METHODOLOGY FOR ESTABLISHING GROUNDWATER THRESHOLD VALUES AND THE ASSESSMENT OF CHEMICAL AND QUANTITATIVE STATUS OF GROUNDWATER, INCLUDING AN ASSESSMENT OF POLLUTION TRENDS AND TREND REVERSAL

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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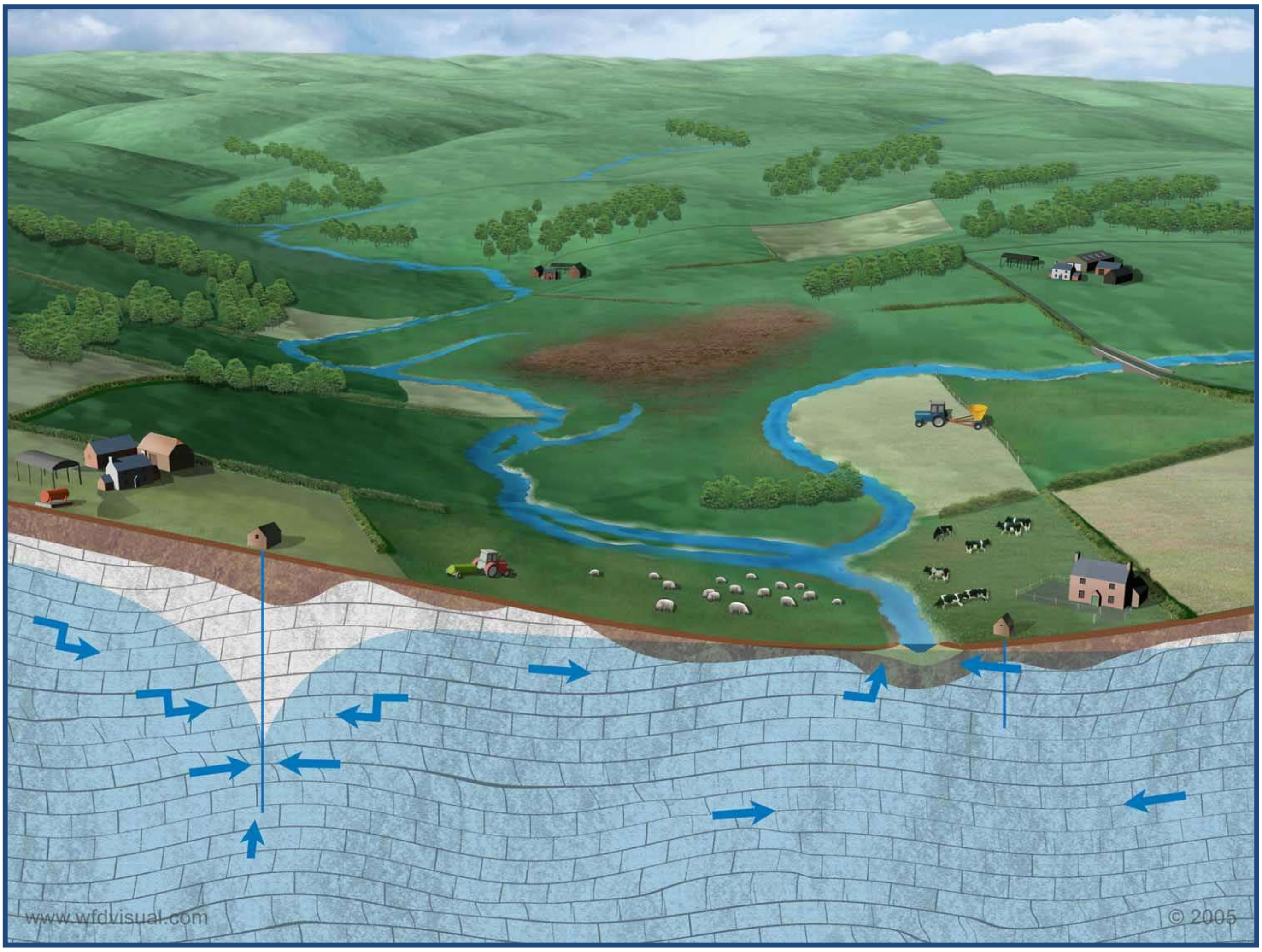

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Contents

1 Introduction

The European Communities Environmental Objectives (Groundwater) Regulations, 2010 (S.I. 9 of 2010), as amended, (hereafter referred to as the “Regulations") have established a strengthened regime for the protection of groundwater in line with the requirements of the Water Framework Directive (2000/60/EC) and the Groundwater Directive (2006/118/EC) (hereafter referred to as the “Directive”).

Parts (IV) – (VI) of the Regulations identify the Environmental Protection Agency (EPA) as the responsible body for establishing and maintaining a list of Threshold Values (TVs) for pollutants in groundwater, assessing the chemical and quantitative status of groundwater bodies and undertaking pollutant trend and trend reversal assessments.

Under Regulations 48–52, the Environmental Protection Agency is required to establish, and where appropriate maintain and update, a list of TVs for pollutants in groundwater. Threshold Values only have to be derived for pollutants placing a groundwater body at risk of failing to achieve a Water Framework Directive (WFD) objective. The values are used as triggers to help determine whether the conditions for good chemical status are being met.

Regulations 33–44 identify the conditions for assessing groundwater body status. The achievement of good groundwater status involves meeting this series of conditions, which are designed to satisfy the criteria defined in the WFD and the Groundwater Directive. In order to assess whether these conditions are being met, a series of tests has been prescribed for each of the quality elements defining good (chemical and quantitative) groundwater status.

There are five chemical and four quantitative tests (Figure 1). Each test is applied independently, and the results are combined to give an overall assessment of groundwater body chemical and quantitative status. The worst-case classification from the relevant chemical status tests is reported as the overall chemical status for the groundwater body, and the worst-case classification of the quantitative tests is reported as the overall quantitative status for the groundwater body. The worst result of the chemical and quantitative assessments is reported as the overall groundwater body status.

For transboundary groundwater bodies between the Republic of Ireland and Northern Ireland, groundwater monitoring data and status information, made available from the Northern Ireland Environment Agency (NIEA), are incorporated into the relevant chemical and quantitative test to determine the overall groundwater body status.

Part VI of the Regulations indicates that the Environmental Protection Agency shall undertake an assessment of pollution trends. This includes the identification of significant and sustained upward trends in the concentration of pollutants in groundwater bodies or groups of groundwater bodies identified as being at risk of failing to achieve the objectives of the WFD. Where necessary, the Environmental Protection Agency should undertake an assessment of trends to verify that plumes from contaminated sites do not expand to such an extent that they put a groundwater body at poor status.

The Environmental Protection Agency must also identify the starting point for trend reversal. The starting point for trend reversal is to be expressed as a percentage of the relevant groundwater quality standard or TV. The start date for trend reversal is based on the significance of the trend and the risk associated with failing an objective of the WFD.

The assessment of trends in groundwater pollutant concentrations is also required in two of the chemical status assessments. For the Drinking Water Protected Area and Saline Intrusion tests, trend assessments are required, on a case-by-case basis, where TVs have been exceeded for one or more pollutants.

The classification assessments generally follow the procedures set out in the following documents:

- EU Guidance Document No. 18: Guidance on Groundwater Status and Trends (EC, 2009);
- UKTAG Paper 11b(i): Groundwater Chemical Classification for the purposes of the Water Framework Directive and the Groundwater Daughter Directive (UKTAG, 2012a);
- UKTAG Paper 11b(ii): Groundwater Quantitative Classification for the purposes of the Water Framework Directive (UKTAG, 2012b); and,
- UKTAG Guidance on Groundwater Trend Assessments (UKTAG, 2012c).

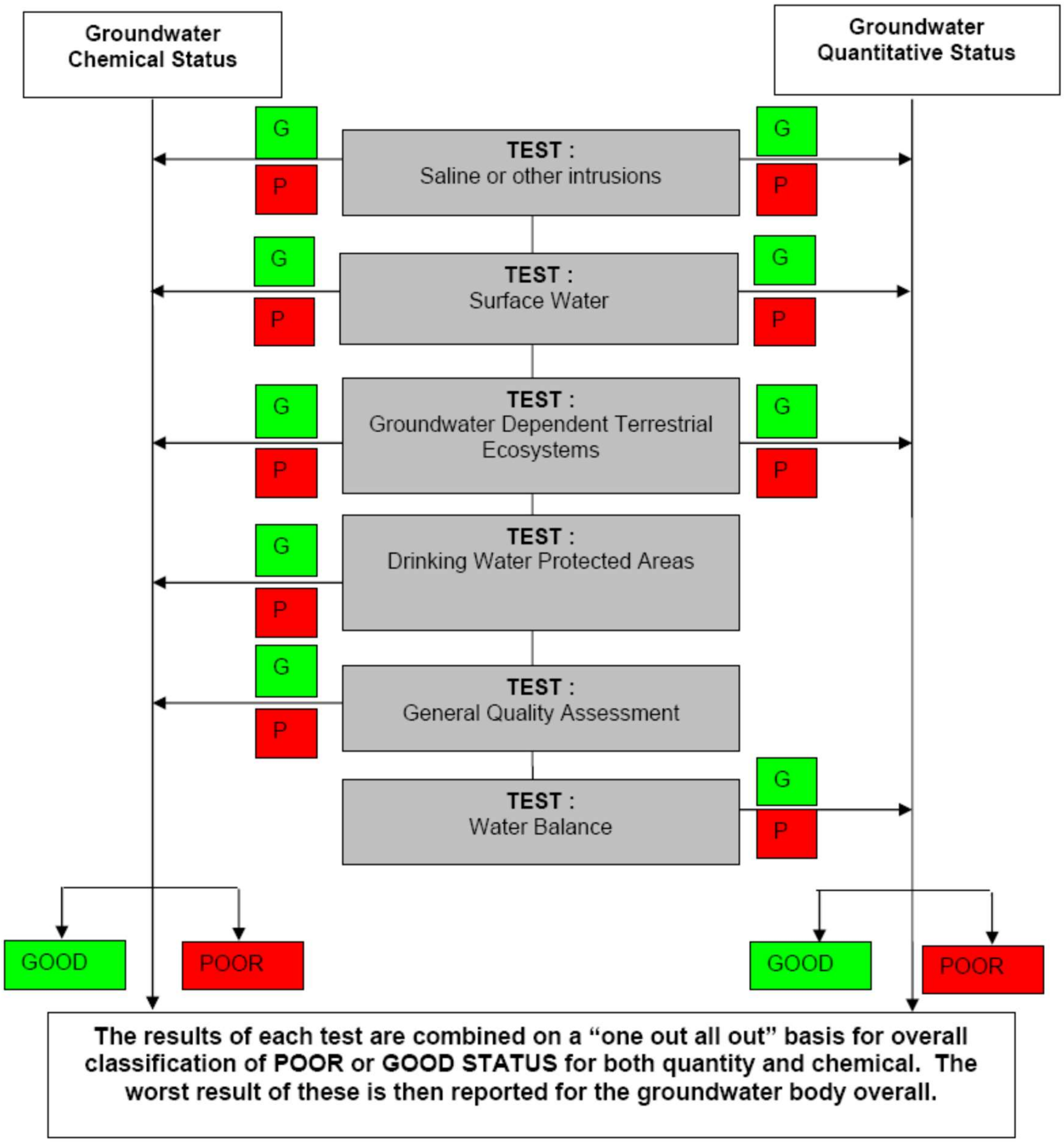

Figure 1 Overview of the status assessment (Classification) process (UKTAG, 2012a)

The results of chemical status, quantitative status, overall status and trend assessments are reported in the River Basin Management Plan, based on a single national River Basin District. The report is based on six-years of data and is available on the Catchments.ie website (https://www.catchments.ie/).

Regulation 58 places a duty on the Environmental Protection Agency to prepare and publish a detailed technical report containing:

a) *The methods and procedures used to assign groundwater quantitative status;*
b) *The methods and procedures used to assign groundwater chemical status;*
c) *All Threshold Values established for all bodies or groups of bodies of groundwater, together with a summary of the information regarding the relevant pollutants and their indicators;*
d) *The methods and procedures used to identify those bodies which are subject to a significant and sustained upward trend in concentration of any pollutant, or which are showing a reversal of that trend, and how trend assessment from individual monitoring points within a body or a group of bodies of groundwater has contributed to this identification;*
e) *The reasons for the starting points for pollution trend reversal;*
f) *Where undertaken by the Agency and other parties, the results of the additional monitoring and trend assessments for identified pollutants used to verify that plumes from contaminated sites do not expand, do not cause the chemical status of the body or group of bodies of groundwater to deteriorate and do not present a risk to human health and the environment.*

Section 2 of this report provides information on the establishment of TVs and how they are used in the chemical status assessments. Sections 3 and 4 document the methods and procedures used to assess the chemical and quantitative status of groundwater bodies. Finally, information on the methods and procedures used to assess pollution trends and trend reversal is provided in Section 5.

2 Threshold Values

Threshold Values are groundwater quality standards established by each Member State for the purpose of assessing the chemical status of groundwater bodies[1]. Threshold Values are also used when undertaking trend assessments. They can be set nationally or on a local groundwater body scale. They are triggers, such that their exceedance prompts further investigation to determine whether the conditions for Good Status have been met. As such, they do not represent the boundary between good and poor status.

Regulation 40 states that when assessing chemical status, the groundwater quality standards for nitrates and pesticides, prescribed in the Directive, shall be used. However, Schedule 4 of the Regulations indicates that more stringent TVs may be required for nitrates and pesticides to ensure the requirements of other Directives are met. In addition, TVs are required for other pollutants that have been identified as contributing to the characterisation of groundwater bodies being at risk of failing to achieve a WFD objective. Schedule 2 of the Regulations provides the indicative list of pollutants that need to be considered when setting TVs.

The groundwater quality standards prescribed for nitrate and pesticides are used in the assessment process in the same way. However, if all standards and TVs are met at all monitoring points in the National Groundwater Monitoring Network then, under Regulation 43(a), the groundwater body is considered to be at Good Status and no further investigation is necessary.

