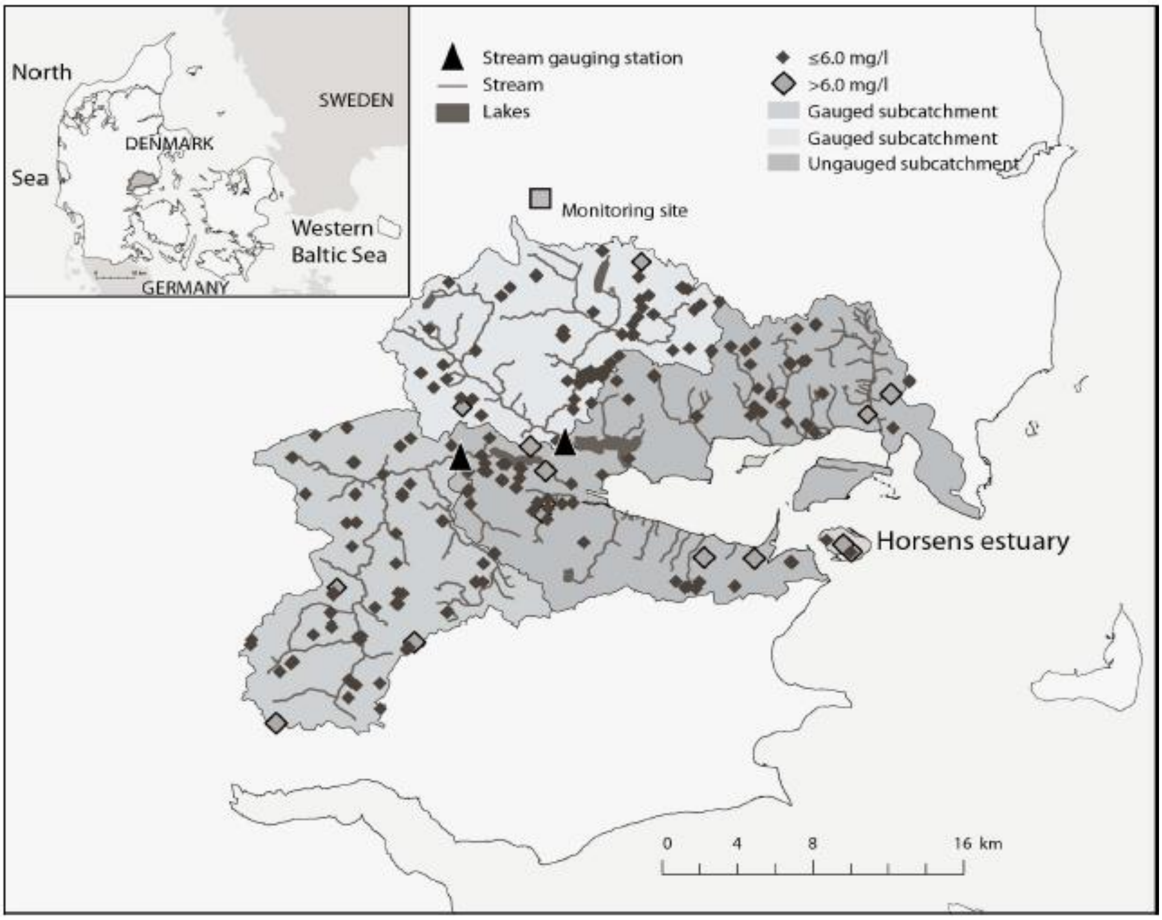

Figure 5.2: **Horsens estuary.** Nitrate-N concentrations (mg/l) in groundwater monitoring wells (2011) compared to the derived groundwater TV of 6.0 mg/l total N (equivalent to ~25 mg/l of nitrate). Most monitoring wells are located in anaerobic groundwater, containing no nitrate and low dissolved inorganic nitrogen (DIN); they have nitrate-N concentrations below the TV, and the average nitrate-N indicates no problems with nitrate. However, the estuary has poor ecological status and the majority of the monitoring points in the oxic zone have nitrate-N concentrations considerably higher than the TV.

5.3 Monitoring in the GWAAE

In addition to monitoring of the GWB, specific monitoring of the GWAAE could be implemented, as part of the "operational monitoring" as described in CIS GD15 (Groundwater monitoring) where there is a risk identified from either the GWB pressure or the condition of the GWAAE (see Chapter 4).

We recommend that firstly, the interactions between GWBs and SWBs are considered using the conceptual model, to understand if the GWAAE depends on groundwater, surface waters or both. Where possible, using the conceptual model, we need to ascertain the level of dependency of the GWAAE (class I or class II, as noted in section 5.2). This affects the specific monitoring list also for the GWAAE. GWAAEs that depend largely on SWBs require specific monitoring (class III) of those bodies.

Three-dimensional (depth discrete) monitoring might be required for GWAAE which are dependent on a specific layer within the GWB, for example, where a GWB layer discharges oxygen rich groundwater, or high alkalinity groundwater.

Specific monitoring can be needed to show that GWAAEs which were not previously classified as "significantly damaged" do not become "significantly damaged" as a result of GWB or surface bodies pressures (risk of deterioration monitoring). This is only possible where an adequate time series of measurements is available.

GWAAE monitoring can be focussed to evaluate the influence of the main bio-geochemical processes (e.g. affecting nitrogen/nutrient cycle) at the site scale; this approach can be used to identify a list of chemical compounds affecting biological characteristics.

Direct ecological status monitoring (incl. biological and hydrological elements) can be included in the monitoring of the GWAAE where this will help understanding the condition of the GWAAE or impacts of GWB or SWB pressures (see section 6.4 about derivation of TVs based on monitoring data from the GWAAE).

If characterisation or monitoring of the GWAAE or the GWB highlight a significant risk of damage to the GWAAE, a list of appropriate parameters has to be defined.

Where damage of a GWAAE has been identified and this has caused status failure of the SWB, GWB or Protected Site we recommend that appropriate monitoring is maintained to identify the effectiveness of the measures put in place to restore the GWAAE.

Recommendation

5.2 GWAAE specific monitoring may be needed where the GWAAE is at risk or is being damaged. It is good practice that this monitoring is developed based upon a conceptual understanding of the interaction between the GWB, SWB and GWAAE and in co-operation with relevant scientists familiar with the SWB or protected area (e.g Natura 2000).

6 THRESHOLD AND CRITERIA VALUES

6.1 Definition of threshold and criteria values

The concept of groundwater **Threshold Values (TVs)** for the assessment of groundwater chemical status is introduced in Recital 7 of the GWD:

"*Having regard to the need to achieve consistent levels of protection for groundwater, quality standards and threshold values should be established, and methodologies based on a common approach developed, in order to provide criteria for the assessment of the chemical status of bodies of groundwater*".

