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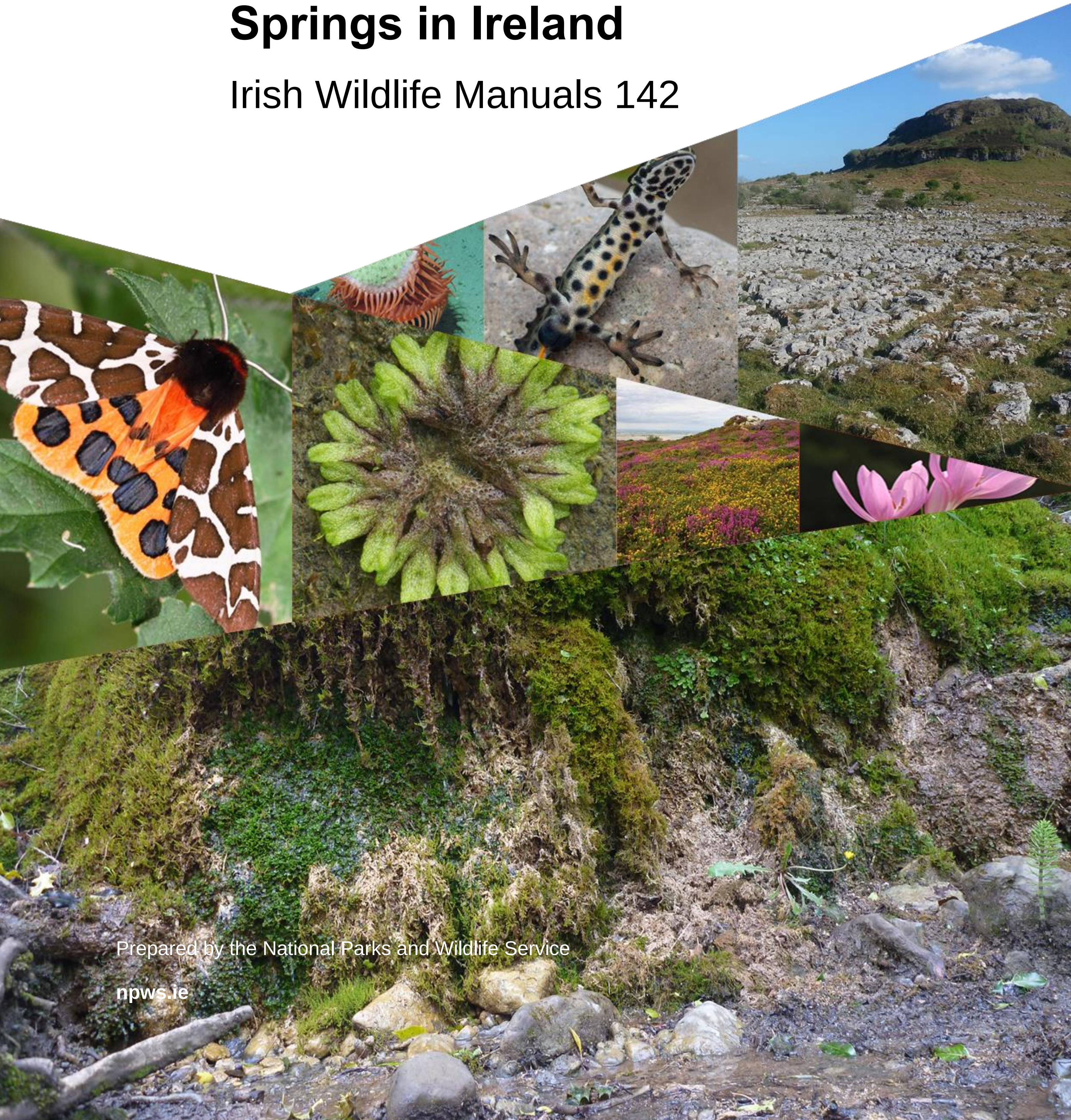
National Parks and Wildlife Service

Guidelines for the Assessment of Annex I Priority Petrifying Springs in Ireland

Irish Wildlife Manuals 142



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Front cover, small photographs from top row:

A deep water fly trap anemone *Phelliactis* sp., Yvonne Leahy; **Common Newt** *Lissotriton vulgaris,* Brian Nelson; **Limestone pavement**, Bricklieve Mountains, Co. Sligo, Andy Bleasdale; **Garden Tiger** *Arctia caja,* Brian Nelson; **Violet Crystalwort** *Riccia huebeneriana*, Robert Thompson; **Coastal heath**, Howth Head, Co. Dublin, Maurice Eakin; **Meadow Saffron** *Colchicum autumnale*, Lorcan Scott

Bottom photograph: **Petrifying Spring in woodland**, Gortnagrelly, Co. Sligo, Joanne Denyer

Guidelines for the Assessment of Annex I Priority Petrifying Springs in Ireland

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Executive Summary

Petrifying springs are a specialised habitat that forms where calcareous waters deposit tufa (a porous rock made of calcium carbonate). The tufa formation may be small deposits around the bases of plants within the spring, or can comprise very large mounds and cascades. Petrifying springs are dominated by bryophytes (mosses and liverworts) and often support rare plant and animal species. They can occur in semi-natural habitats such as seepages on coastal cliffs, springs in upland fens and wooded springs, but are also found in artificial habitats such as quarries, water troughs, seepages on walls and in roadside ditches.