The TV for each status test must be appropriate to the receptor being considered for that test, e.g. an associated surface water body, a groundwater dependent terrestrial ecosystem (GWDTE) or groundwater that is used, or could be used, for drinking water supply. The way in which monitoring data are compared to the TVs during classification (i.e. whether data are aggregated across the groundwater body or used in isolation) varies between the individual classification tests. This is essential to ensure a reliable assessment of status. This is discussed further in Section 3.

2.1 Rationale for Threshold Values

Threshold Values only have to be derived for pollutants placing a groundwater body at risk of failing to achieve a WFD objective. In total there are five chemical status tests (see Figure 1), although in practice, the objectives of the Drinking Water Protected Areas and General Chemical tests are similar, in that they are both designed to assess the impact of pollutants on water that is used, or could potentially be used, for human consumption. The Surface Water Ecological/Chemical and GWDTE Chemical tests are also similar in nature, in that they are designed to assess the impact of pollutants on receptors associated with groundwater bodies.

2.2 Drinking Water Protected Areas and General Chemical Tests

Drinking water standards are expressed as maximum admissible concentrations (MACs), i.e. peak concentrations. Therefore, to ensure consistency, the assessment of groundwater in relation to drinking water criteria, i.e. for the Drinking Water Protected Area and General Chemical status tests, should also be made against peak concentrations. As groundwater quality monitoring programmes are not continuous, it is likely that peak concentrations in pollutants will be missed. Consequently, a statistical approach is required to take account of this. To ensure a consistent approach throughout classification, comparison of monitoring data against a standard or TV should be based upon a 95^{th} percentile or equivalent approach (UKTAG, 2012a).

However, groundwater quality data are often not collected frequently enough to derive statistically robust 95^{th} percentiles. If the 95^{th} percentile cannot be used, a suitable TV is required, against

[1] Whilst the standards and conditions that are applied to environmental permits should reflect the need to meet all WFD objectives, including good chemical status, these are not TVs.

which mean concentrations in the monitoring data can be compared with adequate confidence (UKTAG, 2012a). The outcome should, as far as possible, be equivalent to using a 95th percentile.

Where there are sufficient reliable monitoring data for each individual site, then the 95th percentile value is calculated and used as the TV. Where data are insufficient to calculate 95th percentiles for individual sites, the TV must be set so that, if the mean of a dataset is not exceeded, there is a reasonable expectation that the 95th percentile would not exceed the maximum admissible concentration, if those 95th percentiles could be calculated.

On this basis, the UKTAG guidance (2012a) proposes that where insufficient data are available to determine the 95th percentile, the TV should be set at a value of 75% of the relevant drinking water standard. This percentage has been selected because it takes into account the large variability in hydrogeological settings, potential temporal variability in parameter values and because it introduces what is believed to be an adequate degree of protection such that the risk of misclassification is acceptable. On this basis, 75% of the relevant drinking water standard is used to calculate the TV.

In general, the main pollutants (or indicators of pollution) that are putting groundwater bodies at risk of failing WFD objectives with regard to drinking water requirements are derived from agricultural pressures, point source pressures (e.g. landfill, contaminated land, urban pressures, discharges to groundwater) and mining. These pressures and pollutants are identified and updated at the beginning of each 6-year WFD cycle as part of the characterisation process (EPA, 2015).

The TVs for metals in the Groundwater Regulations are taken to be dissolved metals, whilst the Drinking Water Standards for metals are taken to be total metals. Although the TVs are derived from the Drinking Water Standards for metals, it should be recognised that the standards relate to different assessments. TVs have been derived for dissolved metals and not total metals because, from an environmental perspective, the dissolved fraction is a better representation of the biologically active portion of the metal when considering water going to rivers and springs. Most groundwater supplies are unfiltered because there is little sediment and in most instances the results of total and dissolved analysis in groundwater should be similar, if not the same. Therefore, while the TVs are based on Drinking Water Standards, from an environmental perspective the dissolved fraction is more representative than what is measured at the tap (which includes metals bound to sediment in the water supply network). The dissolved metal concentration should be similar to the total concentration in groundwater before it reaches the water supply network, and as such, it is a comparison of the dissolved metal concentration that should be made with the TV.

2.3 Surface Water Ecological/Chemical and GWDTE Chemical tests

In surface waters and wetlands, TVs are only required for those pollutants that are considered to be contributing to water quality problems and where a surface water Environmental Quality Standard (EQS) or wetland trigger action value has been established. As the associated receptor must be at less than Good Status, or have suffered ecological damage, the TV relates to the water quality standard or trigger action value that has caused the problem in the associated receptor.

The groundwater contribution to surface water bodies and wetlands varies because of differences in rainfall distribution, soil and subsoil type, aquifer type, hydraulic connectivity with the receptor etc. To ensure consistency in the status assessments, the TV is derived from the surface water EQS or wetland trigger action value. Thereafter, if the TV is exceeded at a monitoring point in the groundwater body, further investigation will consider the site-specific dilution and attenuation factors and the groundwater contribution to the associated receptor.

Surface Water EQSs have been established for rivers, lakes and transitional and coastal water bodies (S.I. 272 of 2009, as amended). Molybdate Reactive Phosphorus and Ammonium EQSs are two of the key pollution indicators that have been established for river water bodies. Molybdate Reactive Phosphorus is regarded as the key limiting nutrient that causes eutrophication in rivers.

Nitrogen (in relation to transitional and coastal waters), Total Phosphorus (in relation to lakes), metals (in relation to the impact of mines on surface water) and parameters relating to the impact of point sources on surface water bodies (e.g. metals, organics etc.) have also been considered when assessing the contribution of groundwater to surface water EQS exceedances.

2.4 Saline (or Other) Intrusions test

Schedule 6 (Part B) of the Groundwater Regulations indicates that, as a minimum, Electrical Conductivity TVs should be established where groundwater abstractions could potentially be causing saline intrusion. Other potential indicators of saline (or other) intrusions could be Chloride or Sulphate. The latter parameter is more indicative of deeper connate water intrusions, rather than coastal intrusions. As these parameters occur naturally in groundwater, the TVs are set at the Natural Background Level for these parameters, i.e. when concentrations are above the typical natural concentration, this will trigger further investigation. The Natural Background Levels for these parameters have been established in Ireland (Tedd *et. al.*, 2017).

Threshold Values were established for Chloride and Electrical Conductivity, as these parameters are both indicative of saline intrusion. A TV has not been established for Sulphate to date. However, as part of the status assessments, monitoring data is assessed for increasing trends in Sulphate that may indicate that this parameter is causing groundwater bodies to be at risk of failing to meet a WFD objective or abstractions are causing ingress of deeper connate water. If this occurs in the future, a TV value may need to be established for Sulphate.

2.5 Application of Threshold Values

Exceedance of a TV triggers further investigation, i.e. an assessment of whether the pollution is of sufficient magnitude to prevent the groundwater body achieving its status objectives under the WFD and is therefore not just causing a localised impact. This further investigation is undertaken as part of the status assessments, for example, to determine the pollutant loading from groundwater to surface water ecosystems.

Ultimately, it is only if the concentration of pollutants exceeds the TV and any supporting evidence confirms the presence of an impact that compromises the achievement of WFD status objectives, that the groundwater body is classified as Poor Status.

2.6 Reporting of Threshold Values

Threshold Values are listed in Schedule 5 of the Groundwater Regulations. In accordance with Regulation 48 of the Groundwater Regulations (as amended) if the Environmental Protection Agency wishes to amend the list of TVs in line with characterisation, it may do so by making recommendations to the Minister.

3 Chemical Status classification

An assessment of groundwater body status is required to comply with the Water Framework Directive (2000/60/EC) and the Groundwater Directive (2006/118/EC). Status assessments are required for all such groundwater bodies that are identified as being at risk and are undertaken at the end of every six-year river basin management planning (RBMP) cycle. The status assessments are used to generate a snapshot that shows the impacts of abstraction and pollution on groundwater. The risk assessments are undertaken to identify groundwater bodies that are at risk of failing to meet objectives of the Water Framework Directive (WFD). The risk assessments are carried out at the beginning of the six-year cycle.

Whilst similar in nature, the goals of status assessments and ongoing risk assessments are different in that the risk assessments help determine the requirements for future monitoring and investigation and help identify areas where future developments could impinge on the groundwater status objectives of the WFD. Essentially, the risk assessments are assessments of whether objectives of the WFD may not be achieved in the future, whilst status assessments consider compliance with the WFD objectives in the past.

Additionally, status assessments consider widespread impacts across a groundwater body. For example, a groundwater body can be at Good Status, but there can still be an environmental risk, e.g. where the local impacts on groundwater quality are not substantial enough to impact on the status of the whole groundwater body. However, where a groundwater body has been classified as being at Poor Status, this implies that there is also a risk of failing WFD objectives in the future.

Chemical classification of groundwater bodies is split into five tests (Figure 2). The tests are designed to assess whether the objectives of the WFD are being met. The worst case is reported for a groundwater body, so “failure” of one or more of the tests causes a groundwater body to be at Poor Status.

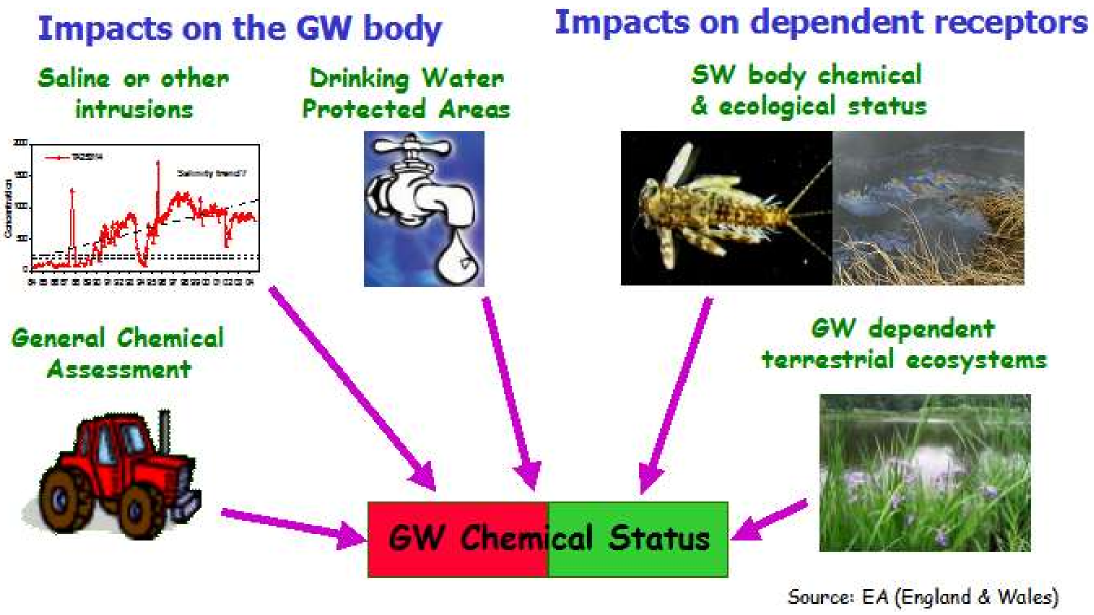

Figure 2 Chemical Status Assessment Tests

Groundwater Body Grouping

In accordance with European guidance on groundwater body delineation, groundwater monitoring and groundwater status assessments; "*groundwater bodies may be grouped for monitoring purposes provided that the monitoring information obtained provides a reliable assessment of the status of each body in the group*".

In Ireland, groundwater body grouping is used in the assessment of groundwater chemical status, where the pressures are widespread and diffuse in nature. The 514 groundwater bodies delineated nationally in Ireland (many of which have similar hydrogeological characteristics and pressures) have been categorised into 39 groundwater body groups. These reflect the different hydrogeological pressure risk characterisation variations across Ireland (EPA, 2022).

Specifically, groundwater grouping is used in the assessment of groundwater body chemical status for the surface water body, GWDTE (groundwater dependent terrestrial ecosystems) and general chemical tests, as each may be impacted by diffuse and/or widespread pressures. The groups are reviewed and updated, if necessary, at the end of each WFD RBMP cycle. Groundwater body grouping is not used for any of the other groundwater body test elements.

3.1 Test 1: Saline or Other Intrusions Test

Key concept:
Status, and the presence of an intrusion of poor quality water into the groundwater body, is determined through an assessment of trends in Electrical Conductivity or other indicator substances. The test is designed to detect the presence of an intrusion that is induced by the abstraction of groundwater.

Threshold Values:
Set at the upper limit of the natural background range for key determinands. Threshold Values are only used in combination with trend assessment(s).

The conditions for good quantitative status are not met when:
Threshold Values are exceeded and there is either a significant and sustained rising trend in one or more key determinands at relevant monitoring points or there is an existing significant impact on a point of abstraction as a consequence of an intrusion.
(UKTAG, 2012a).

3.1.1 Introduction

The Saline (or Other) Intrusions Test is intended to identify groundwater bodies where there is intrusion of poor quality water as a result of groundwater abstraction and this intrusion is leading to sustained upward trends in pollutant concentrations or a significant impact on one or more groundwater abstractions (UKTAG, 2012a).

Note: the saline intrusion test mirrors the test undertaken for the Quantitative Status assessment.

3.1.2 Background

This test is undertaken to identify where groundwater quality is deteriorating, or there have already been impacts on the quality of abstracted water, as a result of the intrusion of poor quality water into the groundwater body. The EU guidance (EC, 2009) and UKTAG guidance (UKTAG, 2012a) indicate that the intrusion must be caused by groundwater abstraction and must be sustained, i.e. temporary intrusions should not be considered. Therefore, the test focuses on groundwater bodies where there is a risk that abstraction pressures may cause significant and sustained intrusions.

Groundwater intrusion can occur when the saline-freshwater interface in coastal regions is drawn inland and upwards by abstraction. Groundwater abstraction can also lead to upward movement (up coning) of poor quality deeper water, the leakage of saline surface waters to an underlying groundwater body or drawing in of poorer quality groundwater from an adjacent aquifer. The EU and UKTAG guidance documents indicate that parameters in groundwater that are indicative of intrusion should be assessed, e.g. Electrical Conductivity and Chloride.

Where Electrical Conductivity and Chloride concentrations are above Natural Background Levels and there is either a significant upward trend[2] in concentration of that parameter, or there is already an impact on a point of abstraction (e.g. where a water supply has been decommissioned due to saline intrusion), then the groundwater body is assigned Poor Status. Otherwise, it is at Good Status.