TVs are then defined in Article 2 as quality standards set by Member States in accordance with Article 3. Article 3 describes the "Criteria for assessing groundwater chemical status", which include TVs, and states that:

Article 3.1(b):

"*The threshold values applicable to good chemical status shall be based on the protection of the body of groundwater in accordance with Part A, points 1, 2 and 3 of Annex II, having particular regard to its impact on, and interrelationship with, associated surface waters and directly dependent terrestrial ecosystems and wetlands and shall inter alia take into account human toxicology and ecotoxicology knowledge*".

Article 3.2:

"Threshold values can be established at the national level, at the level of the river basin district or the part of the international river basin district falling within the territory of a Member State, or at the level of a body or a group of bodies of groundwater.

Member States must report and apply the most stringent TV that will protect all ecosystems and legitimate uses of relevance to the investigated GWB. If groundwater monitoring data from the GWB (or relevant part of the GWB) breach the derived TV, an 'appropriate investigation' follows. The outcome of this investigation will determine whether the GWB is in good or poor chemical status.

For more information on TVs please refer to previous publications (Müller et al., 2006, Hinsby et al., 2008, European Commission, 2009, European Commission, 2012). From these, it is apparent that most Member States, in accordance with GD18, take into account the natural background level of the pollutant when setting TVs for GWBs.

The term **Criteria Value** (CV) is not specifically defined in the GWD, but is introduced in GD18 (Figure 3), as a quality standard that is derived for each relevant pollutant for each specific environmental criteria or receptor (saline intrusion, GWAAEs, GWDTEs) or usage (drinking water, industry, agriculture etc.). These CVs, which are sometimes referred to as receptor based standards, do not take into account the natural background level of the pollutant and may be derived from other legislation. For example, the CV for protection of drinking water is the drinking water standard (DWS) for a given pollutant. The TV for the same pollutant derived to protect groundwater as a drinking water resource is determined by the Member State, but in principle may range between the drinking water standard (DWS) (the CV) and the natural background level (BL) of the pollutant (where the CV>BL). The various considerations and general methodology for deriving TVs is described in GD18, which states that:

"*Threshold values will be set by Member States by comparing the background level to the criteria value (CV). The criteria value is the concentration of a pollutant, not taking into account any background concentrations, that if exceeded may lead to a failure of the* *good status criterion concerned. CVs should take into account risk assessment and groundwater functions*. "

Whilst TV's and CV's only refer to chemical standards, we propose that quantitative standards are developed in a similar way to adequately protect GWAAE, but to avoid confusion these should not be called TV's or CV's.

Recommendation

6.1: Member States are encouraged to develop quantitative standards to protect GWAAEs, in a similar way to TVs and CVs, but all references to these should clearly distinguish them from TVs and CVs.

6.2 Application of threshold and criteria values to GWAAE

It follows from the above that the smallest level for establishment of TVs is the GWB. However, as noted by Müller et al. (2006) and Hinsby et al. (2008) it may be necessary to subdivide the GWB into different hydrochemical environments depending on the pollutant in question, in order to calculate meaningful TVs and background levels, as the pollutant behavior and concentrations may vary significantly in different geochemical settings. Example 5.2 demonstrates this; nitrate (the pollutant most frequently causing GWBs to fail good status) does not occur in anoxic groundwater environments and measurements in this zone would not be representative for comparison with a nitrate TV set to protect a GWAAE, as only conditions in the upper oxic part of the GWB are of relevance to GWAAEs.

The establishment of TVs to appropriately protect GWAAEs could mean in practice that a large GWB, or a GWB containing different geochemical environments could be subdivided into smaller GWBs or different geochemical zones, to help practical management or definition of additional measures, as different management strategies for these smaller water bodies will be more effective and efficient. This approach is evaluated in a research project (Hinsby and Refsgaard, 2015, www.soils2sea.eu) on the evaluation of differentiated regulation and efficient measures to control nutrient (N and P) leaching from farm lands to surface waters/GWAAEs.

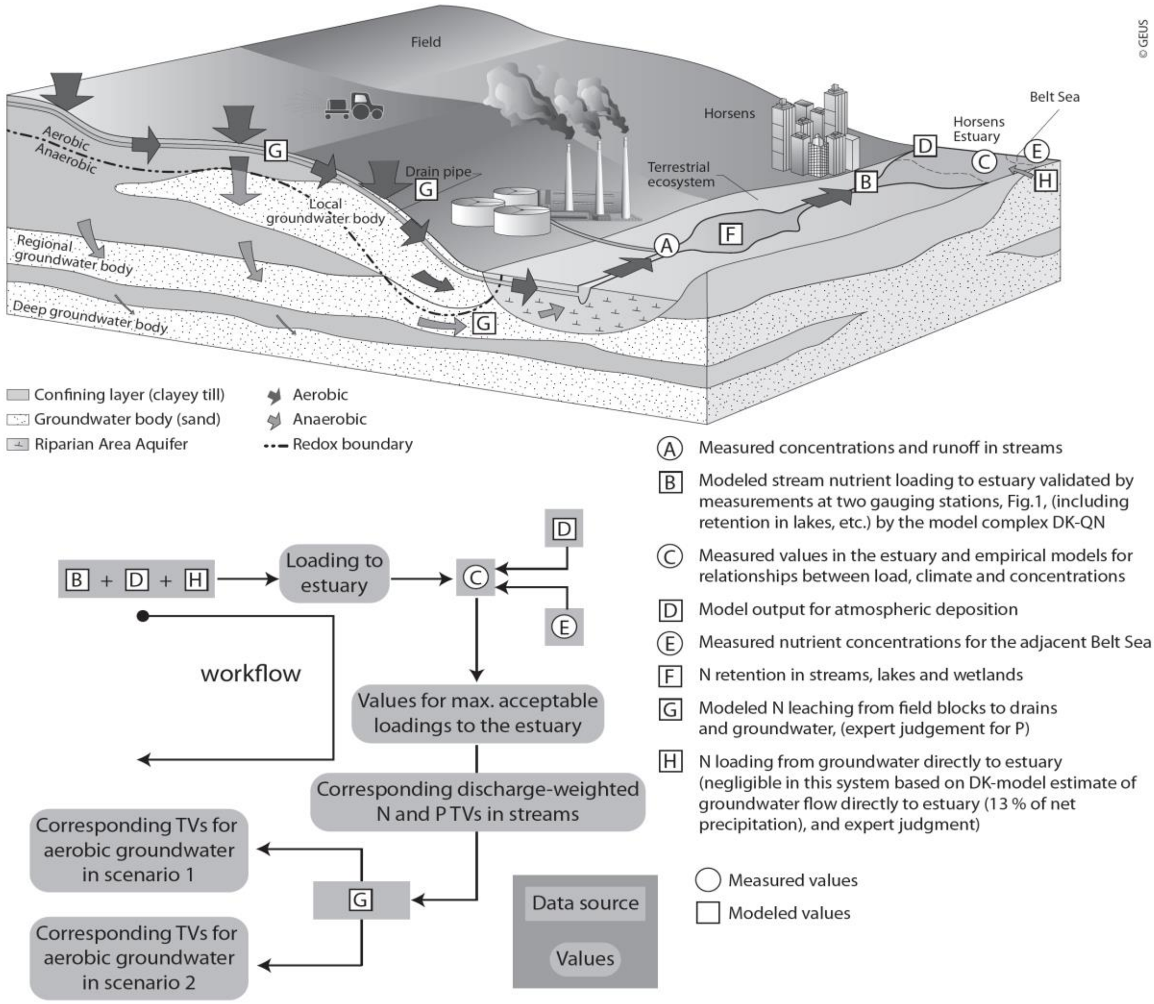

Figure 6.1: **Conceptual model of the catchment of Horsens estuary, Denmark**, with data and nutrient sources, showing the TV calculation process for streams and groundwater (Hinsby et al., 2012).