As small, groundwater dependent wetland habitats, petrifying springs are very sensitive to changes in water quality and quantity and land management. Petrifying springs are designated as a priority habitat in Annex I of the European Union Habitats Directive in recognition of their vulnerability. The correct identification, assessment and evaluation of petrifying springs is therefore essential for wetland conservation

Petrifying springs have been well studied in Ireland and there is existing guidance on the ecological survey, conservation status assessment and monitoring of Irish petrifying springs. However, there are areas where there are currently gaps in guidance provision, for instance the definition of what constitutes an Annex I Priority petrifying spring in Ireland, the specialist expertise required for ecological and hydrogeological assessment and evaluation of atypical petrifying spring types.

This manual provides new information and guidance on the hydrogeological assessment of petrifying springs; the skills and expertise required to undertake an ecological survey of a petrifying spring; the regulatory context of Annex I petrifying springs; and the criteria that should be used to assess the ecological value of Annex I priority petrifying spring habitat. It provides updated information on the most recent names that should be used for petrifying spring plants and bryophytes (nomenclature); lists of plant and bryophyte species used to indicate whether or not a petrifying spring is in good condition (Indicator Species); criteria used to calculate a score to indicate the conservation value of a spring (Conservation Score) and its value in relation to other known Irish petrifying springs (National Ranking). The final section includes twelve examples of petrifying springs. These have been selected to illustrate a number of potential issues that arise when assessing and evaluating petrifying springs such as the assessment of artificial or modified springs; atypical springs; springs with high cover of invasive species; springs without any positive indicator species present; springs without any tufa formation; tufa forming rivers and streams; and springs in poor ecological condition. This will be of assistance to ecologists and conservation practitioners, particularly in relation to ecological or environmental assessments.

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Organisations/groups: Abbeyleix Bog Project, Ballywaltrim Lane Residents Group, BEC Consultants, Blackthorn Ecology, Dún Laoghaire-Rathdown County Council, Sligo County Council, Wetland Surveys Ireland.

Individuals: Peter Foss, Rory Hodd, Melinda Lyons, Jim Martin, Anne Murray, Philip Perrin, George Smith, Andrew Speer, Faith Wilson.

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1 Introduction

1.1 Background

'Petrifying springs with tufa formation (*Cratoneurion*)' [Natura 2000 code 7220] are listed as a Priority Habitat on Annex I of the Habitats Directive. These are bryophyte dominated springs with tufa formation. They can occur in semi-natural habitats such as seepages on coastal cliffs, springs in upland fens and wooded springs, but are also found in artificial habitats such as quarries, water troughs, seepages on walls and in roadside ditches. Note that as the term 'petrifying' by definition denotes tufa formation, this habitat is often abbreviated to 'petrifying springs'.

As a priority Annex I habitat, correct identification and evaluation of petrifying springs is essential for wetland conservation. The most detailed Irish study on this habitat is Lyons (2015) and guidance on monitoring and vegetation classification of Annex I petrifying springs is provided in Lyons & Kelly (2016, 2017). However, there are areas where there are gaps in guidance provision, for instance the definition of what constitutes an Annex I Priority petrifying spring in Ireland, the specialist expertise required for ecological and hydrogeological assessment and assessment and evaluation of atypical petrifying spring types. Lyons (2015) states '*The concept of the petrifying spring habitat type is at once obvious and challenging to define. The bryophyte-dominated vegetation of typical examples is highly distinctive, yet there is considerable variation in floristic composition and it is difficult to determine the boundaries between this and other related vegetation types*'.

The aim of these guidelines is to provide additional guidance on these issues. This will be of assistance to ecologists and conservation practitioners, particularly in relation to ecological or environmental assessments.

A desk-based review was undertaken using a range of data sources on springs in Ireland, including PhD data from Lyons (2015), the Article 17 reporting database (NPWS, 2019) and additional county data on petrifying springs collected post 2019. This includes a county dataset from Dún Laoghaire–Rathdown (DLR) in County Dublin (with permission from Dún Laoghaire–Rathdown County Council). There have been a number of petrifying spring investigations in DLR (2018 to 2020) including a desk-based hydrogeological and ecological review, surveys of potential additional spring sites and a review of the identification and ecological evaluation of Annex I priority 7220 springs in the DLR area.

Consultation was undertaken with wetland ecologists and hydrogeologists. Ecologists were asked to provide information on spring sites where they had difficulty in assessing whether or not a spring was Annex I priority habitat and/or issues when assessing its ecological status, national ranking and/or legal status.