The WFD indicates that confidence in the status assessment must be reported. As per UKTAG guidance (UKTAG 2012a), a weight of evidence approach is adopted when assigning confidence, with High Confidence (HC) or Low Confidence (LC) assigned to status assessments. For example, confidence is high where there is evidence of significant and sustained upward trends and there is evidence of an impact at a water supply. Confidence is low when the evidence is less

[2] Further information on trend assessments is provided in Section 5 of this report.

comprehensive, e.g. no impact on water supplies or when monitoring is limited. Confidence does not indicate how close the groundwater body status is to the status boundary.

The linkages between Risk, Status and Confidence are summarised in Table 1.

Table 1 Risk Assessment and Status for the Saline Intrusion Test

Risk assessment					**Status & Confidence**
Abstraction in GWB	Abstraction <20km from the coast	Concentration at Monitoring Point >TV	Elevated Concentration Caused by Abstraction	Upward Trend in Concentration	
No	-	-	-	-	Good-HC
Yes	No	-	-	-	Good-HC
Yes	Yes	No	-	-	Good-HC
Yes	Yes	Yes	No	-	Good-LC
Yes	Yes	Yes	Yes	No	Good-LC
Yes	Yes	Yes	Yes	Yes	Poor-LC
Yes	Yes	Yes	Yes	Yes	Poor-HC*

* Evidence of impacts of saline intrusion on nearby receptors

3.1.3 Information Required for This Test

The Saline (or Other) Intrusions Test assesses the presence of an intrusion of poor quality water into the groundwater body as a result of groundwater abstraction and is determined through the identification of upward trends in Electrical Conductivity and Chloride.

The following information is gathered for the test:

Threshold Values
Threshold Values are only derived for pollutants that are indicative of saline (or other) intrusions (Electrical Conductivity, Chloride). These are listed in Schedule 5 of the Groundwater Regulations (as amended).

Groundwater Quality Data
Six years of Electrical Conductivity and Chloride data, collected from the monitoring points in the EPA's National Groundwater Monitoring Network, are assessed to identify and calculate the maximum and average parameter concentrations, respectively. Ten years of monitoring data are used to assess trends in the parameter concentration.

Monitoring Points Assessed
Abstraction data is obtained from the EPA's National Water Abstraction Register.

At Risk groundwater bodies: Risk assessments are completed at the beginning of each 6-year WFD cycle to identify the groundwater bodies at risk from saline intrusion. Monitoring points within the groundwater bodies at risk from Saline intrusion are assessed (EPA, 2015).

Coastal location: All monitoring locations within 20 km of the coast or coastal inlets are assessed if the average Electrical Conductivity and Chloride concentrations exceed the TV, or where the averages are lower than the TV, but the maximum Electrical Conductivity and Chloride concentrations are significantly (statistically) higher than the TV.

Groundwater bodies with abstraction pressures: Monitoring locations are assessed in groundwater bodies that are at risk of failing to meet WFD objectives because of unsustainable abstractions.

3.1.4 Methodology

The steps undertaken as part of the Saline (or Other) Intrusion Test are outlined below:

Trend assessments are undertaken using the Mann-Kendall/Sen's non-linear trend analysis model. The model is used to identify statistically significant upward trends in Electrical Conductivity and Chloride at monitoring points. Section 5 of this report contains more detail on the trend analysis that is undertaken.

The annual average concentrations for Electrical Conductivity and Chloride are calculated at monitoring points over a ten-year period, if the maximum Electrical conductivity and Chloride concentrations exceeded the TV during that period.

The trend assessment is not undertaken when a monitoring point had less than six years of data during the ten-year period because at least six years of data is required to determine a significant trend.

Where trends can be determined at individual monitoring points, the statistical significance of the trend is reported. Trends can be identified as being non-existent, upward or downward and the statistical significance of the trend is reported as being 90%, 95%, 99% or 99.9% significant, or not statistically significant.

When assessing the impact of saline intrusion on groundwater, the presence of a statistically significant upward trend in both Chloride and Electrical Conductivity at any individual monitoring point results in the groundwater body being classified as Poor Status. Monitoring locations with significant upward trends in Chloride, but not in Conductivity, or vice versa, remain at Good Status, but are at risk of failing WFD objectives in the future.

Information on the reasons for water supplies being decommissioned are taken into account where appropriate but this information is not always available. Often water supplies are decommissioned when new water infrastructure projects are being undertaken and it is not clear if water quality problems are a contributory factor to supplies being decommissioned.

The overall assessment approach is summarised in Table 2.

Table 2 Summary of criteria to determine status and confidence

Status	Confidence	Example Criteria
Good	High	No exceedance of the TV levels, OR Exceedance of TV levels not caused by abstraction
	Low	Exceedance of TV levels but further investigation has determined there are no sustained rising trends OR Possible risk identified but no monitoring available
Poor	Low	Exceedance of TV levels caused by abstraction with sustained rising trends OR Exceedance of TV levels caused by abstraction AND impacted abstraction
	High	Exceedance of TV levels with sustained rising trends caused by abstraction AND The Intrusions have caused a significant impact on abstraction(s)

3.2 Test 2: Impact of Groundwater on Surface Water Ecological/Chemical Status Test

3.2.1 Introduction

Key concept:
Status is determined through a combination of surface water classification results and an assessment of chemical inputs from groundwater bodies into surface water bodies. The surface water bodies can comprise rivers, standing waters and transitional / coastal waters. The test is designed to determine whether the contribution from groundwater quality to surface water quality, or any consequent impact on surface water ecology, is sufficient to threaten the WFD objectives for these associated water bodies.

Threshold Values:
Surface water quality standards adjusted by dilution and, where appropriate, attenuation factors.

The conditions for good chemical status are not met when:
An associated surface water body does not meet its objectives, TVs are exceeded and groundwater contributes at least 50% of the relevant surface water standard.
(UKTAG, 2012a).

The Impact of Groundwater on Surface Water Ecology and Chemistry Test is undertaken in those groundwater bodies that are contributing to a surface water body that is not meeting its good ecological or chemical status objectives because of diffuse pollution pressures (UKTAG, 2012a).

3.2.2 Background

Most rivers and standing waters (lakes) derive their water from both surface water runoff and groundwater discharge. The contribution from each component varies during the year and with aquifer type underlying the surface water body. In some cases, a large proportion (50–100%) of the surface water can be made up of groundwater discharge and so the quality and quantity of groundwater discharging to surface water will have a big influence on surface water quality.

This test is undertaken to identify surface water bodies that receive a significant proportion of flow from groundwater, and where pollutant concentrations in groundwater are elevated and may contribute significantly to those associated surface water bodies not meeting their environmental objectives, i.e. Good Status or better. There are a number of elements that are assessed in determining overall surface water ecological status, but the key element for this test is chemistry. For surface water bodies to be at Good Status or better there must be no significant impact on the ecology or failures of the Environmental Quality Standards (EQSs) that have been established for surface water.

Where pollutant concentrations in groundwater are elevated above Natural Background Levels and this polluted groundwater is contributing significantly to a corresponding surface water body failure; then the groundwater body will be at Poor Status. When making this assessment, consideration is given to the dilution effects in the surface water by estimating the contribution of groundwater to the overall flow or volume in the surface water. Consideration is also given to the attenuation (degradation) potential within the groundwater system, where this is known.

3.2.3 Information Required for This Test

The Impact of Groundwater on Surface Water Ecology and Chemistry Test assesses the potential adverse impacts of groundwater pollutants on associated surface water bodies (rivers, lakes and transitional and coastal waters) that are at less than Good Status.

The following information is gathered for this test.

Threshold Values
This test is undertaken for parameters identified as causing a surface water body to be at less than Good Status. The TVs are based on the parameter EQSs for the associated surface water receptor and are listed in Schedule 5 of the Groundwater Regulations (as amended).

Groundwater Quality Data
Six years of data, collected from the monitoring points in the EPA's National Groundwater Monitoring Network, are assessed to calculate the average parameter concentrations.

Groundwater Bodies Assessed
The assessment is undertaken for groundwater bodies associated with surface water bodies designated as being at less than Good Status due to diffuse pressures. The assessment is not undertaken where point source discharges are the cause of the less than Good Status designation. Additionally, the assessment is not undertaken where an overriding element (e.g. alien species or absence of a protected area species, such as the *Margaritifera* pearl mussel) is the cause of the less than Good Status designation.

Monitoring Points Assessed
At Risk groundwater bodies: Monitoring points are assessed if they are located in groundwater bodies or groups of groundwater bodies (EPA, 2022) that are at risk of failing WFD objectives in relation to groundwater impacts on surface water ecology/chemistry. At risk groundwater bodies are identified as part of the characterisation exercise undertaken at the start of each WFD cycle (EPA, 2015).

Surface water bodies at less than Good Status: Monitoring locations are assessed if they are located in groundwater bodies or groups of groundwater bodies associated with surface water bodies designated as being at less than Good Status due to diffuse pressures.

3.2.4 Methodology

The steps taken to assess the impact of groundwater on the ecological and chemical status of surface water bodies are detailed below.

(i) A conceptual understanding of the groundwater contribution to surface water bodies was developed for each groundwater body.

- The MIKE NAM model (DHI, 2004) has been used to develop a conceptual representation of the hydrogeological cycle for typical settings in Ireland (RPS, 2009).
- In simple terms, the model separates rainfall into three different stores: overland flow, intermediate flow and deep groundwater flow. RPS (2009) have defined the components of the three stores as follows:

Overland flow:	Surface runoff, including flows in subsurface land drains;
Intermediate flow:	Interflow through soils and subsoils <u>and</u> shallow (top of bedrock) groundwater; and
Deep groundwater flow:	Groundwater flow beneath the water table that interacts with the surface water system.

- Modelling was undertaken on surface water catchments nationwide and flow apportioned to the three components for a total of 124 catchments (RPS, 2009).
- 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". In undertaking this test, the groundwater input consists of both the "deep" groundwater flow and the shallow "top of the rock" groundwater flow.
  - The intermediate flow component was separated using hydrogeological information on the aquifer, subsoil and soil types within each modelled catchment.
  - The calculated "shallow groundwater flow" component was added to the "deep groundwater flow" component to give a "total groundwater" component in line with the WFD definition.

- Modelling in the karst dominated groundwater bodies was not straightforward because of difficulties apportioning/splitting the intermediate flow component, as groundwater can often behave in a similar manner to surface water in karst aquifers and can be difficult to distinguish in a river hydrograph.
  - Therefore, a water balance approach was devised to calculate the groundwater contribution from the karst dominated aquifer types (Rk and Lk aquifers[3]).
  - Five karst dominated catchments were selected for a water balance assessment.
  - It was assumed that the total volume of water entering the catchment was equal to that leaving the catchment. Therefore, the karst component is the total volume of water, less the surface water component and the groundwater component from any other aquifer types in the catchment (which had already been calculated using the model). The remaining volume of water was assumed to be the Rk and Lk karst groundwater component.
- The annual average groundwater contribution to surface water bodies was calculated for each aquifer type across all the 124 modelled catchments. The results are shown in Table 3.
- An overall water balance was calculated for each aquifer type in each groundwater body. This was calculated by dividing the total groundwater component for each aquifer type by the total volume of water entering the catchment, i.e. rainfall less evapotranspiration. The groundwater components from each aquifer type were summed and divided by the total volume of water entering the catchment to give an overall groundwater contribution to surface water bodies for each groundwater body.

Table 3 Estimated groundwater contributions to surface water for different aquifer types

Aquifer type	Annual Average Groundwater contribution (%)
Pl/Pu	21
Ll	27
Rf/Lm	65
Rk/Lk	74
Rg/Lg	90

(ii) Surface water bodies at less than Good Status due to diffuse pressures are identified from the Surface Water Classification results. A Geographical Information System (GIS) shapefile of the groundwater bodies is overlaid with the shapefile of surface water bodies at less than Good Status and groundwater bodies potentially contributing to these surface water bodies are identified.

(iii) The average concentration of Molybdate Reactive Phosphorus (MRP) is calculated using six years of data for monitoring points within groundwater bodies (and associated grouped groundwater bodies) potentially contributing to surface water bodies at less than Good Status.

Whilst locally elevated concentrations of ammonium in groundwater could impact on the ecology and chemistry of a river, ammonium concentrations at groundwater monitoring locations are generally low and not considered to have a regional impact on surface water. Therefore, the test is not undertaken any further for ammonium.

(iv) The test requires an assessment of groundwater inputs (loading) to determine if groundwater contributes greater than 50% of the loading to the surface water body that would result in a breach of the surface water EQS for MRP in rivers. Therefore, the surface water loading relating to the MRP EQS is calculated using the total volume of water entering the catchment x MRP EQS.

[3] Information on the aquifer categories in Ireland can be obtained from the GSI website (https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/Pages/default.aspx)

(v) The groundwater loading of MRP to rivers is calculated using the total volume of groundwater entering the river system (total volume of water entering the catchment x average groundwater contribution across the groundwater body x average MRP concentration across the groundwater body).

(vi) Groundwater bodies that contribute greater than 50% of the loading that would result in a breach of the surface water body EQS are at Poor Status. Groundwater bodies that contribute less than 50% of the loading are at Good Status.

Confidence is high where there is extensive monitoring in the groundwater body and/or good supporting evidence of the groundwater contribution. Where monitoring and/or the evidence is more limited, confidence is low.

The overall assessment approach is summarised in Table 4.

Table 4 Summary of criteria to determine status and confidence

Status	Confidence	Example Criteria
Good	High	No surface water body at less than Good Status OR Surface water body at less than Good Status, but groundwater concentrations < 50% of EQS and therefore Groundwater unable to contribute > 50% of the load to surface water.
	Low	Surface water body at less than Good Status, but further investigation indicates groundwater loading < 50% of loading required to breach EQS OR Elevated pollution concentrations in groundwater unlikely to impact on the associated surface water body, e.g. where MRP is likely to be bound or attenuated by the overlying subsoil
Poor	Low	Surface water body at less than Good Status, and further investigation indicates groundwater loading > 50% of loading required to breach EQS
	High	Surface water body at less than Good Status, and further investigation indicates groundwater loading > 50% of loading required to breach EQS AND Detailed site-specific studies (e.g. groundwater tracing) identify and quantify direct connection between groundwater and surface water.