As described in the GWD and further elaborated in GD18*,* the derivation of groundwater TVs to protect GWAAEs may be performed at scales from relatively small lakes at local scale to coastal and marine waters at large transboundary scales. In many cases, GWAAEs will be the most vulnerable receptors in the investigated river basin, and the acceptable mean concentrations in and the total loadings to the GWAAE will have to be used in the derivation of a corresponding groundwater TV for the relevant pollutant.

As GWB TVs have to protect the specific needs of GWAAEs, the ecological requirements of GWAAEs are the starting point for developing these TVs. Their derivation requires close collaboration between hydro(geo)logists and ecologists in order to understand and quantify the interactions between groundwater and surface water (Figure 6.1). This quantification is essential for estimating, for example, the maximum acceptable loading (ecological threshold) of a specific nutrient to an ecosystem, which may be the basis for deriving a TV. An example of the GWAAE monitoring data required for estimation of a GWAAE threshold for an estuary is shown in Figure 6.2.

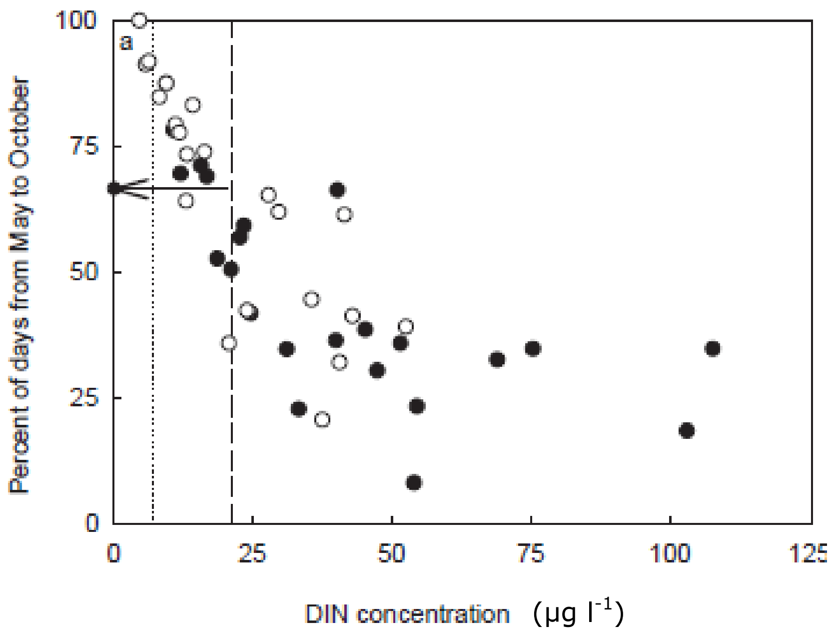

Figure 6.2: Relationship between mean concentration and percent of days with limitation for inorganic nitrogen, DIN. Calculated annually from 1985 to 2006 for Horsens estuary, Denmark; filled circles (inner part), open circles (outer part), respectively. The calculations are performed on data from May to October (184 days), and limitation is assumed to occur when DIN < 14 µg l−1. The vertical dashed lines indicate when limitations occur for 2/3 of the time, and the corresponding concentrations (DIN 21 µg l−1) are considered the target values for good ecological status of the estuary. The vertical dotted line is the resulting DIN concentration for the outer part of the estuary with an annual N load of 560 t yr−1. Hinsby et al. (2012).

Example process for deriving a GWAAE TV:

a. Define maximum allowable concentration in the GWAAE (and at what time of the year for example monthly or seasonal averages);
b. Calculate existing and maximum acceptable loading to the GWAAE (from groundwater and surface water sources);
c. Assuming all other loads are constant, calculate load coming from the groundwater;
d. Convert GW derived load into a concentration in the groundwater = TV.

Recommendations

6.2: The development of TVs that are appropriate to protect GWAAE should be based upon knowledge of the ecological needs of the GWAAE and the conceptual interlinkage between the GWB and the GWAAE.

6.3: GWAAE ecologists, hydrogeologists and hydrologists should work together and communicate at each phase of the development of the TVs.

6.3 Examples of TV derivation and application for the protection of GWAAEs

Member State examples

Based on the questionnaire on TVs sent to all Member States (European Commission, 2015b), very few examples exist where groundwater TVs have been derived based on the objectives for GWAAEs. Generally, Member States report that the data for deriving groundwater TVs for the protection of GWAAEs are not available, and they either use drinking water standards (DWS) or environmental quality standards (EQS) for surface water, in some cases multiplied by a factor less than one (e.g. 0.75) as a precautionary safety factor. The surface water EQS normally applies to a whole SWB and not only to the GWAAE. However, the specific needs of the GWAAE could be more stringent than the wider needs of the whole SWB.

Member states have however extensively used quantitative standards to protect GWAAE, such as base-flow in rivers. It is recommended that this approach, where a GWAAE is at risk, is extended to other SWB categories such as lakes and transitional or coastal water bodies.

Annex 1 to this report presents two case studies, one from the UK and a second from Belgium (Wallonia).

Research examples

Similarly, there are only a few examples in the scientific journals on derivation of groundwater TVs (or other groundwater quality standards) for protection of GWAAEs according to the WFD and GWD (Hinsby et al., 2008, 2012, 2015), based on literature searches in Web of Science and Scopus. The reason is most probably that the derivation requires a large amount of monitoring data in time and space from groundwater, rivers and coastal waters (or lakes), insight into both quantitative and chemical aspects of the hydrological cycle, as well as a sound understanding of ecosystem status and dynamics (see Figure 6.1), and hence close collaboration and transdisciplinary research between hydrogeologists, hydrologists and freshwater/marine ecologists.