The information from these sources was collated and expert judgement and consultation were used to refine the current criteria used for the identification and ranking of Annex I Petrifying springs. These guidelines should be used in conjunction with Lyons (2016).

1.2 Current national survey and assessment guidance

The current guidance for the survey and assessment of petrifying springs habitat within Ireland is based on three key publications:

- Lyons, M.D. & Kelly, D.L. (2016) **Monitoring guidelines for the assessment of petrifying springs in Ireland**. Irish Wildlife Manuals, No. 94. National Parks and Wildlife Service, Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs, Ireland.

- Lyons, M.D. and Kelly, D.L. (2017). **Plant community ecology of petrifying springs (*Cratoneurion*) – a priority habitat**. Phytocoenologia: 47 (1) 13–32.
- Lyons, M.D. (2015). **The flora and conservation status of petrifying springs in Ireland**. Ph.D. thesis, The University of Dublin, Trinity College, Dublin

Guidance and information in these publications is used to survey and assess petrifying springs as summarised below:

- **Detailed spring survey** (relevé sampling) follows Lyons & Kelly (2016). Criteria recorded include: tufa (type and cover); water (type and cover); vascular plant, bryophyte and *Chara* species (presence and percentage cover); woody species and vegetation height.
- **Petrifying spring vegetation communities** are classified using Lyons & Kelly (2017), with additional information provided in Lyons (2015). Eight plant communities are recognised.
- **Condition assessment** follows Lyons & Kelly (2016). Criteria include: positive and negative indicator species (frequency and cover); woody species cover; vegetation height and disturbance.
- **Conservation score and National ranking** follows Lyons & Kelly (2016). Criteria such as: species diversity; High Quality indicator species; tufa-forming capacity and other positive characteristics are used to calculate the conservation score for each spring. This score is then used to rank the quality of the spring at a national level Lyons & Kelly(2016); Lyons, (2015).

Under Article 17 of the EU Habitats Directive, Member States of the European Union are required to report every six years on the conservation status of all habitats and species listed on the annexes of the Habitats Directive. The latest National Conservation Status Assessments for petrifying springs is for the 2013 to 2018 reporting period (NPWS, 2019). There is a backing document, which accompanies this report with additional relevant information (Denyer & Long, 2018). Conservation Status assessments for previous reporting periods are also available (NPWS, 2013 and 2008), and the backing document for 2013 (Kimberley, 2013).

1.3 Guidance provided in this document

These guidelines on the identification and assessment of Annex I priority petrifying springs (*7220) in Ireland provide new information and guidance on:

- Hydrogeological assessment of petrifying springs (Section 2)
- Ecological assessment of petrifying springs (Section 3)

In relation to the ecological assessment of petrifying springs these guidelines should be read in conjunction with Lyons & Kelly (2016, 2017) (see Section 1.1)

These guidelines provide additional information not included in the above publications on:

- Required ecological surveyor expertise (Section 3.1)
- Regulatory context of Annex I petrifying springs (Section 3.5.1)
- Ecological evaluation of Annex I priority petrifying spring habitat (Section 3.5.3)
- Examples of petrifying spring identification and assessment (Section 4)

These guidelines provide updated information on guidance included in the above publications on:

- Vascular plant and bryophyte nomenclature (Section 3.2)

- Indicator species lists (Section 3.3)
- Identification of Annex I priority petrifying springs (Section 3.4)
- Conservation Score calculation (list of 'Additional positive characteristics' provided) (Section 3.5.2)
- National Ranking (information in relation to Annex I priority habitat status provided) (Section 3.5.3)

2 Hydrogeological assessment

This section provides updated criteria and additional guidance on the assessment and evaluation of Annex I priority petrifying springs. It is based on existing national guidance (Section 1.2) and only includes sections which have been revised, or which are additional to the guidance in these publications. It includes:

- Summary of petrifying springs hydrogeology.
- Required hydrogeologist expertise.
- Examples of site-specific hydrogeological studies.
- Catchment based water balance approach for delineation of the Zone of Contribution to petrifying springs.
- Petrifying springs Conceptual Site Models.
- Recommended water chemistry sampling for petrifying springs.
- Notes on the assessment of hydrogeological impacts to petrifying springs.

2.1 Petrifying springs hydrogeology

Petrifying springs are recognised as groundwater-dependent terrestrial ecosystems under the requirements of the Water Framework Directive 2000/60/EC, which imposes an obligation to maintain and improve the status of the groundwaters which feed the springs. The most important process in the formation of tufa occurs in the subsurface environment and Pentecost (2005) recognises several hydrological and hydrogeological conditions required for its formation:

1. The presence of geological materials rich in calcium carbonate. This may be in the form of carbonate bedrock and/or carbonate derived soils or subsoils.
2. The presence of carbon dioxide ($CO_{2)}$ in the soil is required to transform groundwaters into a weak carbonic acid capable of dissolving calcium carbonate and transporting it as soluble calcium bicarbonate. CO_2 may be from epigenic (respiration in the soil) or hypogenic sources (deep sources such as the metamorphism of carbonate bedrock).
3. Suitable groundwater characteristics and flow regimes. This can include shallow groundwater flows through permeable overburden or deeper groundwater flow through fractured/faulted bedrock. To allow for tufa aggradation, flow rates should be low, to prevent erosion exceeding tufa formation.
4. Suitable location where the CO_2-rich groundwaters can emerge, degas and deposit insoluble calcium carbonate as tufa. Emergence of groundwater may occur where the ground level intersects stratigraphic surfaces, perched water tables or permeable fractures and fault zones.