3.3 Test 3: Groundwater Dependent Terrestrial Ecosystems – Chemical Assessment Test

3.3.1 Introduction

Key concept:
Status is determined through a combination of GWDTE assessments to determine ecological damage and an assessment of chemical inputs from groundwater bodies into GWDTEs. The test is designed to determine whether the contribution from groundwater quality to GWDTEs and consequent impact on GWDTE ecology is sufficient to threaten the WFD objectives for these associated GWDTEs.

Threshold Values:
Wetland quality standards or action values adjusted by dilution and, where appropriate, attenuation factors (EC, 2015).

The conditions for good chemical status are not met when:
The ecology of an associated GWDTE is damaged due to the chemical contribution from the groundwater body, TVs are exceeded and groundwater loading is sufficient to cause a breach of the relevant GWDTE quality standard.

This section describes the method used to assess the chemical status of groundwater bodies with respect to significant damage to GWDTEs, i.e. wetlands. The test is only applied to wetlands/GWDTEs that have been formally identified as protected areas under Regulation 8 of S.I. 722 of 2003 (as amended).

3.3.2 Background

GWDTEs are defined here as wetlands where habitats and species are dependent on groundwater to maintain the environmental supporting conditions that are required to sustain the habitat and/or species.

This test considers the concentrations of nutrients (primarily Total Phosphorous) in groundwater bodies and the potential for these to affect groundwater dependent wetlands, such that the groundwater chemistry causes significant damage to the wetland ecology. Where significant damage as a result of chemical pressures is confirmed, the groundwater body is at Poor Status.

To assess the impact there is a need to determine whether, and if so how, chemical pressures in the groundwater body affect the quality of the water supporting the wetland and also whether the change in water quality (if any) affects the groundwater dependent ecological features (flora and fauna).

The National Parks and Wildlife Service (NPWS) produced a list of Sites of Special Scientific Interest (SSSIs) which they considered to be GWDTEs for the Article 5 Risk Assessment in 2005. In addition, the Article 5 Risk Assessment (Working Group on Groundwater, 2005) identified GWDTEs where the ecology was potentially damaged and therefore may have been impacted by groundwater abstraction or pollution. However, generally the cause of the damage was unclear, and may have been caused by quantitative or chemical contributions from groundwater, or both.

Since 2005, several research projects on GWDTEs have helped to:

- refine the GWDTE boundaries (Kilroy *et. al*., 2008);
- determine the chemical (and quantitative) requirements of wetlands (Kimberly & Coxon, 2013);
- delineate the Zones of Contribution (ZOCs) (Waldren *et. al*., 2015); and,

- identify environmental supporting conditions required for GWDTEs (fens, turloughs and raised bogs) (Gill *et. al*., 2022).

This research has resulted in an improved understanding of GWDTEs in the Irish context and has enabled NPWS to update the GWDTE list and improve upon the initial Article 5 Risk Assessment.

The findings of the EPA-funded research project on the environmental supporting conditions required for GWDTEs in Ireland proposed a set of metrics that could be used in the future to assess whether the supporting conditions of a GWDTE are being met and, in this way, to determine whether the GWDTE is being impacted by chemical (and/or quantitative) pressures. The research suggested that, given the current scientific understanding and available data, appropriate metrics for nutrients (N and P) could only be defined by a range and that further research would be required to establish pragmatic nutrient TVs (Gill *et. al*., 2022). This highlights the complex nature of wetlands which may be highly sensitive to both chemical (and/or quantitative) pressures. Since 2022, five turloughs have been added to the EPA groundwater monitoring network in order to support the establishment of TVs.

3.3.3 Current Methodology

Groundwater Dependent Terrestrial Ecosystems (GWDTE) are currently assessed on an individual basis. Monitoring information is available from the NPWS and EPA for a small number of GWDTEs.

3.3.4 Methodology for Future Assessments

Assessments of GWDTEs require confirmation from NPWS that the ecology of a wetland is damaged (or at risk of being damaged) and that this damage is being caused by changes in the regional groundwater contributions to the wetland. This groundwater contribution to the wetlands could be quantitative (flow or levels) or chemical (pollutants), or both.

Where pollutants are contributing to the ecological damage in the wetland, chemical standards (or action values) will need to be established for the wetland, and in turn TVs will be established for the groundwater body. The development of TVs will take account of natural background concentrations for a particular pollutant. If pollutants exceed these TVs at monitoring points in the National Groundwater Monitoring Network that are located in the associated groundwater body, then further investigation will be undertaken to determine if groundwater is contributing to ecological damage in the associated GWDTE.

Once TVs have been established for a GWDTE, the groundwater loading to the wetland will be calculated in a similar manner to the surface water ecological/chemical status test. Groundwater inputs (loading) to the GWDTE will be calculated for the parameters of concern. If the loading from groundwater exceeds the environmental supporting condition of the GWDTE, then the groundwater body will be at Poor Status.

Groundwater monitoring locations are assessed if they are located in groundwater bodies or groups of groundwater bodies associated with GWDTEs designated as being at less than Good Status due to diffuse pressures.

The overall assessment approach is summarised in Table 5.

Table 5 Summary of criteria to determine status and confidence

Status	Confidence	Example Criteria
Good	High	No ecological damage to GWDTE OR Ecology of GWDTE damaged, but groundwater concentrations < wetland trigger action value/concentration
	Low	Ecology of GWDTE damaged, but further investigation indicates groundwater loading < loading required to breach wetland trigger action value/concentration
Poor	Low	Ecology of GWDTE damaged, and further investigation indicates groundwater loading > loading required to breach wetland trigger action value/concentration
	High	Ecology of GWDTE damaged, and further investigation indicates groundwater loading > loading required to breach wetland trigger action value/concentration AND Detailed site-specific studies identify and quantify direct connection between groundwater and GWDTE.

3.4 Test 4: Drinking Water Protected Area Test

Key concept:
Good chemical status requires an assessment, at the point of abstraction for water intended for human consumption, of whether there is deterioration in groundwater quality due to anthropogenic influences that could lead to an increase in purification treatment. **Note:** the stated aim of the Drinking Water Protected Area (DWPA) objective in the WFD is to provide the necessary protection to avoid deterioration in water quality in order to reduce the need for purification treatment. This has been interpreted as a minimum requirement to prevent deterioration in groundwater quality at the point of abstraction for drinking water supply.

Threshold Values:
An appropriate percentage of Drinking Water Standards or any other requirement to ensure that drinking water is free from contamination that could constitute a danger to human health (in accordance with the Drinking Water Directive). Threshold values in Ireland have been derived as 75% of the Maximum Admissible Drinking Water Standards or an appropriate health-based standard / guidelines e.g. from World Health Organization.

The conditions for good chemical status are not met when:
There is a significant and sustained rising trend in one or more key determinands at the point of abstraction and TVs are exceeded (UKTAG, 2012a).

3.4.1 Introduction

This section describes the steps that are taken in classifying the chemical status of groundwater bodies for the “Drinking Water Protected Area Test”. The test identifies groundwater bodies which are currently failing to meet the DWPA objectives defined in Article 7 of the Water Framework Directive and those that are risk of doing so in the future. In Ireland, all groundwater bodies are DWPAs and so this test applies to all groundwater bodies.

3.4.2 Background

The DWPA objectives of the WFD require that groundwater is protected to avoid deterioration in water quality that would lead to an increased level of treatment at points of abstraction. DWPAs are groundwater bodies that are used for the abstraction of more than 50 m^3/day of water intended for human consumption, or for supplying more than 50 people. Because of these low thresholds, all groundwater bodies have been designated as DWPAs in Ireland.

This test is undertaken to identify where there is likely to be a need for water purification treatment in the future, or an increase in the level of existing treatment, as a result of deteriorating water quality that has been caused by pollution. The test requires an assessment of the concentrations of pollutants in groundwater and how they are changing over time at a representative selection of drinking water abstractions. Trend assessments are used to identify current exceedances of drinking water standards and to project pollutant concentrations into the future, in order to identify exceedances of drinking water standards that are likely to occur in the next two River Basin Management cycles. It is at these sources (and associated groundwater bodies) that there may be a need for increased treatment of raw water in the future.

Groundwater bodies are at Poor Status where there is evidence that there is an existing exceedance of a TV and where there is a significant upward trend in the concentrations of the relevant pollutant(s). Where there is evidence that concentrations are less than the TV, but there are significant and sustained upward trends in the concentrations of the relevant pollutant(s) and the concentrations are projected to exceed the TV by the end of two cycles, the groundwater body is at Good Status, but is at risk of failing to meet its WFD objectives in future.

The relatively low frequency of sampling at monitoring sites means that exceedances of drinking water standards may not be easily detected in the national monitoring programme. Therefore, the only reliable statistic that can be used effectively for assessment is the mean concentration.

However, because the drinking water standards relate to maximum admissible concentrations, the TVs have been set at a lower value than the drinking water standard, to allow comparison of mean concentrations. The use of this TV is equivalent to comparing the maximum concentration with the drinking water standard (see Section 2 on Threshold Values for more information).

Where there is evidence of exceedances and significant upward trends at a monitoring point and local authority data shows similar concentrations, confidence in the assessment is high. Where limited or no local authority data exists, or there is conflict between the datasets, then confidence is low. Confidence does not indicate how close the groundwater body status is to the Good/Poor status boundary.

3.4.3 Information Required for this Test

The Drinking Water Protected Area Test assesses trends in the concentration of pollutants at representative drinking water sources. This test is only undertaken for pollutants that have a prescribed standard relating to the human use of water, i.e. drinking water standard.

Most water supplies already have chlorination in place, so this forgoes the need for microbiological assessment, although viruses and protozoa such as cryptosporidium, are more difficult to assess. Additional treatment and/or blending should not be used to mask deterioration in water quality. Therefore, it is important that samples are taken prior to any treatment/blending being implemented. However, if additional treatment is required to reduce the impacts of pollution (including increased chlorination), then the monitoring point, and therefore the associated groundwater body, default to Poor Status.

The following information is gathered for this test:

Threshold Values
Threshold Values are only derived for pollutants that are placing a groundwater body at risk of failing WFD objectives and where these pollutants have a prescribed drinking water standard. These are listed in Schedule 5 of the Groundwater Regulations, as amended.

Trend Assessments
Trend assessments are undertaken using the Mann-Kendall/Sen's non-linear trend analysis model (Salmi *et. al.*, 2002). This model reports the significance for the trend assessment, i.e. trend not significant (<90% significance) or the trend is 90%, 95%, 99%, or 99.9% significant. Further information on the trend assessment is provided in Section 5 of this report.

Groundwater Quality Data
Ten years of monitoring data from the EPA's National Groundwater Monitoring Network are used to identify trends for this test.

Monitoring Points Assessed
Drinking Water Abstractions: All monitoring locations in the EPA's National Groundwater Monitoring Network that are also used for drinking water supply.

3.4.4 Methodology

The steps taken in carrying out the Drinking Water Protected Area test are outlined below.

(i) Groundwater monitoring data are compiled for representative monitoring points in the EPA's National Groundwater Monitoring Network that are also drinking water abstractions.

(ii) The maximum and annual average concentrations are calculated for a 10-year reporting period at these monitoring sites.

(iii) Initially the data are screened at these monitoring sites – no further assessment is undertaken where the average concentration is less than the screening value (half the drinking water standard) or where there are no measured individual concentrations above the TV. These sites default to Good Status (with high confidence).

(iv) Where elevated concentrations for a pollutant are detected at monitoring points, checks are made to determine if the natural background concentrations are elevated in the aquifers being monitored, e.g. for iron and manganese. If the Natural Background Levels are higher than monitored concentrations, these sites default to Good Status (high confidence).

(v) Further assessment is required at the remaining sites:

- For the 10-year reporting period, where the mean concentration for a pollutant is greater than the TV in the first year of the reporting period, further assessments are undertaken to determine if there are significant upward trends in the pollutant concentration.
- Where the mean concentration for pollutants is less than the TV in the first year, the sites default to Good Status, but trends are assessed to determine if the site is at risk of failing WFD objectives in the future.

  Note: increases in pollutant concentration beyond the first year of the reporting period are allowable, as long as they do not exceed the TV or bring about the need for an increased level of purification / treatment at the water supply.

- Trend assessments are undertaken at individual monitoring sites to determine if there are statistically significant upward trends in pollutants:
  - To undertake the statistical assessment, a minimum of 80% real data in the dataset is required, i.e. there must be no more than 20% LOD/LOQ data.
  - Statistically significant trends cannot be calculated for datasets with less than six years data because the Mann-Kendall/Sen's (Salmi *et. al.*, 2002) model cannot detect significant trends with less than six years of data.
  - The trend significance is calculated using the Mann-Kendall/Sen's model.
- Where the concentration for a particular pollutant in the first year of the reporting period is above the TV, but trends are downward or are not statistically significant, or assessments cannot be undertaken because of a lack of data, then the monitoring sites default to Good Status (with low confidence).
- Where the concentration for a particular pollutant in the first year of the reporting period is below the TV, but assessments cannot be undertaken because of a lack of data, then the monitoring sites default to Good Status (with low confidence).
- Where the concentration for a particular pollutant in the first year of the reporting period is below the TV, and trends are downward or are not statistically significant, the monitoring sites default to Good Status (with high confidence).
- Where statistically significant upward trends are detected at monitoring sites, the trend is projected forward until the end of the next two WFD cycles (using the Mann-Kendall model), to determine if the trend will be environmentally significant in the future.
  - Where there is a significant trend and the concentration is already exceeding the TV, these sites (and associated groundwater bodies) are at Poor Status (high confidence) in the last year of the reporting period. As the TV has already been exceeded, the last year of the reporting period is identified as the starting point (year) for trend reversal.
  - Where there is a significant trend and the first year concentration is below the TV but is projected to exceed the TV by the end of two cycles, these sites (and associated groundwater bodies) are at Good Status (low confidence) but are at risk of failing to meet the WFD objectives in the future.
  - In the case of the previous point, the year when 75% of the TV concentration is breached is identified from the Mann-Kendall/Sen's model. This is the starting point (year) that trend reversal should begin, i.e. measures should be introduced prior to this year.

The overall assessment approach is summarised in Table 6.