No other examples for groundwater TVs or similar groundwater quality standards were found in a global search. However, the USA approach using estimated total maximum daily loads (TMDLs) to ecosystems (e.g. Bjorneberg et al., 2015, Reuben and Sorensen, 2014, Paolisso et al, 2015, US EPA, 2015) is based on similar philosophy/reasoning to the protection and status assessment of freshwater and ecosystems. This may be used to derive groundwater as well as stream threshold values comparable to the European examples. The approach used to derive WFD/GWD threshold values based on good status objectives and acceptable maximum loadings ("TMDLs") for two Danish estuaries, described in Hinsby et al. (2008, 2012, 2015), is comparable to the American TMDL approach. Groundwater and stream thresholds may also be used to introduce new and differentiated regulation and land use management strategies as described in section 6.1.

7 STATUS ASSESSMENT

7.1 Background

The achievement of good status in groundwater involves meeting a series of conditions, which are defined in the WFD/GWD. GWAAE are those SWBs, including rivers, standing waters and transitional waters where the surface water ecology and hydrology is dependent on contributions from groundwater in order to meet its environmental objectives under the WFD. The environmental objectives of these SWBs may vary, and therefore the associated EQS or flow / level requirements of GWAAEs may differ between high status and good status SWBs.

The WFD defines groundwater as "all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil". GWAAEs by their nature may receive contributions from "deep" or shallow "top of the rock" groundwater, or in many instances both. Therefore, consideration should be given to both the deep and the shallow groundwater flow that may be contributing to the associated SWB when undertaking the GWAAE status test. The understanding of these flows and interactions are important considerations when developing conceptual models for GWAAEs (see chapters 2.3 and 4).

The definition of **good groundwater quantitative status** is set out in WFD Annex V 2.1.2. As noted in this Annex, in relation to GWAAE, good groundwater quantitative status is achieved when the level of groundwater is not subject to anthropogenic alterations such as would result in:

- *failure to achieve the environmental objectives specified under Article 4 for associated surface waters; or*
- *any significant diminution in the status of such waters*.

The definition of **good groundwater chemical status** is set out in WFD Annex V 2.3.2. In relation to GWAAE, it states that this is achieved when the chemical composition of the GWB is such that the concentrations of pollutants:

- *are not such as would result in failure to achieve the environmental objectives specified under Article 4 for associated surface waters nor any significant diminution of the ecological or chemical quality of such bodies nor in any significant damage to terrestrial ecosystems which depend directly on the groundwater body.*

In order to assess whether those conditions have been met, five chemical and four quantitative tests were identified in CIS GD18 (Groundwater Status and Trend Assessment). Two of the tests, one chemical and one quantitative, relate to the contribution of groundwater chemistry or groundwater abstractions to the failure of WFD Article 4 objectives of associated SWBs.

"In accordance with the GWD, status assessment only needs to be carried out for groundwater bodies identified as being at risk and in relation to the receptor and each of the pollutants which contribute to the GWB being so characterised (Annex III 1 GWD). Groundwater bodies not at risk are automatically classified as being of good status" (CIS GD18).

"Status assessment is carried out using available surveillance and operational monitoring data collected during the period of the RBMP. It has to be performed at the end of a

RBMP in order to reflect on the effectiveness of the programmes of measures previously established" (CIS GD18).

Although a SWB may be small, relative to the associated GWBs, failure of the GWAAE test (like its GWDTE test counterpart) is sufficient to cause a whole GWB to be at poor status. There may be multiple pressures that are causing a SWB to fail to meet its WFD objectives, but the common agreed approach in GD18 is that where groundwater is contributing greater than 50% of the chemical load or groundwater abstractions are greater than 50% of the allowable groundwater abstraction to a SWB that is failing its WFD environmental objectives then the GWB should be considered to be of poor status. However, it is recognised that other approaches may be more suitable to a specific MS and GWAAE.

7.2 Quantitative Status

Annex V of the WFD indicates that groundwater level should be the principal parameter for assessing good quantitative status. However, to properly understand Groundwater/GWAAE relationships, other information, such as groundwater flow and contribution to the GWAAE, will generally be required to inform the status assessment.

Unlike the water balance test, the GWAAE test considers whether, at a local scale, the pressures from groundwater abstraction are having a significant effect on individual SWBs once all the different pressures on these are taken into account. By definition, where a groundwater abstraction can significantly contribute to the failure of an associated SWB, then it is appropriate to undertake the GWAAE test. A GWB may potentially contain many different SWBs, each with their own objectives.

This test requires the identification of the flow (flow) or water level (e-level) requirements (see CIS Guidance no. 31 on Ecological Flows) of SWBs to ensure that these water bodies achieve their WFD objectives. By definition, if this flow/level requirement is not being met as a result of a significant impact from groundwater abstraction, the SWB will not achieve its WFD objectives and then the GWB will be of poor status.

Given the challenge of directly linking groundwater abstractions to the flow/level in the SWB, a modelling approach, based on conceptual understanding, is suggested to estimate the component of surface water failure caused by the groundwater abstraction. "*A suggested threshold for significance of groundwater abstractions could be where the groundwater abstractions are greater than 50% of the "allowable" groundwater abstraction within the total upstream catchment*" (CIS GD18). The definition of what is allowable will vary depending on overarching water abstraction management practices, taking account of Eflow, e-level and socio-economic requirements. In stressed systems the allowable volume for groundwater abstraction may be a small fraction of effective rainfall or recharge, but may be a larger proportion of effective rainfall or recharge in systems that have few quantitative issues.

One of the key challenges identified by Member States during the second WFD reporting cycle was how to develop quantity criteria that would protect GWAAE, and how these criteria link to exisiting surface water flow criteria such as river flow or lake level standards. As an interim measure broad consideration of low flow conditions (e.g. 95%ile flow), or a fraction of annual recharge or effective rainfall could be taken as surrogates as the minimum flow to be maintained during a critical time of the year (for the GWAAE) or maximum percentage of groundwater that could be abstracted in the upgradient catchment. We recommend that time specific (e.g. seasonal) sensitivities of the GWAAE are incorporated into flow criteria as soon as practically possible. Additionally, where there are records of shifting groundwater divides, reduced river flows or lake levels and/or ecological impacts that are not attributed to pressures other than groundwater abstractions in the catchment, then additional characterisation of these SWB catchments could be undertaken. This would enable the development of Eflow and e-level standards, associated abstraction management regimes and groundwater level standards.

7.3 Chemical Status

With regard to chemical status, Annex III 2(c) of the GWD states that:

"*Member States will take into account […] (c) any other relevant information including a comparison of the annual arithmetic mean concentration of the relevant pollutants at a monitoring point with the groundwater quality standards […] and the threshold values […]."Consequently the annual arithmetic mean concentration of a pollutant, that is relevant to the failure of a GWAAE, should be compared to the relevant water quality standard or threshold value, at an operational or surveillance monitoring point within the groundwater body, or group of groundwater bodies associated with the GWAAE*.