In Ireland, petrifying springs have a wide distribution due to the extensive cover of limestone derived glacial sediments and the associated limestone bedrock, high precipitation rates and a mild climate.

2.2 Required hydrogeologist expertise

Based on a review of available reports and studies (Section 2.3), it is clear that the hydrogeological component of any petrifying spring study is critically important in characterising a known spring site. Moreover, even with a wealth of field data it is apparent that complete certainty of such characterisation is often hard to achieve. Notwithstanding this, very good conceptual site models (CSM) can be determined to allow further assessment, and the certainty around the conclusions of such assessments is a function of the quality of the field data collected and the interpretation of that data.

In short, an experienced hydrogeologist is needed to characterise known petrifying spring sites. The level and detail required depends on the required assessment type. More often than not, in order to generate a robust CSM for impact assessment (Environmental Impact Assessment Report (EIAR)/Natura Impact Statement (NIS) assessments), iterative phases of site investigation and seasonal monitoring (see Table 1 for suggested hydrogeological data types) may be required at known spring sites to generate the confidence and detail needed to underpin a robust CSM and any subsequent impact assessment on the spring(s).

2.3 Site-specific hydrogeological studies

A number of site-specific hydrogeological studies have been completed at spring locations, including:

Slieve Bloom Mountains Special Area of Conservation (SAC): A previous study (Heery, 2007) of tufa forming springs in the Slieve Bloom Mountains in County Offaly revealed that the source of the calcium rich groundwater feeding the springs was predominantly from the limestone derived glacial drift. Some groundwater, however, was also found to be derived from caliche, a hardened natural carbonate cement, found within certain strata of the underlying Old Red Sandstone. In addition, the majority of the identified springs were classified as “cascades”, with water trickling down a steep slope. Occasionally springs were found to emerge on flat ground and result in the formation of alkaline fens.

Dun Laoghaire-Rathdown: Hydro-Environmental Services (HES) have previously investigated the occurrence of petrifying springs in Dun Laoghaire-Rathdown council area (Denyer Ecology, 2020). The study identified two common hydrogeological attributes associated with known occurrences of petrifying springs. These included the proximity to limestone derived gravels and tills, with the former supporting more favourable conditions, and the presence of steeply sloping ground in close proximity to watercourses, where seepages and groundwater discharges were likely to occur. The combination of both of these conditions were found to increase the likelihood of the occurrence of petrifying springs.

Knocksink Wood SAC: HES investigated the occurrence of petrifying springs in Knocksink Wood SAC (HES, 2020). The study was associated with a proposed housing development at Kilgarron, so it mainly focused on the western and southern banks of the Glencullen River upstream of Enniskerry. The study involved field mapping, geological investigations, seasonal water level monitoring, seasonal spring flow measurements, water chemistry sampling, and delineation of a Zone of Contribution (ZoC) to the spring discharges, and an impact assessment arising from the proposed housing development. A conceptual site model was described and illustrated in cross-section, indicating the local hydrogeology as consisting of two separate groundwater flow systems, a shallow sand and gravel system and an unproductive flow system in the underlying bedrock. The identified springs were a combination of: cascades with some discrete and some diffuse groundwater seepages; and stream crust with oncoids.

Ballyman Glen SAC: An EIAR prepared by Creagh House Environmental Ltd. (2021a, and 2021b) for an extension to Dun Laoghaire Golf Club investigated the local hydrogeological regime of the Ballyman area, Co. Wicklow. Additional hydrogeological reporting was completed by IE Consulting (2021) in response to several Request for Information (RFI) item requests. The proposed development is located upstream of Ballyman Glen SAC, for which petrifying springs with tufa formation (*Cratoneurion*) [7220] are a qualifying interest. The springs occur along the slopes of the glen and also along the margins of the Ballyman Stream. They mostly occur as seepage areas with massive cascade tufa deposits restricted to the riverbanks. Site investigations at Ballyman Glen included surface water catchment delineation, analysis of existing borehole information (geological logs and groundwater level monitoring), geophysical investigations and hydrochemical analysis of spring discharges. This information was used to produce a CSM and delineate a catchment for the petrifying springs. The CSM suggests that the springs are sustained by a shallow groundwater system in the sand and gravel aquifer rather than a larger regional groundwater flow system in deeper bedrock, although the underlying bedrock may play a supporting hydrogeological role during periods of drought. Groundwater recharge percolates through the soil and subsoils, dissolving CO_2 from soil gas and calcium carbonate from limestone derived material in the subsoils, until it reaches the groundwater table in the gravel aquifer. Groundwater follows the local topographic gradient, flowing downslope towards Ballyman stream and discharges as seepage zones or baseflow into the stream.