Table 6 Summary of criteria to determine status and confidence

Statistically significant trend in data	Mean concentration currently below TV	Mean concentration currently above TV
Down	Good (also not at risk)	Good (at risk)
No trend	Good (also not at risk)	Good (at risk)
Up	Good (at risk where predicted concentration at the end of two cycles > TV, otherwise not at risk)	Poor (at risk)

3.4.5 Future Developments

Additional information is required on the current level of treatment at water supplies. Blending of water from multiple abstraction points is commonly used to maintain the quality of water supplied from drinking water schemes. Additional water supply sources and abstraction points are often introduced to maintain the status quo in water quality, but this would be perceived as additional treatment under WFD and therefore the groundwater body would be at Poor Status. Therefore, information on the actual abstractions, blending and treatment regimes are required to ensure compliance with this WFD objective in the future.

3.5 Test 5: General Chemical Assessment Test

Key concept:
Status is determined through an assessment of the areal extent of a groundwater body exceeding a TV for a pollutant. It is only conducted for determinands for which:
- an EU prescribed standard is set; or
- the risk characterisation process has indicated that pollutants may cause significant impairment of human uses of groundwater.

Threshold Values:
An appropriate percentage of the EU prescribed standards for nitrates and pesticides or a use-related standard that is appropriate for existing or planned use of the groundwater body.

The conditions for good chemical status are not met when:
Threshold Values are exceeded at individual monitoring points, and a representative aggregation of the monitoring data at the groundwater body scale indicates that there is a significant environmental risk or a significant impairment of human uses of the groundwater body (UKTAG, 2012a).

3.5.1 Introduction

The General Chemical Assessment Test identifies groundwater bodies where widespread deterioration in quality has, or will, compromise strategic use of groundwater. The status of the groundwater body is Poor if there is a widespread exceedance of relevant groundwater TVs or quality standards (UKTAG, 2012a).

3.5.2 Background

The General Chemical Assessment Test is undertaken where there is deterioration in groundwater quality at a scale that may compromise strategic use of groundwater for existing or planned, human consumption and/or other potential purposes. The test is not intended to identify local pollution impacts.

This test looks at concentrations of nitrate, pesticides and other pollutants in groundwater that put groundwater bodies at risk of failing to meet WFD objectives. Where TVs are exceeded at individual monitoring points, an aggregated average pollutant concentration across the groundwater body (or group of bodies) is calculated. Where the pollution of groundwater is confirmed as being widespread, i.e. widespread exceedance of the TV, the groundwater bodies are at Poor Status for this test, otherwise they are at Good Status.

This test assesses the impact of widespread diffuse pressures on groundwater quality and includes an assessment of pollutants from significant point sources, e.g. mining activities and contaminated land.

3.5.3 Information Required for This Test

The General Chemical Assessment Test assesses whether there is a widespread exceedance of relevant groundwater quality standards or groundwater TVs. This test is only undertaken for determinands that are applicable to human uses of groundwater.

The following information is gathered for this test.

Pressures
As part of the initial groundwater characterisation in 2005, groundwater bodies were delineated along hydrogeological boundaries. In addition, groundwater bodies were delineated when activities, such as contaminated land or mining, were considered to be having a widespread impact on groundwater quality. The EPA, as part of the WFD characterisation process, establish the risk of groundwater bodies not achieving their environmental objectives based on monitoring data, and identify the pressures that are impacting on waterbodies. These risk assessments are

carried out at the beginning of the WFD six-year cycle, which includes any necessary amendments to the delineated groundwater bodies e.g. merging smaller groundwater bodies associated with contamination from industrial activities back into their parent groundwater body once the water quality issues have been addressed.

Threshold Values

Threshold Values are only derived for pollutants that are placing a groundwater body at risk of failing to meet WFD objectives and where these pollutants have a prescribed standard relating to the human use of water, i.e. drinking water standard. These are listed in Schedule 5 of the Groundwater Regulations (as amended).

Groundwater Quality Data

Six years of data collected from the monitoring points in the EPA's National Groundwater Monitoring Network are assessed to calculate the average parameter concentrations.

Point Source Data

Mines:

Groundwater quality data is gathered for historic mines by the Geological Survey of Ireland/Exploration and Mining Division. Data includes samples taken from wells and mine adits, as well as leach test data from mine waste areas and mine workings. The data is collectively assessed to determine the average concentrations of different metals across the worked mine area. Further information is available in the report "Classification of Groundwater Bodies: General Chemical Test for Closed Mines" (GSI, 2009), with additional reports published by the Department of Communications, Climate Action and Environment on the former mining areas at Silvermines and Avoca.

Historical Landfill:

All known and suspected historic landfills have been identified and registered in accordance with Section 22 of the Waste Management Act (1996), as amended. Hydrogeological risk assessments have been carried out on these unregulated landfills and where required, remediation works were undertaken to limit the on-going impacts of the sites on groundwater and surface water (EPA, 2007). Landfill monitoring is carried out periodically for contaminants of potential concern (COPC) at these sites to assess whether the impact of these sites on groundwater and surface water is reducing over time. This monitoring data informs the status and risk of these sites during each WFD cycle.

Contaminated Land at EPA Licensed Facilities:

Following the publication of the Groundwater Regulations, hydrogeological assessments were carried out at all EPA licensed sites in order to assess the impact of the licenced activity on groundwater and compliance with the "prevent or limit" requirement of Part 2(i) the European Communities Environmental Objectives (Groundwater) Regulations 2010 (EPA, 2013).

EPA licenced facilities that were identified as non-compliant with the Groundwater Regulations were required to develop and implement an appropriate remediation strategy with a compliance groundwater monitoring programme and on-going reporting of results to the EPA, including trends assessments of contaminants of potential concern (COPC) identified during the hydrogeological assessment. This monitoring data informs the status and risk of these sites during each WFD cycle.

A list of "Significant Pressure Sites" (including mines, landfills and EPA licensed sites) is maintained by the EPA. Due to the generally localised but significant impact of these sites, they have been "clipped out" of the regional groundwater bodies and assigned a groundwater body code specific to these sites. The "status" and "risk" at these sites are reviewed and updated during each 6-year WFD assessment cycle.

3.5.4 Methodology

Data from the EPA's National Groundwater Monitoring Network is used to assess whether there is a widespread impact on groundwater quality across groundwater bodies. The steps taken in carrying out the General Chemical Assessment Test for a groundwater body are detailed below:

(i) Groundwater monitoring data are compiled for individual monitoring points in the EPA's National Groundwater Monitoring Network.

(ii) In accordance with EU Guidance (EC, 2007), groundwater bodies with similar hydrogeological characteristics and pressures are grouped, and monitoring data from the group of monitoring points within these groundwater bodies are used to assess groundwater quality. The average concentrations from the group of groundwater monitoring points are compared against the groundwater Threshold Values to determine status. If the average group concentration exceeds the Threshold Value, then all groundwater bodies in the group are at Poor Status.

(iii) Where a TV is exceeded at an individual monitoring point, an aggregated average pollutant concentration is calculated across the groundwater body group for the relevant pollutant. This quantifies the extent of the problem and whether there are any significant risks to the environment or impairment to human use.

- The six-year average concentration for the relevant pollutant is calculated at all monitoring points in the groundwater body group.
- Data from all monitoring points in the groundwater body group are aggregated and the six-year average concentration for the relevant pollutant is calculated for the groundwater body group.
- For some groundwater body groups, a weighting factor is applied to certain monitoring points in the group to ensure that the monitoring data is representative of the groundwater quality across the groundwater bodies. However, for most groundwater body groups, a weighting factor is not required, and the aggregation is an un-weighted average from the monitoring points.

(iv) Average concentration exceedances of the Threshold Value at individual monitoring points within a group are further investigated to determine if the Zone of Contribution (ZOC) to that monitoring point represents more than 20% of the overall groundwater body group area. This would lead to the groundwater bodies being assigned Poor Status, where the ZOC of any individual monitoring point is greater than 20% of the groundwater body group area (EPA, 2022). An assessment is undertaken to determine if the elevated concentrations are due to natural conditions. Where the Natural Background Levels for the relevant pollutant are higher than the average concentration, the group of bodies default to Good Status.

(v) For the remaining pollutants, where the aggregated concentrations are higher than the TV, all groundwater bodies in the group are assigned Poor Status.

(vi) High confidence is assigned where there is good evidence of widespread impacts on human uses of groundwater, i.e. concentrations above TVs established to protect drinking water.

Further assessment is undertaken to determine if pollution from activities such as contaminated land or mining is impacting on the status of the "clipped out" groundwater bodies that represent them. The assessment is based on a conceptual understanding of contaminant transport from the contaminated areas of the groundwater body, taking into account variations in groundwater quality across the whole groundwater body.

(i) Groundwater monitoring data are compiled for areas contaminated by point sources activities.

(ii) Up-to-date information on the extent of contaminant plumes, if any, is obtained.

(iii) Supporting evidence of impact on receptors is also gathered, i.e. any evidence of impact on drinking water abstractions, surface water courses or wetlands.

(iv) For each of the assessed groundwater bodies, there are monitoring sites that are representative of the contaminant plume and those that are representative of the remaining areas of the groundwater body.

- The mean concentrations of hazardous contaminants in the remaining areas of the groundwater body are assumed to be zero, unless there are additional contaminated land sites within the groundwater body (e.g. in urban areas);
- The mean concentration of the non-hazardous contaminants in the remainder of the groundwater body should reflect the mean concentrations in the groundwater body that surrounds the contaminated land site, i.e. the average concentrations calculated from the EPA's National Groundwater Monitoring Network.

(v) An assessment is undertaken to determine whether the extent of the pollution is significant enough to impact on the groundwater body status, based on the following Yes/No criteria:

- Is the average area-weighted concentration of the contaminant(s) in the groundwater body greater than the TV (see below)?

Area-Weighted Average Concentration = ((Polluted area x Estimated average concentration in polluted area) + (Area of the remainder of the GWB x Estimated average concentration in this area)) / Total GWB area

- Are there any groundwater contaminant plumes greater than $2km^2$?
- Are the concentrations of any individual contaminant greater than 100-times the associated TV?
- Is there any evidence of impacted surface water or drinking water supplies?

(vi) If "Yes" is the response to any of the above questions, then the groundwater body is assigned Poor Status. High confidence is assigned where there is good evidence of widespread impacts of contamination i.e. recorded impacts on drinking water abstractions, surface water courses or wetlands.

(vii) Crosschecks are made with EPA site inspectors to ascertain if remediation programmes are in place at the contaminated sites and whether the remediation would bring about marked improvement by the end of two cycles. If remediation is completed or is on-going, and is likely to cause a significant reduction in the contaminant plume concentrations and the extent of the plume, the groundwater body defaults to Good Status, but with low confidence.

(viii) Crosschecks are made with the GSI and the Exploration and Mining division (EMD) to assess whether trends in metal concentrations at mines caused by mining activities, are increasing or decreasing. If the concentrations are not directly caused by the mining activity i.e., considered to be naturally elevated, the groundwater body defaults to Good Status, but with low confidence.

The overall assessment approach is summarised in Table 7.

Table 7 Summary of criteria to determine status and confidence

Status	Confidence	Example Criteria
Good	High	No individual site concentrations higher than TV(s)
	Low	Aggregated pollutant concentration < TV(s), but individual site concentrations higher than TV(s) OR Aggregated pollutant concentration > TV(s), but aggregated pollutant concentrations lower than Natural Background concentrations OR Evidence of remediation causing a significant reduction in pollutant concentrations
Poor	Low	Aggregated pollutant concentration > TV(s)
	High	Aggregated pollutant concentration > TV(s) and individual sample concentrations greater than Drinking Water Standard OR Aggregated pollutant concentration > TV(s) and evidence of impact on drinking water abstractions, surface water courses or wetlands

4 Quantitative Status

Quantitative status assessments are undertaken once every six years, at the end of the river basin management planning cycles and are used to generate a snapshot that shows the impacts of groundwater abstraction on groundwater. The risk assessments are carried out at the beginning of the six-year cycle. Whilst similar in nature, the goals of status assessments and ongoing risk assessments are different in that the risk assessments help determine the requirements for future monitoring and investigation and help identify areas where future developments could impinge on the groundwater status objectives of the WFD. Essentially, the risk assessments are assessments of where objectives of the WFD may not be achieved in the future, whilst status assessments consider compliance with the WFD objectives in the past.

Additionally, status assessments consider widespread impact across a groundwater body. Therefore, a groundwater body can be at Good Status, but there can still be an environmental risk, e.g. a local reduction in water levels in close proximity to an abstraction can impact on neighbouring water supplies but are not substantial enough to impact on the status of the whole groundwater body. However, where a groundwater body has been classified as being at Poor Status, this implies that there is also a risk of failing to meet WFD objectives in the future.

Quantitative classification of groundwater bodies is split into four tests (see Figure 3). The tests are designed to assess whether the objectives of the WFD are being met. The worst case is reported for a groundwater body, so “failure” of one or more of the tests causes a groundwater body to be at Poor Status.

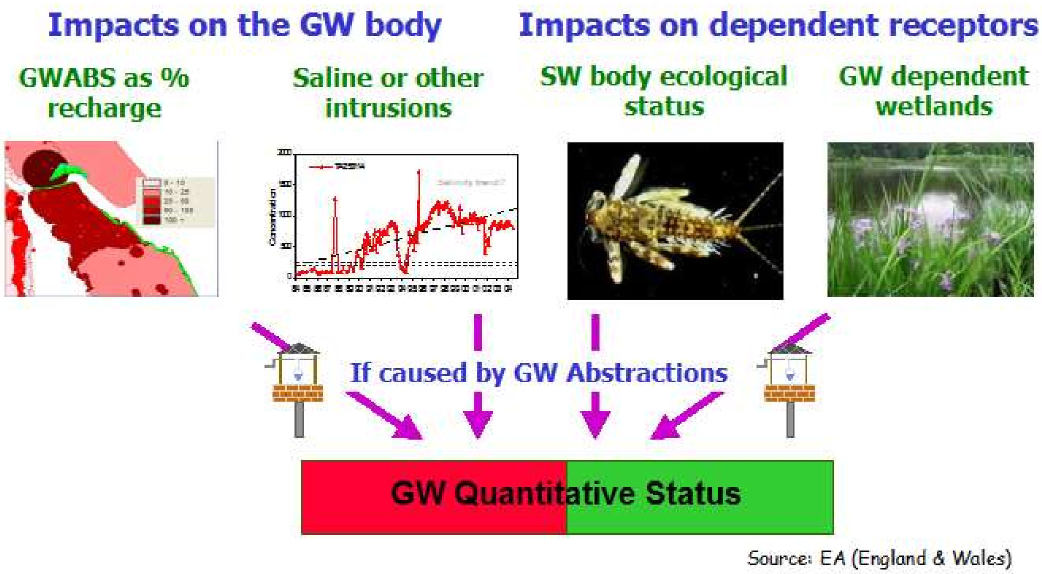

Figure 3 Quantitative Status Assessment Tests

4.1 Test 1: Saline (or Other) Intrusions Test

Key concept:
Status, and the presence of an intrusion of poor quality water into the groundwater body, is determined through an assessment of trends in Electrical Conductivity or other indicator substances. The test is designed to detect the presence of an intrusion that is induced by the abstraction of groundwater.