Consequently, a GWAAE chemical status assessment is triggered if:

- an associated SWB is failing to achieve its environmental objectives and the failure is not due to point source discharges (e.g. piped discharges) or other elements such as invasive species or hydromorphology i.e. the suspected cause is diffuse pollution; **and**
- groundwater is a significant pathway through which diffuse pollution can reach the SWB i.e. by definition these SWBs are GWAAE; **and**
- the groundwater quality standard(s) and/or TV(s) associated with the failing pollutant in the SWB are exceeded in a surveillance or operational groundwater monitoring point in the GWB or group of GWBs associated with the SWB.

The test is designed to determine whether the transfer of pollutants from groundwater to surface water or any consequent impact on surface water ecology or chemistry is sufficient to threaten the WFD objectives for these associated SWBs. Therefore, where an EQS failure is not identified, but an ecological failure occurs and the suspected cause of failure is diffuse in nature, then the GWAAE test may still be undertaken, using groundwater quality standards or TVs that are reflective of diffuse pressures in the catchment to the failing SWB.

Note: Consideration should also be given to the natural background quality of the groundwater discharging to the associated SWB(s) as the perceived impacts on surface water may simply be a reflection of the natural groundwater quality. This should be flagged with those responsible for surface water classification.

Where a GWB is identified as potentially being a significant contributor to a SWB then the groundwater load/flux to the SWB should be estimated. This estimate should consider the GWB contribution to the SWB catchment e.g. using baseflow indices, hydrograph separation, groundwater recharge estimates etc.

A GWB is at good status for this test if no monitoring points in the GWB or group of GWBs exceed the groundwater quality standard or TV for the relevant pollutant. Thereafter, if the concentration exceeds the groundwater quality standard or TV for the relevant pollutant (or inferred pollutant in the case of an ecological failure), causing the failure in the SWB, then the mean concentration for the associated GWBs could be estimated using:

- surveillance or operational monitoring data in close proximity to the SWB, in particular where impacts from groundwater are confined to discrete reaches along the SWB, that would be representative of groundwater discharging to the SWB;
- aggregated data from surveillance or operational monitoring in GWBs or groups of GWBs associated with the failing SWB.

Where elaborate catchment models are not available, dilution factors can be derived from simple indices such as baseflow index or the ratio of groundwater recharge to effective precipitation. In these instances, the following formula can be used:

$$\text{Threshold Value} = 0.5 \times \frac{\text{Surface Water Quality Standard}}{\text{Dilution factor}}$$

Where the dilution factor is normally in the range between 0.1 and 0.9

For standing waters, the relevant value can be calculated from the estimated groundwater input at the surface water outlet. For transitional waters, the value can be calculated from the estimated groundwater input at the tidal limit. Increased levels of confidence can be built into the assessment if dilution and attenuation factors e.g. in the hyporheic zone are known.

8 RECOMMENDATIONS

A number of recommendations are noted in the preceding chapters of the report, from which several common themes may be identified. These highlight the need to:

1. Promote and improve joint working and interaction between scientific disciplines. Hydrogeologists and surface water hydrologists and ecologists need to interact throughout GWAAE identification, characterisation and status assessment; where Natura 2000 sites are involved, Nature conservation staff should be consulted.

2. Share current practices and methods for GWAAEs on:
    a. Identification (what are GWAAE and where are they);
    b. Risk assessment/characterization;
    c. Monitoring;
    d. Data, development and defined TVs and CVs for protection of GWAAEs.

3. Ensure that WGGW and other working groups work together to develop a EU common approach/conceptual methodology for GWAAE identification, needs assessment and protection under the WFD. More specifically, WGGW should work with surface water WGs (such as ECOSTAT) and with the EU DG ENV Nature conservation colleagues to develop a common framework for assessing the needs of individual GWAAE, so that the outcomes of these assessments can be analysed in a coherent fashion and used across the EU. We recognise that the specific situations and needs of individual GWAAE will vary because of local conditions, such as hydrological variations, but feel that a common framework would assist consistent assessment and decision making.

The above issues should be considered in the future work of WGGW in the next period. The mechanisms and identification of the lead organisations to facilitate the recommended actions above will be key questions for WGGW, in terms of principles, and Member States, in terms of local action. The last point (3) in particular is a matter that merits referral to the WFD Strategic Coordination Group with a request for SCG to support the exchange of information under the next work programme.

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Annex 1 : Case Studies

Case study 1: Poole Harbour, Dorset, Southern England

Type of study and key words
Status assessment using the GWAAE test *Groundwater, transitional waters, chemical status, nitrates, predictive modelling*
Background information
Poole Harbour is of international importance for its populations of wildfowl and wading birds (SPA), rare estuarine plants and invertebrates, wetland and ecological diversity (SAC). The harbour is directly dependent on outflow from an associated groundwater body (Figure 1) and is failing to meet Habitats Directive and WFD objectives due to elevated nitrate entering the harbour, causing the proliferation of macroalgae (seaweed).

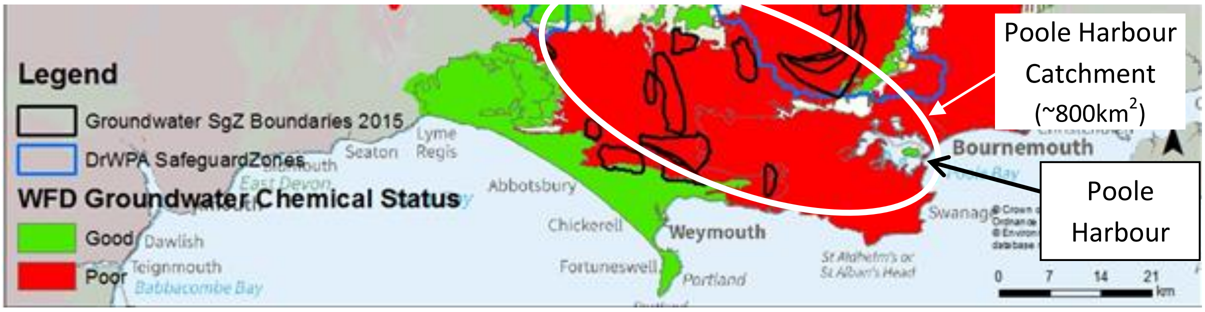


Figure 1: Poole Harbour catchment and groundwater body status

Case Study description

Nitrate concentrations within groundwater, rivers and the harbour have been rising rapidly over the last 50-60 years (Figures 2 and 3). From source apportionment, the key source of nitrogen is diffuse agriculture (Figure 4). Because of the permeable nature of the catchment, nitrogen entering the harbour is largely transported via groundwater pathways before discharging as baseflow to the Rivers Frome and Piddle (BFI of 85% & 89% respectively) and then to the harbour. The average age of groundwater baseflow to the Poole Harbour catchment is 30 years; nitrates leaching from the soil zone in 2015 will not appear in the Frome & Piddle/harbour until 2045.