Garrycastle, Athlone: A soil and Water Environmental Assessment Report prepared by AWN Consulting (AWN, 2020) for a proposed development at Garrycastle investigated the local hydrogeological regime of the area. Petrifying springs have been mapped in a narrow woodland area adjacent a small stream to the south of the proposed development site (Denyer Ecology, 2018). Site investigations included trial pitting, borehole drilling and soakaway tests. The investigation found that the hydrogeological regime responsible for the tufa springs is very localised and does not represent the wider hydrogeological regime of the site. Site investigations (not specific to the spring ZoC) encountered permeable limestone-derived sand and gravels with no evidence for extensive low permeability horizons which would prevent the vertical recharge of groundwater. The occurrence of the springs is attributed to the presence of localised lower permeability silt which is visible along the riverbanks close to the seepage zone. This silt causes local recharge to migrate horizontally rather than vertically as seen across the majority of the site, allowing the groundwaters rich in calcium carbonate to emerge in the River valley.

Louisa Bridge, Leixlip: A hydrogeological study of the Louisa Bridge "Leixlip Spa" site was completed by Hydro-G in 2008 (Hydro-G, 2008). The wetland area has developed on five distinct terraces with shallow bedrock and constitutes part of the Rye Water Valley SAC (site code 001398). The site contains many rare and protected habitats and species, including calcareous grassland and petrifying springs. Investigations of local water resources included identification of springs and seepages, in situ physiochemical analyses, hydrochemical analyses of selected discharge locations and flow measurements. Results facilitated identification of different groundwater discharge zones and conceptualisation of groundwater flow pathways within the site. The field monitoring and data analysis suggest that water at the Leixlip Spa site originates from a complex groundwater system combining two sources. The main source of water comes from a deeper, older and warmer groundwater system, discharging at the top of the first terrace through the Spa Well. The second is a more recent, shallow groundwater that flows through the karstified limestone bedrock with the main groundwater discharge located in the vicinity of the fen wetland habitat at the most elevated, southern terrace. Rainfall runoff also plays a part. A conceptual site model for groundwater flow was developed and presented in the study. It is inferred in the study that the hydrogeology of the site has been modified over the years, and a number of different mitigation/engineering measures are discussed and assessed to determine the most effective solution to observed hydrological and ecological changes.

Domville, Cherrywood: A hydrogeological risk assessment was undertaken by SBEC (2021) to support a planning application for a proposed residential development at Domville, Cherrywood. A preceding study by JBA (2019) also contains site investigation data and hydrogeological analysis. A series of tufa springs emerge at an escarpment to the east of the proposed development site, with the site lying within the precautionary catchment area to the springs (based on ArcGIS flow accumulation analysis and recharge calculations). Site investigations included trial pitting, borehole drilling, water level monitoring and hydrochemistry. Weathered granite bedrock underlies the area and hosts a groundwater body, with the area overlain by glacial till. Site investigations have found that recharge in the area immediately upgradient of the springs is limited by thick low permeability till deposits. Groundwater chemistry results suggest that higher permeability tills found in the upper area of the spring catchment, located further west, act as the key source of calcium carbonate. Spring recharge is therefore likely to be predominantly derived from this area rather than the area immediately adjacent the springs. The localised occurrence of the tufa springs has also been found to coincide with the location of a buried valley, cut into the granite bedrock, which is filled with silty sands. The springs emerge where this buried valley intersects the steep escarpment. The CSM states that the upper weathered layer of granite bedrock acts as a high permeability layer which discharges groundwater to the sand filled buried valley which acts as a preferential groundwater flowpath which, in turn, feeds the tufa springs to the east.

Gloucestershire: A UK study at 22 Gloucestershire sites was undertaken by BGS (Farr & Graham, 2017). The geological and topographical conditions (often steep topography, very high levels of saturated calcium carbonate associated with springs of the Stroud Valley area and large areas of woodland), was identified as having a high potential for petrifying spring habitat. Fifteen sites (68%) were identified as having the European Annex 1 habitat 7220, Petrifying springs with tufa formation (*Cratoneuron*), while seven sites had tufa formation without the requisite species complement to qualify as 7220. Identified pressures on the spring habitats included shading from forestry cover and water quality (nitrogen). Water chemistry sampling was completed at all sites (including field chemistry - pH, electrical conductivity, and temperature) and laboratory analysis for major ions, nutrients, and trace elements was also completed. The 22 sites were characterised using Wetland Water Supply Mechanisms (WetMEC) descriptions (Environment Agency, 2009) , with the most appropriate for the majority of the sites within this study being 'WETMEC 10a Permanent Seepage Slopes' and 'WETMEC 17 Groundwater flushed slopes', which often occurred together.

A summary of methods and analysis techniques used in previous Irish/UK petrifying spring studies is shown in Table 1.