Threshold Values:
Set at the upper limit of the natural background range for key determinands. Threshold Values are only used in combination with trend assessment(s).

The conditions for good quantitative status are not met when:
Threshold Values are exceeded and there is either a significant and sustained rising trend in one or more key determinands at relevant monitoring points, or there is an existing significant impact on a point of abstraction as a consequence of an intrusion.
(UKTAG, 2012a).

4.1.1 Introduction

The Saline (or Other) Intrusions Test is intended to identify groundwater bodies where there is intrusion of poor quality water as a result of groundwater abstraction and this intrusion is leading to sustained upward trends in pollutant concentrations or a significant impact on one or more groundwater abstractions (UKTAG, 2012a).

Note: the saline intrusion test mirrors the test undertaken for the Chemical Status assessment.

4.1.2 Background

This test is undertaken to identify where groundwater quality is deteriorating, or there have already been impacts on the quality of abstracted water, as a result of the intrusion of poor quality water into the groundwater body. The EU guidance (EC, 2009) and UKTAG guidance (UKTAG, 2012a) indicate that the intrusion must be caused by groundwater abstraction and must be sustained, i.e. temporary intrusions should not be considered. Therefore, the test focuses on groundwater bodies where there is a risk that abstraction pressures may cause significant and sustained intrusions.

Groundwater intrusion can occur when the saline-freshwater interface in coastal regions is drawn inland and upwards by abstraction. Groundwater abstraction can also lead to upward movement (up coning) of poor quality water, the leakage of saline surface waters to an underlying groundwater body or drawing in of poorer quality groundwater from an adjacent aquifer. The EU and UKTAG guidance documents indicate that parameters in groundwater that are indicative of intrusion should be assessed, e.g. Electrical Conductivity and Chloride.

Where Electrical Conductivity and Chloride concentrations are above Natural Background Levels and there is either a significant upward trend in concentration of that parameter, or there is already an impact on a point of abstraction (e.g. where a water supply has been decommissioned due to saline intrusion), then the groundwater body is assigned Poor Status. Otherwise, it is at Good Status.

The WFD indicates that confidence in the status assessment must be reported. UKTAG guidance suggests a weight of evidence approach when assigning confidence, with High Confidence (HC) or Low Confidence (LC) assigned to status assessment. For example, confidence is high where there is evidence of significant and sustained upward trends and there is evidence of impact at a water supply. Confidence is low when the evidence is less comprehensive, e.g. no impact on water supplies or when monitoring is limited. Confidence does not indicate how close the groundwater body status is to the status boundary.

The linkages between Status and Confidence are summarised in Table 8.

Table 8 Risk Assessment and Status for the Saline Intrusion Test

Risk assessment					Status & Confidence
Abstraction in GWB	Abstraction <20km from the coast	Concentration at Monitoring Point >TV	Elevated Concentration Caused by Abstraction	Upward Trend in Concentration	
No	-	-	-	-	Good-HC
Yes	No	-	-	-	Good-HC
Yes	Yes	No	-	-	Good-HC
Yes	Yes	Yes	No	-	Good-LC
Yes	Yes	Yes	Yes	No	Good-LC
Yes	Yes	Yes	Yes	Yes	Poor-LC
Yes	Yes	Yes	Yes	Yes	Poor-HC*

* Evidence of impacts of saline intrusion on nearby receptors

4.1.3 Information Required for This Test

The Saline (or Other) Intrusions Test assesses the presence of an intrusion of poor quality water into the groundwater body as a result of groundwater abstraction and is determined through the identification of upward trends in Electrical Conductivity and Chloride.

The following information is gathered for this test.

Threshold Values
Threshold Values are only derived for pollutants that are indicative of saline (or other) intrusions (Electrical Conductivity, Chloride). These are listed in Schedule 5 of the Groundwater Regulations, as amended.

Groundwater Quality Data
Six years of Electrical Conductivity and Chloride data, collected from the monitoring points in the EPA's National Groundwater Monitoring Network, are assessed to identify and calculate the maximum and average parameter concentrations, respectively. Ten years of monitoring data are used to assess trends in the parameter concentration.

Monitoring Points Assessed
Abstraction data is obtained from the EPA's National Water Abstraction Register.

At Risk groundwater bodies: Risk assessments are completed at the beginning of each 6-year RBMP cycle to identify the groundwater bodies at risk from saline intrusion. Monitoring points within the groundwater bodies at risk from Saline intrusion are assessed (EPA, 2015).

Coastal location: All monitoring locations within 20km of the coast or coastal inlets are assessed if the average Electrical Conductivity and Chloride concentrations exceed the TV, or where the averages are lower than the TV, but the maximum Electrical Conductivity and Chloride concentrations are significantly (statistically) higher than the TV.

Groundwater bodies with abstraction pressures: Monitoring locations are assessed in groundwater bodies that are at risk of failing to meet WFD objectives because of unsustainable abstractions.

4.1.4 Methodology

The steps undertaken as part of the Saline (or Other) Intrusion Test are outlined below:

Trend assessments are undertaken using the Mann-Kendall/Sen's non-linear trend analysis model (Salmi *et. al.*, 2002). The model is used to identify statistically significant upward trends in

Electrical Conductivity and Chloride at monitoring points. Section 5 of this report has more detail on the trend analysis that is undertaken.

The annual average concentrations for Electrical Conductivity and Chloride are calculated at monitoring points over a period of ten years, if the maximum Electrical Conductivity and Chloride concentrations exceeded the TV during that period.

The trend assessment is not undertaken when a monitoring point had less than six years data during the ten-year period because at least six years data is required to determine significant trends.

Where trends can be determined at individual monitoring points, the statistical significance of the trend is determined. Trends are identified as being non-existent, upward or downward and the statistical significance of the trend is reported as being 90%, 95%, 99% or 99.9% significant or the trend is not statistically significant.

When assessing the impact of saline intrusion on groundwater, the presence of a statistically significant upward trend in both Chloride and Electrical Conductivity at any individual monitoring point results in the groundwater body being classified as Poor Status.

Monitoring locations with significant upward trends in Chloride, but not in Conductivity, or vice versa, remain at Good Status, but are at risk of failing to meet WFD objectives in the future. These monitoring points are investigated further in the subsequent River Basin planning cycle.

Information on the reasons for water supplies being decommissioned are taken into account where appropriate but this information is not always available. Often water supplies are decommissioned when new water infrastructure projects are being undertaken and it not clear if water quality problems are a contributory factor to supplies being decommissioned.

The overall assessment approach is summarised in Table 9.

Table 9 Summary of criteria to determine status and confidence

Status	Confidence	Example Criteria
Good	High	No exceedance of the TV levels, OR Exceedance of TV levels not caused by abstraction
	Low	Exceedance of TV levels but further investigation has determined there are no sustained rising trends OR Possible risk identified but no monitoring available
Poor	Low	Exceedance of TV levels caused by abstraction with sustained rising trends OR Exceedance of TV levels caused by abstraction AND impacted abstraction
	High	Exceedance of TV levels with sustained rising trends caused by abstraction AND The Intrusions have caused a significant impact on abstraction(s)

4.2 Test 2: Impact of Groundwater on Surface Water Ecological/Quantitative Status Test

4.2.1 Introduction

Key concept:
Status is determined through a combination of surface water classification results and an assessment of the potential impact of groundwater abstraction on the flow required to support and maintain surface water ecology. The surface water bodies can comprise rivers and lakes.

Standards:
Ecological flow or water level requirements/standards for surface water bodies.

The conditions for good quantitative status are not met when:
The ecology of an associated surface water body is damaged due to groundwater abstraction(s) impacting the groundwater flow from the groundwater body to the associated surface water receptor.

This section describes the method used to assess the Quantitative Status of groundwater bodies with respect to deterioration of dependent surface water body ecological status that is caused by groundwater abstraction(s). The assessment is undertaken in those groundwater bodies where groundwater abstractions are causing an associated surface water body to not meet the ecological objectives of the WFD (UKTAG, 2012b).

4.2.2 Background

This test considers the impact of groundwater abstractions on the ecological status of surface water bodies. This requires an assessment of the impact of groundwater abstraction on the ecological flow or water level requirements of surface waters, i.e. surface water flow or water level standards.

Groundwater abstractions can impact on the flow (stream depletion) and potentially the ecology of surface waters and wetlands, particularly during periods of naturally lower flows. The ecological flow requirements for surface water are needed so the impacts of groundwater abstraction on flows can be assessed. The methods used to determine the impact of groundwater abstractions depends on the degree to which groundwater abstractions affect the surface water. Depending on the complexity of the hydrogeological interactions, the methods may use local technical knowledge, simple tools or sophisticated models.

EU guidance (EC, 2009) and UKTAG guidance (UKTAG, 2012b) recommend estimating the groundwater contribution needed to support rivers and ecosystems across the groundwater bodies as part of the calculation of the available groundwater resource; this in turn is used to decide on the status.

This test can only result in a Poor Status groundwater body where the surface water body is also classified as less than Good Status; and where this is due to a failure of surface water body flow or water level standards, which are caused by groundwater abstraction. Where there is a significant upstream groundwater abstraction(s), then the groundwater body, upon which both the abstractions and surface water depend, is classified as being at Poor Status. Otherwise, the groundwater body is at Good Status.

4.2.3 Information Required for This Test

The Surface Water Ecological/Quantitative Test assesses the potential adverse impacts of groundwater abstraction(s) on the flow requirements of associated surface water bodies that are at less than Good Status.

The following information is gathered for this test.

Less Than Good Status Surface Water Bodies
The locations of surface water bodies that are at less than Good Status because they did not meet their ecological objectives.

Environmental Flow Standards for Surface Water Bodies
Environmental flows are the river flows required to support and maintain health river ecology. Environmental flow standards currently do not exist for Ireland. However, the approach used in this assessment is closely based on the UKTAG abstraction impact assessment metrics for rivers and lakes (UKTAG, 2013).

Abstraction Data
The location and current volume of water abstracted from groundwater abstraction points. The Environmental Protection Agency maintains a register of abstractions, a national database of all abstractions greater than 25m^3/day, as required under the Water Environment (Abstractions and Associated Impoundments) Regulations 2024 (S.I. No. 419 of 2024).

4.2.4 Current Methodology

Environmental flow and level standard(s) are required for surface water bodies that are at less than Good Status, i.e. the minimum flow or water level required to maintain and support the ecology of the river. However, environmental standards currently do not exist for Ireland. In the absence of evidence-based impact assessment metrics tailored to Irish hydrological conditions, the UKTAG (2013) method provides a best-available alternative.

4.2.5 Methodology for Future Assessments

Groundwater bodies associated with surface water bodies that are at less than Good Status due to ecological damage are identified.

If the flows in the surface water body do not fall below the environmental flow standard (e-flow limit) or environmental water level limit for lakes, then the ecology of the surface water body is not being damaged by over-abstraction, and the damage is being caused by something else, e.g. pollution. Therefore, the groundwater body would be at Good Status in relation to this test. Similarly, if there are no groundwater abstractions in the surface water body catchment, then the groundwater body would be at Good Status.

If the flows or levels in the surface water body fall below the standard, then it is likely that abstractions are contributing to the reduced flow and are causing the surface water body to be at less than Good Status. The impacts of groundwater abstractions up-gradient of the surface water body should be assessed to determine their impact on surface water flow or level.

Where there are groundwater abstractions up-gradient of a surface water body that has not met the environmental flow/level standard, then the “allowable abstraction” in the surface water catchment is calculated. The “allowable abstraction” is the total volume of water available to the surface water catchment, i.e. rainfall less evapotranspiration, less the volume required to maintain the flow or level standard in the surface water body.

Groundwater abstractions within these groundwater bodies should be identified and the total abstracted volume calculated for all groundwater bodies contributing to the surface water body that is at less than Good Status.

Where a groundwater abstraction is identified as being a significant contributor to the surface water environmental objectives not being met, then the groundwater body will be at Poor Status.

Note: Assessments should take into account any water locally returned and ignore non-consumptive abstractions, as these are being discharged back into the surface water catchment.

4.2.6 Future Developments

Regulatory standards and an associated regulatory regime are currently under development in Ireland.

4.3 Test 3: Groundwater Dependent Ecosystems – Quantitative Assessment Test

Key concept:
Status is determined through determination of ecological damage at the GWDTE, and the assessment of the impact of groundwater abstraction on GWDTE ecology. The test is designed to assess whether groundwater abstractions reduce the contribution from groundwater (in terms of water level or groundwater flow) to GWDTEs and if the consequent impact on GWDTE ecology is sufficient to threaten the WFD objectives for these associated GWDTEs.

Standards:
Wetland flow and/or water level standards.

The conditions for good quantitative status are not met when:
The ecology of an associated GWDTE is damaged due to groundwater abstraction reducing the contribution of flow/water level in the groundwater body, which in turn has an impact in flow/water level in the GWDTE.

4.3.1 Introduction

This section describes the method used to assess the Quantitative Status of groundwater bodies with respect to significant damage to GWDTEs, i.e. wetlands. The test is only applied to wetlands/GWDTEs that have been formally identified as protected areas under Regulation 8 of S.I. 722 of 2003 (as amended).

4.3.2 Background

GWDTEs are defined here as wetlands where habitats and species are dependent on groundwater to maintain the environmental supporting conditions that are required to sustain the habitat and/or species.