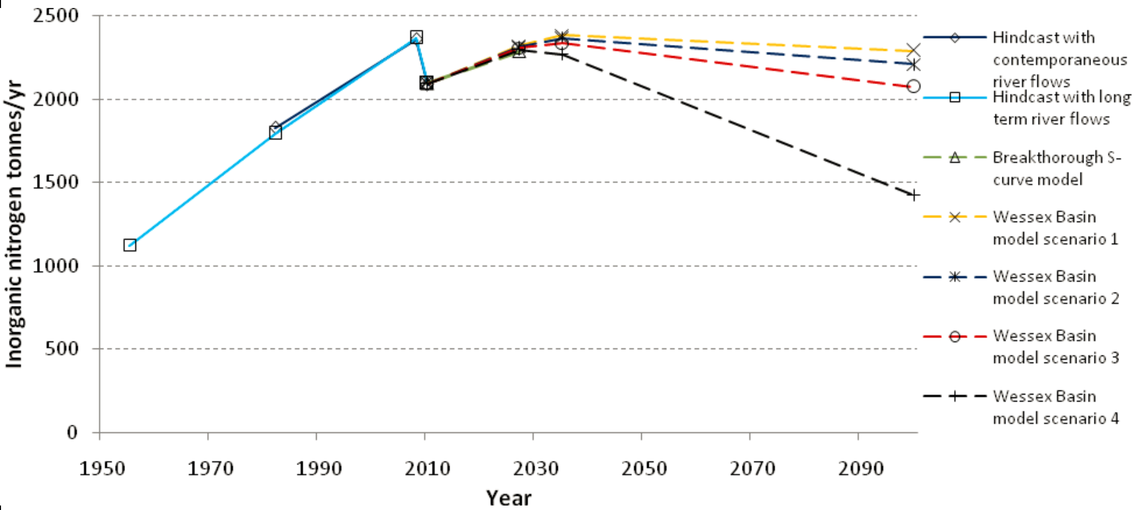


Figure 2 : Modelled trends in inorganic nitrogen loads to Poole Harbour for 4 agricultural nitrate leaching scenarios (1 - do nothing; 2 – current NVZ AP measures; 3.- „best case" management measures; 4 – 50% catchment conversion to woodland or similar).

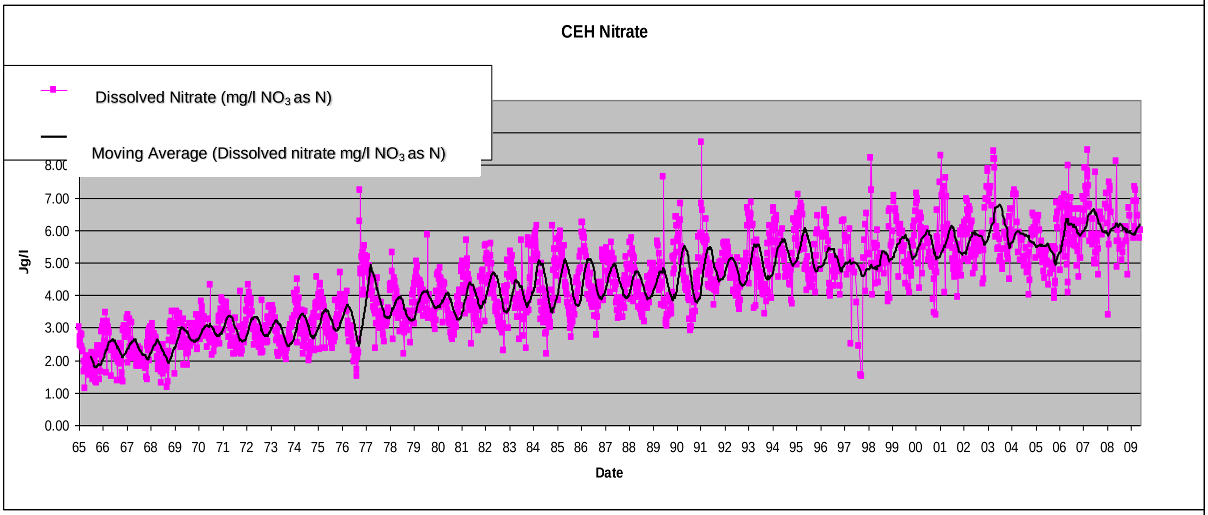


Figure 3 : Water Quality for the River Frome at East Stoke (Database rights/copyright NERC – Centre for Ecology & Hydrology & FBA (Freshwater Biological Association).

Groundwater modelling indicates that the nitrate load entering the harbour will continue to rise between 2015 and 2025, before stabilising and potentially dropping slightly (Figure 5). This trend results from the intensification in agriculture that started during the 1940s and 50s, with peak nitrogen application rates occurring in the late 1980's and early 1990's, and also the delay in this nitrate as it moves along the groundwater pathway.

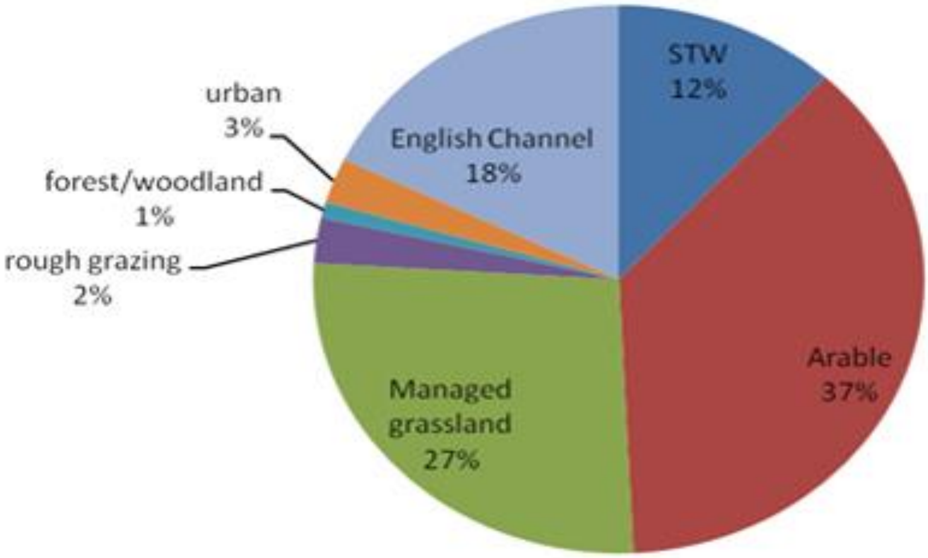


Figure 4 : Source Apportionment for Poole Harbour Catchment.