Table 1 Summary of methods and analysis techniques used in previous Irish/UK petrifying spring studies

Hydro-geological data type	Slieve Bloom	DLR Study	Knocksink Wood	Ballyman Glen	Gary-castle	Louisa Bridge	Cherry-wood	UK Study (22 sites)
Desk Study	√	√	√	√	√	√	√	√
Field Mapping	√	√	√	√	√	√	√	√
Trial Pits (in ZoC)			√		√		√	√
Boreholes (in ZoC)			√	√	√		√	
Seasonal Water level monitoring (in ZoC)			√	√	√		√	
Spring flow: a) Single b) Seasonal			√ √			√		
Geophysical surveys (in ZoC)				√				
Subsoil/Bedrock Permeability tests			√		√			
Water Chemistry (SW and/or GW)			√	√	√	√	√	√
Water Balance (ZoC delineation)			√	√		√	√	
Conceptual Site Model			√	√	√		√	
WetMEC								√

On an international scale, Cantonati *et al.* (2016) conducted a literature review of known limestone forming springs, noting a general overlap of their worldwide distribution and the occurrence of carbonate bedrock. For example, in the Italian Northern Apennines, springs are found to occur in conjunction with siliciclastic-calcareous turbidites, in South Tibet they occur with metamorphosed carbonates and in the Andes with conglomerates and limestones. However, in some localities they occur in the absence of carbonate bedrock and must be fed with a different non-local source of CO_2 rich groundwater. For example, in south-east Utah, groundwaters in shallow aquifers are charged with CO_2 from depth and transported laterally for several kilometres before emerging as calcareous springs.

However, from all of these studies it is clear that these groundwater dependent habitats are highly vulnerable to changes in both groundwater quantity and quality. The threats to petrifying springs are numerous. Springs require a permanent discharge of groundwater and any lowering of water levels or change in flow rates can have an adverse impact. Water abstraction or drainage can therefore cause the springs to dry out and result in desiccation of the sensitive groundwater dependent habitats. In addition, water pollution through various land use changes in the catchment can lead to nutrient enrichment and contamination of emerging groundwater. Petrified springs are particularly sensitive to elevated nitrogen levels due to the absence of the buffering effect of peat, which can mitigate impacts in other habitats, such as fens.

It is therefore important to derive the catchment area of these springs to ensure that the hydrological/hydrogeological regimes are preserved. This allows any anthropogenic or land use pressures to be identified and mitigated against or to prevent future land use changes, which may negatively impact the springs.

2.4 Petrifying spring catchments – Zones of Contribution

A catchment-based water balance approach for delineation of the Zone of Contribution (ZoC) to groundwater supplies and spring supplies has been developed (DoELG, EPA/GSI, 1999). Similar to groundwater supplies (*i.e.* a pumped well or spring discharges), the catchment area that contributes (via recharge → groundwater flow → groundwater discharge) to a petrifying spring flow, *i.e*. its ZoC can be estimated using hydrogeological, topographical and water balance approaches. From an ecological perspective, a ZoC to a Petrifying Spring is equivalent to its Zone of Influence (ZoI).

The important differences are that petrifying spring discharges are often very small, are difficult to measures, they may be ephemeral, and there may be clusters of seepages/springs that occur along valley edges and discharge zones. The local geological structure and likely sources of calcium carbonate need to be considered when developing ZoCs for petrifying springs.

For discrete spring discharges it may be possible to measure spring flows seasonally and therefore quantify likely annual discharge flows and the required ZoC to support those flows. For more diffuse flows (seepages occurring over tens or hundreds of metres along a stream bank or break in slope), the ability to measure those seepages accurately, and to do so without modifying or damaging the tufa deposits and associated vegetation, may be a limiting factor in determining a likely ZoC.

Depending on the level of certainty required and the complexity of the spring location (there may be multiple springs discharging in any one area), then the ZoC delineation can be undertaken in two potential ways. The Max Potential ZoC approach is based on the largest possible extent of upstream groundwater catchment that feeds towards a spring/cluster of springs. This method is a very conservative approach, and may be considered where no flow measurements have been taken, or where it is not possible to accurately quantify spring flows without the potential for damaging the existing habitat. The standard ZoC approach uses conservative water balance methods to estimate the area of the ZoC (this method requires seasonal measurement of spring flows). These approaches are further explained in Table 2.

Table 2 Potential methods to delineate ZoC

ZoC Determination Method	Available Data → Assessment Approach
Max Potential ZoC	• No flow measurement possible (large seepage area, may cause damage to springs or need to modify springs to facilitate flow measurements, which is not recommended) • May not be possible to complete representative water sampling due to access limitations • Apply precautionary principle due to lack of data and ability to characterise the actual ZoC • Define outline Conceptual Site Model (CSM) • Estimate Max Potential ZoC boundaries based on topography and/or other logical hydraulic boundaries (groundwater divides, ridges, faults, etc)
Standard ZoC (Groundwater Protection Schemes Method)	• Based on seasonal flow measurements at discrete springs • Analysis of hydrochemistry to determine sources of water (shallow and/or deep) • Define actual CSM based on available hydrogeological data • Determination of recharge area required from long-term groundwater recharge • Apply a factor of safety of 1.5 or 2 depending on the quantity and quality of available hydrogeological and hydrochemical data • Determine ZoC boundaries based on catchment area required and other logical hydraulic boundaries (groundwater divides, ridges, faults, etc)

An example of a ZoC map for springs in Knocksink Wood SAC is shown below in Figure 1. This ZoC was determined using the ZoC (Groundwater Protection Schemes Method), as seasonal spring flow measurements were available.