Several research projects in this area have improved our understanding and knowledge of GWDTEs. An EPA-funded research project examining the environmental supporting conditions required for GWDTEs in Ireland proposed a set of metrics, including water level depth (m) and its duration (months) and frequency (per year). These metrics could be employed to assess whether the supporting conditions of fens, raised bogs and turloughs are being met and, in this way, to determine whether the GWDTE is being impacted by quantitative (and chemical) pressures (Gill *et. al*., 2022).

A joint NPWS and Trinity College Dublin (TCD) project undertook an in-depth assessment of the hydrology, ecology and conservation status of 22 turloughs in Ireland which improved the conceptual understanding of the hydrodynamics of karst systems and the derivation of hydrological factors that influence biological diversity within and among the turloughs (Waldren *et. al*., 2015).

Ongoing assessments by NPWS and EPA funded research projects is required, as the environmental supporting conditions for GWDTE are typically case specific.

4.3.3 Current Methodology

This test considers the potential impact regional groundwater abstraction(s) have on the hydrological conditions of a wetland that support groundwater dependent ecological features.

Where a GWDTE suffers significant ecological damage as a result of groundwater abstractions, the groundwater body is at Poor Status.

To assess the impact, it must be determined whether abstractions from the groundwater body affect the flow and water levels supporting the wetland, and also whether the change in water flow or level affects the groundwater dependent ecological features (flora and fauna).

Environmental flows or water level-duration standards (or action values) for a GWDTE are the minimum flows or water levels required to maintain and support the ecology of the GWDTE. The standards require good understanding of the hydraulic links between the groundwater body and the wetland, and the links between water level and ecology. For example, the integrity of the raised bog ecosystem is dependent on water level/water tables remaining within 100 mm of the ground surface for approximately 90% of a given year. In some site-specific situations, the water table may be linked to the interaction between the peat and the underlying regional groundwater (Gill *et. al*., 2022).

Where flow or water level standards (or action values) have been established for a GWDTE, e.g. at Pollardstown Fen in Co. Kildare, a regional water balance assessment for the supporting groundwater body is undertaken to establish the impact abstractions may be having on the wetland.

Where the ecology of the GWDTE has been damaged and water level/flow in the GWDTE has fallen below the environmental standard, the impact of groundwater abstractions in the groundwater body that supports the GWDTE is assessed.

Where there is evidence (through groundwater monitoring) that groundwater abstraction(s) are causing a regional reduction in groundwater flow or levels, or where the groundwater abstractions exceed an identified “allowable abstraction” volume, that relates to a reduction in flow and drop in groundwater levels at the GWDTE, then the groundwater body is at Poor Status.

Assessments take into account any water locally returned and ignore non-consumptive abstractions, as these are being discharged back into the groundwater body.

Where the ecology of the GWDTE has not been damaged or the water level/flow in the GWDTE has not fallen below the environmental supporting condition, or where the ecological damage is being caused by other factors, such as small drains, then the groundwater body is at Good Status. Similarly, if there are groundwater abstractions in the groundwater body that supports the GWDTE, then the groundwater body is at Good Status.

Extensive research has resulted in the establishment of guideline water level, duration and frequency metrics that can be applied to various types of GWDTEs (turloughs, fens, raised bogs etc.) (Gill *et. al*., 2022). These metrics are applied on a case-by-case basis by the NPWS for certain individual GWDTEs and types of GWDTEs. The “status” and “risk” at these sites are reviewed and updated by the NPWS during each 6-year WFD cycle.

The overall assessment approach is summarised in Table 10.

Table 10 Summary of criteria to determine status and confidence

Status	Confidence	Example Criteria
Good	High	No ecological damage to GWDTE OR Ecology of GWDTE damaged, but no associated significant groundwater abstractions in the GWB
	Low	Ecology of GWDTE damaged, but further investigation indicates groundwater abstractions not impacting on the wetland
Poor	Low	Ecology of GWDTE damaged, and further investigation indicates groundwater abstractions are impacting on the wetland
	High	Ecology of GWDTE damaged, and further investigation indicates groundwater abstractions are impacting on the wetland AND Detailed site-specific studies identify and quantify direct connection between groundwater and GWDTE.

4.3.4 Future Developments

There is a level of uncertainty with this test. Future research projects and the ongoing collection of measurable data on the flow/water level environmental supporting condition requirements of wetland flora and fauna will inform future assessments.

Future assessments of GWDTEs will require confirmation that the ecology of the wetland is damaged (or at risk of being damaged) and that this damage is being caused by change in the regional groundwater contributions to the wetland. This groundwater contribution to the wetlands could be quantitative (flow or levels) or chemical (pollutants), or both.

4.4 Test 4: Water Balance Test

Key concept:
Status is determined through an assessment of a water balance that is undertaken at the groundwater body scale. The test is designed to detect the presence of groundwater body wide-scale over-abstraction, resulting in insufficient water being left to support water uses and the wider environment in the catchment, or is resulting in falling groundwater levels.

Standards:
Groundwater abstractions do not exceed an appropriate percentage of recharge and groundwater levels are not falling.

The conditions for good quantitative status are not met when:
The long-term annual average volume of water abstracted from the groundwater body represents more than 80% of the long-term annual average volume of recharge.
OR
The long-term annual average volume of water abstracted from the GWB represents more than the appropriate percentage of recharge required to support dependent surface water receptors **and** there is a long-term drop in groundwater levels.

4.4.1 Introduction

This section describes the method used to assess the Quantitative Status of groundwater bodies with respect to groundwater abstraction pressures on the groundwater body resource balance. This test considers the cumulative effects of groundwater abstraction across the groundwater body.

4.4.2 Background

Groundwater levels are referred to in the WFD as a monitored parameter which should provide a basis for quantitative status classification, but EU guidance (EC, 2009) and UKTAG guidance (UKTAG, 2012b) recognises that literal application of this wording is problematic because groundwater levels vary continuously, as a reflection of the locally shifting balance between recharge and discharge. Whilst water levels may identify impact in the vicinity of the abstraction, it is possible that they may not pick up the regional effects of abstraction; in particular the impacts on un-monitored streams, rivers and wetlands.

However, groundwater levels assist conceptual understanding of the way an aquifer system works, particularly when long-term falling water levels are observed, which are indicative of over abstraction. Generally, on their own, groundwater level monitoring data can rarely be considered to represent the overall groundwater body Quantitative Status.

4.4.3 Information Required for This Test

For the Water Balance Test, an assessment of annual average groundwater abstraction against “available groundwater resource” in the groundwater body is required. The available groundwater resource is an approximate value, based on recharge and the flow requirements needed to support water uses and the wider environment in the catchment.

Where reliable groundwater level data across the groundwater body is available, it is used to identify the presence of a sustained long-term decline in water levels caused by long-term groundwater abstraction. Where such a decline is present it may indicate that the conditions for Good Status are not being met and the groundwater body is assigned Poor Status.

The annual average groundwater abstraction rate includes all abstractions from the groundwater body. Abstracted groundwater that has been locally returned to the aquifer or, in certain circumstances, to a river that is directly in connection with the aquifer, may be discounted (for example, this may occur during irrigation or at a quarry / mine dewatering operation).

Flow (lateral or vertical) between adjacent groundwater bodies is taken account of when carrying out the water balance test. Alternatively, groundwater bodies can be grouped to simplify the water balance assessment. Therefore, groundwater bodies that have been delineated because of the presence of point sources of pollution, or for urban areas, may be joined with their parent groundwater body for the purposes of this test.

The WFD Working Group on Groundwater Guidance Document No. 5 (2004) and the SNIFFER WFD 53 Report (2005) provide abstraction-recharge ratio figures that can be used to determine abstraction risk, and these are applied for the status assessment in Ireland.

4.4.4 Criteria for Poor Status

In accordance with the WFD, groundwater bodies where abstraction exceeds recharge are classified as Poor Status (with high confidence). Therefore, if the calculated abstraction: recharge ratio is greater than 100%, the groundwater body automatically defaults to Poor Status.

However, this does not leave any water resource to support water uses and the wider environment across the groundwater body. An arbitrary figure of 20% of recharge is left to support water uses and the wider environment. Therefore, where the Abstraction: Recharge ratio is greater than 80%, the groundwater body is at Poor Status (with high confidence).

From the WFD Working Group on Groundwater Guidance Document No. 5 (2004), a groundwater body is at risk of failing its WFD objectives if the Abstraction: Recharge ratio is greater than:

- 5% for groundwater bodies that are supporting a GWDTE;
- 20% for bedrock groundwater bodies; and
- 30% for gravel groundwater bodies.

Where these percentages are exceeded and there is evidence of falling groundwater levels, the groundwater body is at Poor Status (with low confidence).

4.4.5 Methodology

The test is based on an analysis of recharge, ecological flow needs and groundwater abstraction volumes. It is a groundwater body-wide test.

The following information is required for this test.

Average annual recharge: This is estimated for each groundwater body using the most recently published GSI recharge map. No account is taken of any potential inflows from the surrounding groundwater bodies, although some groundwater bodies are grouped together for the assessment.

Average annual abstraction: The average annual abstraction quantity is approximated as the sum of all the groundwater abstractions from each groundwater body; these include public water supplies, private group schemes, larger private supplies, industrial supplies and dewatering of mines and quarries. This data is obtained from the EPA’s National Water Abstraction Register. Private domestic supplies less than 25m^3/day are not accounted for.

Note: On-site wastewater treatment discharges are not taken into account. Additionally, spring abstractions that have intercepted flows and are not actively pumped are not included in the abstracted quantity.

Groundwater level monitoring data: Where a groundwater body is considered to be at risk from over-abstraction and there is evidence of sustained falling water levels in the EPA’s National Groundwater Monitoring Network, the groundwater body is classified as Poor Status.

The Abstraction: Recharge ratio is calculated for each groundwater body and used to assign status categories, as show in Table 11.

Groundwater bodies are classified as Poor Status if the Abstraction: Recharge ratio is greater than 80%. Groundwater bodies are also classified as Poor Status where the Abstraction: Recharge ratio is greater than 5%, 20% or 30% for groundwater bodies supporting GWDTEs, bedrock groundwater bodies, or gravel groundwater bodies respectively, and where there is evidence of sustained falling groundwater levels at monitoring points within the groundwater body.

Table 11 Status category based on proportion of recharge used by abstractions

Annual Abstraction / Recharge Ratio	Groundwater Body Type	Falling Water Levels	Status & Confidence
>80%	-	-	Poor – High Confidence
30-80%	Gravel	Yes	Poor – Low Confidence
30-80%	Gravel	No	Good – Low Confidence
<30%	Gravel	-	Good – High Confidence
20-80%	Bedrock	Yes	Poor – Low Confidence
20-80%	Bedrock	No	Good – Low Confidence
<20%	Bedrock	-	Good – High Confidence
5-80%	Supporting a GWDTE	Yes	Poor – Low Confidence
5-80%	Supporting a GWDTE	No	Good – Low Confidence
<5%	-	-	Good – High Confidence

4.4.6 Future Developments

This is a groundwater body wide test, which uses average annual abstraction and recharge values. Therefore, estimates of the groundwater abstraction impacts used in the test are taken at a very high level and the more detailed surface water and GWDTE tests should identify impacts on receptors that are dependent on groundwater.

5 Trend and Trend Reversal Assessments of Pollution

5.1 Introduction

Part VI of the Groundwater Regulations indicate that the Environmental Protection Agency should identify significant and sustained upward trends in the concentration of pollutants in groundwater bodies or groups of bodies identified as being at risk of failing to achieve the objectives of the WFD. In groundwater bodies or groups of bodies that are not at risk of failing to achieve the objectives of the WFD, it may also be necessary to undertake trend assessments, to determine changes in natural conditions or to identify future changes due to anthropogenic activity.

Regulation 56 indicates that trend assessments must be undertaken, where necessary, to verify that plumes from contaminated sites do not expand to such an extent that they put a groundwater body at Poor Status.

Where significant and sustained upward trends are identified, Member States are required to reverse these trends through the introduction of programmes of measures (PoMs). Generally, it will take a number of years before the impact of measures is seen in groundwater systems. Therefore, upward trends need to be identified in sufficient time, so PoMs can bring about a reduction in pollution and prevent deterioration in groundwater quality, thereby reducing the chance of failing the relevant WFD objectives.

Regulation 55 indicates that the starting point for trend reversal must be expressed as a percentage of the relevant groundwater quality standard or Threshold Value (TV). The start date for trend reversal is based on the significance of the trend and the risk associated with it. By default, Schedule 8 (Part B) of the Regulations indicates that the starting point for trend reversal is the date when 75% of the standard or TV is likely to be exceeded, but an earlier or later starting date can be chosen to meet the environmental objectives in a cost-effective manner.

Regulation 58 require that the trend assessment methodology and, where sufficient data are available, the first assessment of trends, be reported in, or with, the first River Basin Management Plan, and then at least every six years thereafter.

Regulation 32 indicates a black dot must be used on River Basin Management Plan maps to identify groundwater bodies with significant upward trends. A blue dot must be used where upward trends have been reversed within a groundwater body.

5.2 Background

Trend and trend reversal assessments are based on monitoring data gathered at individual surveillance and operational monitoring points (EC, 2009), although this may be supplemented by additional representative data from other sources, where this improves confidence in the assessment. Monitoring should be sufficient (spatially and temporally) to take account of short-term variability in pollutant concentrations and natural fluctuations (e.g. in groundwater recharge).

The length (period) of time series required for robust trend assessments depends on the hydrogeological characteristics of the groundwater body and how the system reacts to changes in land use practices and remedial measures. The minimum assessment period should relate to the monitoring frequency and the robustness of the statistical trend method used. However, in order to avoid bias in the assessment, a consistent length of time series of data should be used for each monitoring point undergoing trend assessment. On this basis, a standard period of ten years of monitoring data from the EPA's National Groundwater Monitoring Network is used to identify trends for chemical status tests.

In the context of the WFD, Regulation 3 indicates that a significant and sustained upward trend is a trend that is both statistically and environmentally significant, causing an increase in concentration of a pollutant, group of pollutants, or indicator of pollution in groundwater for which trend reversal would be required. Article 2 of the Groundwater Directive indicates that the pollutants are those that would present a significant risk of harm to the quality of aquatic or terrestrial ecosystems, to human health, or to actual or potential legitimate uses of the water.