Forward prediction based on repeating water levels and rainfall from 1992 to 2006

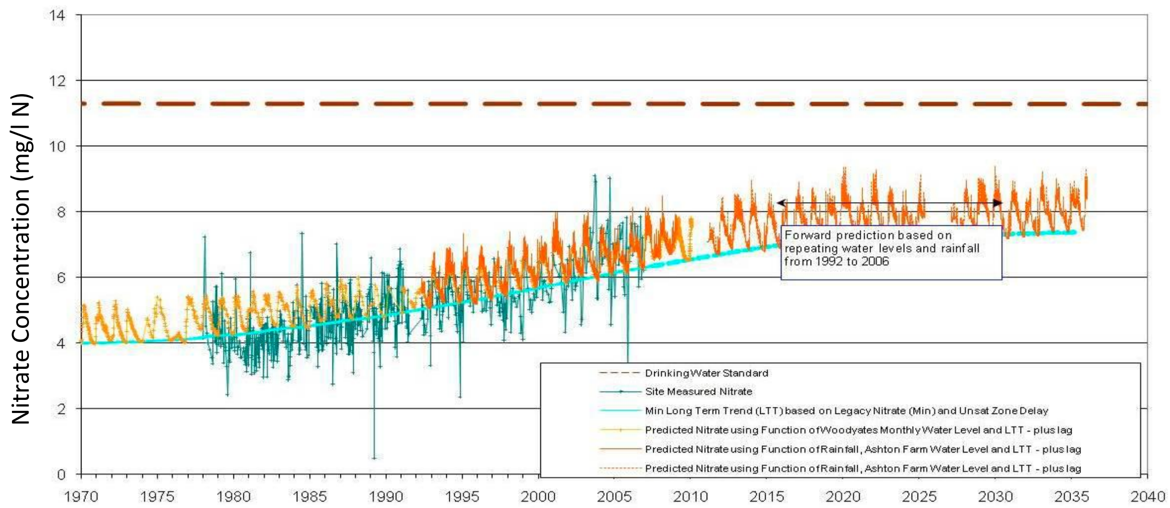


Figure 5. Wessex Basin modelled (orange line) and observed (blue line) nitrate concentrations and baseline trend (thick blue line) for the River Frome at Bockhampton

Assessing groundwater body status

The first step was to calculate the total nitrogen load supplied by all groundwater bodies feeding into Poole Harbour. Then the nitrogen loading needed to put the Poole Harbour transitional water body into poor status was calculated. By comparison it was concluded that the groundwater bodies flowing into Poole Harbour via surface water contributed in total more than 50% of the load needed to put this transitional water body at poor status.

Conclusions

Poole Harbour has failed to achieve good status because of eutrophication. The groundwater bodies supplying Poole Harbour have also failed the GWAAE test and hence are at poor chemical status as a result of nitrate impacts on the harbour.

The findings of the investigation and recommended measures to achieve good status are summarised in the "Strategy for Managing Nitrogen Across the Poole Harbour Catchment" and can be found at the web link noted below. These measures will ensure that diffuse agricultural loads are reduced by around 550 N tonnes/yr, which will ensure that future development and population growth does not increase nitrogen loads in the harbour.

References/key outputs/other web links

http://webarchive.nationalarchives.gov.uk/20140328084622/http://www.environment-agency.gov.uk/research/library/publications/148450.aspx

https://www.wessexwater.co.uk/About-us/Environment/Catchment-management/Poole-Harbour-Catchment-Initiative/

Case Study 2: Groundwater – surface water interaction in limestone areas of the GWB BE_Meuse_RWM021 (Belgium)

Type of case study and key words

Characterisation of a GWAAE

Characterisation, baseflow, macroinvertebrates, diatoms, monitoring, abstraction impacts

Background information

The '*characterisation of water bodies whose status depends on groundwater and surface water interactions*' project, was led by hydrogeologists, freshwater ecologists and agronomists for the Public service (Department of Water and Environment) of the Walloon Region of Belgium.

The Carboniferous aquifers of the Condroz region (central Wallonia), are important groundwater reservoirs that are subject to significant quantity (groundwater abstraction) and quality (mainly nitrate from agriculture) pressures. Draining rivers host fragile GWAAE, such as biological travertines (Fig.1) and other freshwater ecosystems, particularly in the Hoyoux (MV07R) and Triffoy (MV08R) rivers. Detailed investigation (Fig.2) over two years characterized (1) GW – river interactions and their impact on GWAAE and (2) the transfer of nitrate in the soil – GW – river continuum.