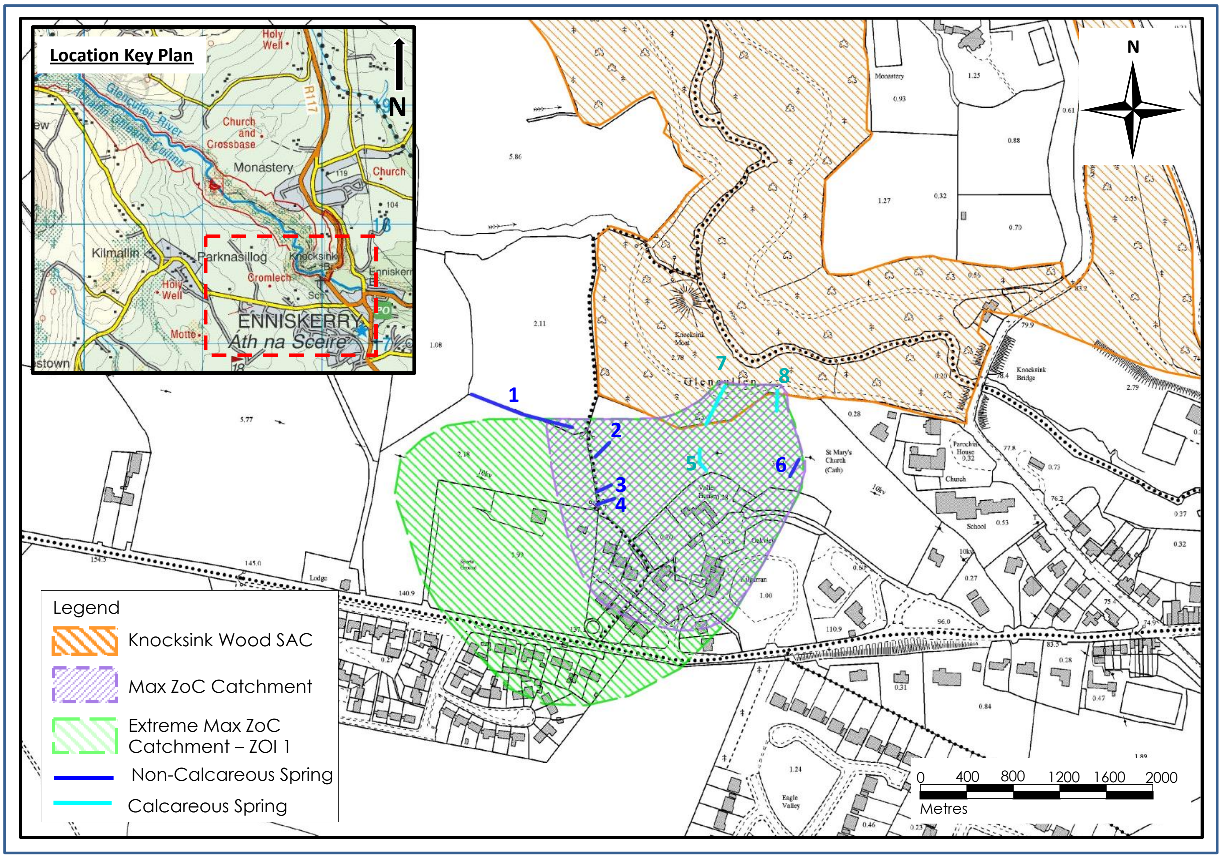

Figure 1 Example ZoC map for springs in Knocksink Wood SAC

2.5 Petrifying springs – Conceptual Site Models

Another important aspect of hydrogeological characterisation is the generation of a Conceptual Site Model (CSM) for each spring location or, if required, for a cluster of spring locations that exist in close proximity to each other. CSMs can be descriptive and illustrative, or both. Experience indicates that best results and understanding are transferred/demonstrated with a illustrative CSM, underpinned by quality site specific hydrogeological data (see Table 1 for suggested hydrogeological data types).

The CSM should not be confusing or cluttered. There should be a clear illustration of the source, flow directions and discharge points of groundwater feeding towards the spring(s).

A petrifying spring CSM should include at least the following information:

- A horizontal and vertical scale.
- The topography (existing ground level) across the ZoC.
- Locations of site investigation points.
- A summary representation of the geological profiles within the ZoC:
  - Subsoil thickness and composition
  - Top of bedrock profile
  - Bedrock description, including fault locations if necessary
- Measured water levels and indicative or actual groundwater flow equipotential lines.
- Spring discharge locations.