A statistically significant trend is one that is identified using a recognised statistical trend assessment technique. An environmentally significant trend is one that is statistically significant, which if not reversed would lead to the failure of one or more of the WFD's environmental objectives (EC, 2009).

5.3 Requirements for Trend and Trend Reversal Assessment

5.3.1 Initial Assessment of Trend Significance

Trend assessments are initially undertaken at individual monitoring points to determine whether a groundwater body has significant and sustained upward or downward trends in concentrations of natural parameters or pollutants (UKTAG, 2012c). Where a statistically significant upward trend is identified at an individual monitoring point, this trend must be tested for environmental significance.

Regulation 53 indicates that trend assessments must be undertaken for parameters that are placing a groundwater body at risk of failing a groundwater chemical status objective, i.e. those parameters that relate to drinking water, saline intrusion, surface water or groundwater dependent wetland assessments.

For each of these objectives, the test for environmental significance depends on the WFD objective being assessed, e.g. when assessing the use (or potential use) of groundwater as a source of drinking water, the test for environmental significance relates to TVs derived from drinking water standards.

5.3.2 Assessing Trends Across Groundwater Bodies

Where an environmentally and statistically significant upward trend is identified at an individual monitoring point, EU Guidance (EC, 2009) recommends that an additional trend assessment should be undertaken using aggregated data from all the monitoring points within the groundwater body or group of bodies. The presence of an environmentally and statistically significant upward trend at any individual monitoring point will not on its own lead to a requirement to report that the groundwater body or group of bodies have an upward trend (UKTAG, 2012c). However, the presence of an environmentally and statistically significant upward trend for the aggregated data will lead to a requirement to report that the groundwater body or all bodies in the group have an upward trend.

To ensure that PoMs are introduced in sufficient time, the test for environmental significance requires a determination as to whether the environmental objectives of the WFD will not be met in the future. Given the planning cycle for PoMs and the likely timescale required before the impact of measures are seen in groundwater, the test of environmental significance is projected forward two River Basin Management Planning cycles (UKTAG, 2012c).

Where an environmentally and statistically significant upward trend has been reported for a groundwater body or group of bodies, and where PoMs have been implemented, further trend assessments should be undertaken to demonstrate the reversal of trends.

5.3.3 Assessing Trends to Support Status Assessments

In addition to identifying whether significant and sustained upward trends in the concentration of pollutants exist in groundwater bodies or groups of bodies, trend assessments are also used as part of the status assessments in relation to certain WFD objectives, e.g. Drinking Water and Saline Intrusion. The status trend assessments are undertaken at individual monitoring points.

When assessing the use of groundwater as a source of drinking water or when assessing the impact of saline intrusion, the presence of an environmentally and statistically significant upward trend at any individual monitoring point results in the whole groundwater body being reported as having an upward trend (UKTAG, 2012c).

5.3.4 Data Requirements and Trend Assessment Techniques

When assessing trends, data should be considered for as long a time series as is deemed necessary to demonstrate a trend. As a minimum, a time series length of six years is required, with at least one measurement in each year (UKTAG, 2012c). Where data gaps exist, the length of time series should be extended. Identification of trend reversal is only required where an environmentally significant upward trend has been identified, and measures have been put in place to reverse the trend. A standard period of ten years of monitoring data from the EPA's National Groundwater Monitoring Network is used to identify trends for chemical status tests.

As groundwater data have asymmetric or non-normal distributions, non-parametric statistical methods are required for trend assessment (UKTAG, 2012c). Many groundwater systems have considerable seasonal variability in parameter concentrations, which can impact on trend assessments. The non-parametric seasonal Kendall test is a statistical method that reduces the impact of seasonality on trend assessments (Salmi *et. al.*, 2002). Where significant trends have been detected, the Sen's method can be used to project the trend into the future, as this method is robust when there are outliers or gaps in the time series data (Salmi *et. al.*, 2002).

Where parameter concentrations are reported as being below the analytical limit of quantification (LOQ), the recommended approach for statistical analysis is to replace these values with half the reported LOQ (UKTAG, 2012c). However, trend assessments are not undertaken on datasets that comprise of more than 80% of values that are below the LOQ (UKTAG, 2012c).

As data availability improves, confidence in the assessment should also improve, although for a trend to be reported as being statistically significant there should be at least 90% confidence that the trend is statistically significant (UKTAG, 2012c).

5.4 Methodology

5.4.1 Statistical Approach

The Mann-Kendall test for trends and a Sen's test for slope projection is used for detecting and estimating trends in time series using annual values. The presence of a monotonic increasing or decreasing trend is tested with the non-parametric Mann-Kendall test, and secondly, the slope of a linear trend is estimated with the non-parametric Sen's method (Gilbert, 1987).

The statistical programme reports a positive value for an upward trend and a negative value for a downward trend. In addition, a two-tailed test is used to determine the significance of trends at four different levels (Salmi *et. al.*, 2002). Respectively, a significance level of 0.1 means that there is a 90% probability that there is a significant trend, 0.05 means that there is a 95% probability that there is a significant trend. 0.01 means that there is a 99% probability that there is a significant trend and 0.001 means that there is a 99.9% probability that there is a significant trend. Where no value is reported, the trend is not deemed to be significant.

The Sen's non-parametric method is used to estimate the true slope of an existing trend (recorded as a change year on year) and projects the slope forward to a pre-defined date. Confidence intervals of 99% and 95% are computed around the predicted concentrations. If a positive trend is detected, the trend is projected forward two River Basin Planning cycles to determine environmental significance, i.e. to determine if a TV will be breached within two planning cycles.

5.4.2 Determination of Trends at Individual Monitoring Points

Annual average concentrations are calculated at monitoring points over a period of ten years and are calculated for parameters deemed to be placing a groundwater body at risk. Parameters are not considered for trend assessment unless they had a minimum of six years data during the ten-year period.

Where trends are determined at individual monitoring points, the statistical significance of the trend is calculated in accordance with the approach outlined in Section 5.4.1.

If a statistically significant upward trend is discovered at an individual monitoring point, the environmental significance of the trend is determined, i.e. the concentration of the parameter with the significant trend is predicted in two WFD cycles. This predicted concentration is compared with the appropriate TV. If the predicted concentration exceeds the TV in two WFD cycles, the trend is deemed to be statistically and environmentally significant.

5.4.3 Determination of Trends for Groundwater Bodies or Groups of Bodies

Where a statistically significant trend is discovered at an individual monitoring point, data for the upward trending parameter is aggregated for all monitoring points in the groundwater body or group of bodies. Annual average concentrations are then calculated for the whole group of monitoring points and trends are determined using the Mann-Kendall test and Sen's method (Gilbert, 1987). If a statistically significant upward trend is discovered for the group of monitoring points, the concentration of the parameter with the significant trend is predicted in two WFD cycles. If the concentration exceeds the TV after two cycles, the groundwater body or group of bodies are deemed to have statistically and environmentally significant trends and are therefore subject to trend reversal.

5.4.4 Determination of the Starting Point for Trend Reversal

Regulation 58(e) requires the Environmental Protection Agency to define the starting point for trend reversal as a percentage of the groundwater quality standards or TVs. As per Schedule 8 (Part B) of the Regulations, the starting point for trend reversal is when the concentration of the pollutant reaches 75% of the parametric value of the groundwater quality standards or TVs included in the Regulations. Therefore, measures should be introduced on or before the date when 75% of the TV (concentration) of the parameter with the statistically and environmentally significant trend is exceeded. The statistical package predicts the concentration for a particular parameter in each year until the last year for the subsequent two WFD cycles. This allows the year in which the trend is predicted to exceed 75% of the TV to be determined. This year becomes the starting date for trend reversal and is the year in which PoMs should be introduced, although an early start date can also be chosen.

6 References

DHI (2004), *MIKE 11 User & Reference Manual*, Danish Hydraulic Institute, Denmark.

Environmental Protection Agency (2006). *Water Framework Directive Monitoring Programme*. Environmental Protection Agency, Wexford, Ireland. 140

Environmental Protection Agency (2007). *Code of Practice: Environmental Risk Assessment for Unregulated Waste Disposal Sites*. Environmental Protection Agency, Wexford, Ireland.

Environmental Protection Agency (2011). *Guidance on the Authorisation of Discharges to Groundwater.* Environmental Protection Agency, Wexford, Ireland.

Environmental Protection Agency (2013). *Guidance on the Management of Contaminated Land and Groundwater at EPA Licensed Sites*. Environmental Protection Agency, Wexford. Ireland.

Environmental Protection Agency (2015). *An Approach to Characterisation as Part of the Implementation of the Water Framework Directive, Version 2 Revised*. Environmental Protection Agency, Wexford. Ireland.

Environmental Protection Agency (2022). *Assigning WFD Status to Unmonitored Water Bodies in 2013-2018*. Environmental Protection Agency, Wexford. Ireland.

European Commission (2007) *Identification of Water Bodies*, CIS Guidance Document No. 2, Luxembourg: Office for Official Publications of the European Communities, 2003.

European Commission (2003) *Monitoring under the Water Framework Directive*, CIS Guidance Document no. 7, Luxembourg: Office for Official Publications of the European Communities, 2007.

European Commission (2007) *Guidance on Groundwater Monitoring*, CIS Guidance Document no. 15, Luxembourg: Office for Official Publications of the European Communities, 2007.

European Commission (2009) *Guidance on Groundwater Status and Trend Assessments*, CIS Guidance Document no. 18, Luxembourg: Office for Official Publications of the European Communities, 84 pp.

European Commission (2015) *Technical Report on Groundwater Associated Aquatic Ecosystems.* Technical Report No. 9, Luxembourg: Office for Official Publications of the European Communities.

European Communities (Water Policy) Regulations, 2003 (S.I. No. 722 of 2003).

European Communities (Drinking Water) (No. 2) Regulations, 2007 (S.I. No. 278 of 2007).

European Communities Environmental Objectives (Surface Waters) Regulations, 2009 (S.I. No. 272 of 2009).

European Communities Environmental Objectives (Groundwater) Regulations, 2010 (S.I. No. 9 of 2010).

European Council Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive).

European Council Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration (Groundwater Directive).

European Union (Water Policy) (Abstraction Registration) Regulations 2018. (S.I. No.261 of 2018).

Gilbert, R. (1987) *Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York, 320 pp.*

Gill, L., Bhatnagar, S., Ella Bijkerk, E., Regan, S., Somlai, C., Naughton, O., Bidisha Ghosh, B., Waldren, S., Coxon, C. and Johnston, P. (2022). *Ecometrics – Environmental Supporting Conditions for Groundwater-dependent Terrestrial Ecosystems*. (EPA Research Report No. 403). Environmental Protection Agency, Wexford. Ireland.

Geological Survey of Ireland (2009), *Classification of Groundwater Bodies: General Chemical Test for Closed Mine Sites*. Geological Survey of Ireland, Dublin, pp 31 (report available from the Environmental Protection Agency).

Geological Survey of Ireland (2020). *National Groundwater Recharge Map.* IE_GSI_Groundwater_Recharge_40K_IE26_ITM. Geological Survey of Ireland, Dublin.

Kilroy, G., Dunne, F., Ryan, J., O'Connor, Á., Daly, D., Craig, M., Coxon, C., Johnston, P. and Henning Moe, H. (2008). *A Framework for the Assessment of Groundwater-Dependent Terrestrial Ecosystems under the Water Framework Directive.* STRIVE Research Report. Environmental Protection Agency, Wexford, Ireland.

Kimberley, S. and Coxon, C. (2013). *Evaluating the Influence of Groundwater Pressures on Groundwater dependent Wetlands*. STRIVE Research Report. Environmental Protection Agency, Wexford, Ireland.

RPS (2009), *WFD Programmes of Measures and Standards Water Balance Study*. Study undertaken by RPS on behalf of the Shannon River Basin District, pp. 72 (report available from the Environmental Protection Agency).

Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T. and Amnell, T. (2002) *Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Slope Estimates-The Excel Template Application MAKESENS*. Finnish Meteorological Institute, pp. 35.

SNIFFER Research project WFD53 (2005): *Criteria for WFD Groundwater 'Good Quantitative' Status and a Framework for the Assessment of Groundwater Abstractions, pp. 88.*

Tedd, K., Coxon, C., Misstear, B., Daly, D., Craig, M., Mannix, A. and Taly Hunter Williams, T. (2017). *Assessing and Developing Background Levels for Chemical Parameters in Irish Groundwater*. (EPA Research Report No. 183). Environmental Protection Agency, Wexford. Ireland.

UKTAG (2012a) *Groundwater Chemical Classification for the purposes of the Water Framework Directive and the Groundwater Daughter Directive.* Paper 11b(i), UK Technical Advisory Group on the Water Framework Directive, pp 28.

UKTAG (2012b) *Groundwater Quantitative Classification for the purposes of the Water Framework Directive*. Paper 11b(ii), UK Technical Advisory Group on the Water Framework Directive, 14 pp.

UKTAG (2012c) *Groundwater Trend Assessment (Draft V0.4).* UK Technical Advisory Group on the Water Framework Directive.

UKTAG (2013) *Updated Recommendations on Environmental Standards.* UK Technical Advisory Group on the Water Framework Directive.

Water Environment (Abstractions and Associated Impoundments) Regulations 2024 (S.I. No. 419 of 2024).

Waldren, S., Allott, N., Coxon, C., Cunha Periera, H., Gill, L., Gonzalez, A., Irvine, K., Johnston, P., Kimberley, S., Murphy, M., Naughton, O., O'Rourke, A., Penck, M., Porst, G. and Sharkey, N. (2015). *Turlough Hydrology, Ecology and Conservation*. National Parks and Wildlife Services, Department of Arts, Heritage and the Gaeltacht, Dublin.

WFD Working Group on Groundwater (2004) *Assessment of the Impact of Groundwater Abstractions.* Guidance Document No. 5, undertaken by the Irish Working Group on Groundwater, 25pp (available from the Environmental Protection Agency).

WFD Working Group on Groundwater (2005) *The Characterisation and Analysis of Ireland's River Basin Districts*, undertaken by the Irish Working Group on Groundwater, 166 pp. (available from the Environmental Protection Agency).