Fig. 1 : Travertine fall in the Triffoy River

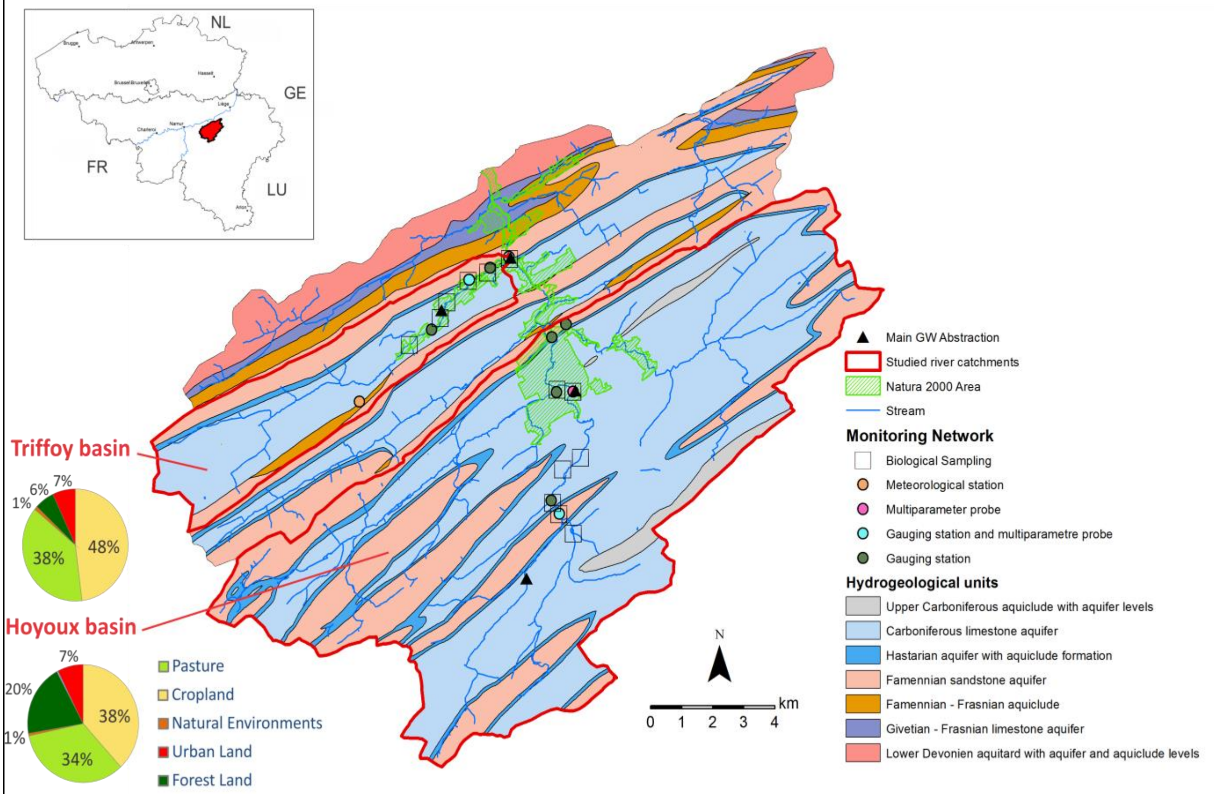


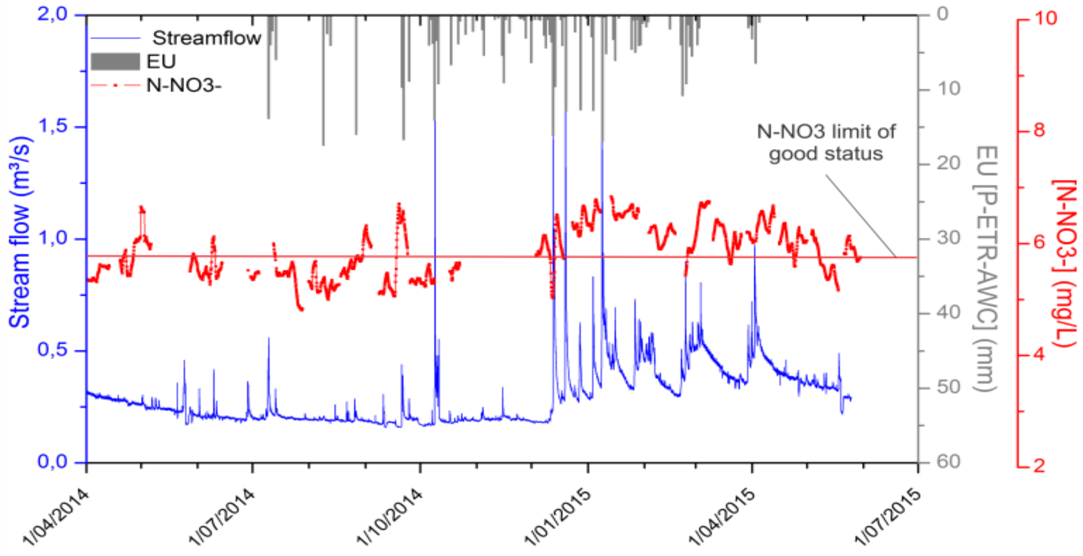
Fig. 2 : Studied areas

Case Study description

The two rivers are characterized by very high base flow index (BFI=0.92-0.87) and significant groundwater abstraction (I_{GWA}=0.56-0.48) (see table below). Nitrate concentrations are relatively constant throughout the year, close to the limit of good status (Fig.3). However, during the winter, these concentrations increase temporarily and exceed the limit in rivers due to leaching of agricultural soil nitrate residue by infiltrating water.

From September 2013 to August 2014			**Hoyoux**	**Triffoy**
Climatic parameters	Annual precipitation	*P mm (%)*	897 *(100)*	
	Evapotranspiration	*ETR mm (%)*	612 *(68)*	
	Soil Available Water Content variation	*SAWC mm (%)*	67.2 *(7.5)*	
	EU = P – ETR - SAWC	*EU mm (%)*	217.4 *(24.5)*	
Basin parameters	Surface	*S (km²)*	145.2	30.5
	Abstracted GW	*Qa mm (%)*	163.4 *(18)*	117.9 *(13)*
	River flow	*Qt mm (%)*	127.1 *(14)*	129.2 *(14)*
	Base flow	*Qb mm (%)*	116.3 *(13)*	112 *(12)*
	Annual variation of GW reserves	*Δres mm (%)*	-21 *(-2)*	-12 *(-1)*
	GW budget closure (including interbasin GW flow)	*ε mm (%)*	-51 *(-6)*	-17 *(-2)*
	Infiltration (EU-(Q_t-Q_b))	*I mm (%)*	206.6 *(23)*	200.2 *(22)*
Indicators	Base flow index (Q_b/Q_t)	*BFI*	0.92	0.87
	Infiltration index (I/EU)	I_{ESO}	0.95	0.92
	GW Abstraction index (Q_a/(Q_t+Q_a))	I_{GWA}	0.56	0.48

Macroinvertebrates and benthic diatoms were sampled at several sites to assess ecological status and response to alterations in water quality (nutrient enrichment) and quantity (current velocity and stream habitats). Monitoring of pH and dissolved oxygen showed typical daily variations due to ecosystem metabolism, suggesting that natural ecosystem function has not been impaired in the studied streams. The analysis of the streams' biological communities revealed a contrasting response of macro-invertebrates and benthic diatoms. Biotic indices based on benthic macroinvertebrates confirmed good ecological status except in one site. A detailed functional analysis of the macrobenthic assemblage at this site revealed a low taxonomic, biological and ecological diversity related to low current velocities allowing sedimentation and accumulation of particulate organic matter. Diatom indices and community structure indicated good to very good status in both streams, indicating that elevated nitrate concentrations have no detectable effect on their biological quality.



Conclusions

The results highlight the need to consider the possible influence of groundwater abstraction on stream hydromorphology in karstic watersheds, as well as nutrient inputs to surface waters. The study also demonstrates that the analysis of the biological and ecological traits of benthic macroinvertebrates is an adequate tool for detecting the response of aquatic communities to alteration of stream flow resulting from groundwater and surface water interactions.

Data mining of existing databases is needed to further explore the effects of nutrient enrichment (N vs. P) on biological indicators (diatoms in particular), as well as establishing relationships between hydrological variables on hydromorphological status in streams. This will support the development of predictive models to assess the effects of reduced baseflow on benthic assemblages (relevant to the e-flow). Specific conductance monitoring has improved understanding of the system as it reflects mineralization of watershed and groundwater discharge to the stream and has allowed more accurate hydrograph separation and base flow index computation.

To improve knowledge, all strategical monitoring systems (gauging stations with conductivity probes, frequent groundwater and surface water sampling) will be sustained in the mid to long term. Monitoring water quality at high temporal resolution in streams can be implemented if frequent sensor calibration is ensured: it is an adequate tool to assess ecosystem metabolism. However, nitrate concentration could be monitored once daily to study the influence of groundwater and other inputs from the catchment.

The presence of travertines in the studied streams raises a conservation issue, as these Natura 2000 biotopes are sensitive to eutrophication and to reduction of flow due to water abstraction. To some extent, this issue is related to the ecological flow (CIS guidance document Nº31).

References/key outputs/other web links

All results of the studies are available on the website of the project : http://goo.gl/5lLVGA or http://www.facsa.ulg.ac.be/upload/docs/application/pdf/2015-10/characterisation_of_water_bodies_whose_status_depends_on_groundwater_and_surface_water_interactions.pdf

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