An example of a CSM for springs in Knocksink Wood SAC is shown below as Figure 2.

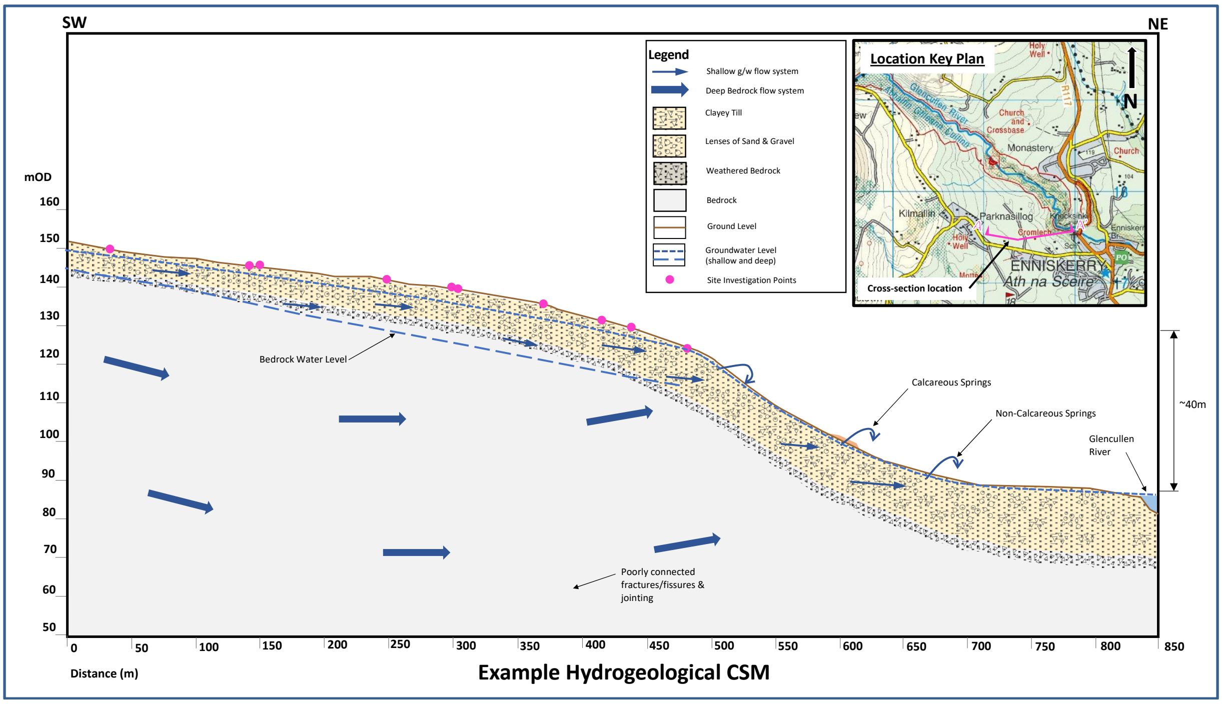

Figure 2 Example CSM for springs in Knocksink Wood SAC

2.6 Water chemistry sampling

The analysis of water chemistry from petrifying springs generally comprises two parts. The first, involves the collection of field measurements of unstable hydrochemical parameters. This entails taking field readings for temperature, electrical conductivity and pH. The second requires taking water samples for laboratory analysis. From the Irish case studies described above, a general suite of parameters tested for at petrifying springs includes alkalinity (HCO_3^-), pH, electrical conductivity and several major cations (calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+)) and anions (bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{-2}), nitrate (NO_3^-)), additional nutrient parameters are also included (such as ortho-phosphate (soluble reactive phosphorus), and ammonia (NH_3 and NH_4^+)).

In addition to this standard Irish suite, the British Geological Survey have also tested for a wide range of trace elements during sampling of petrifying springs in Gloucestershire.

The British Geological Survey (Farr & Graham, 2017) outlined the following methodology for the collection of water samples from petrifying springs. That methodology has been reproduced below and added to, where required, for the Irish context:

- Each sample should be collected as close to the source of water, at a springhead or seepage face, if possible.
- It may be necessary to take the sample using a syringe, and decant the syringe into the relevant laboratory sample bottles.
- Care should be taken to only collect water samples that represent water associated with tufa formation and supply to the main tufa forming bryophytes.
- Field parameters for pH, electrical conductivity and temperature should be measured using a calibrated field meter.
- Sample bottles should be filled to the brim to avoid interaction with trapped air.
- Samples should be devoid of debris and organic litter.
- Samples for ortho-phosphate and metals analysis (if required) should be filtered on-site using a 0.45 μm filter.

- An ionic balance should be performed on laboratory analysis results.
- In addition to the field readings a laboratory reading of electrical conductivity and pH should also be completed.

Work by Lyons (2015) on the conservation status of petrifying springs in Ireland analysed the hydrochemistry of water from 91 separate petrifying spring locations. A selection of results for key parameters are included in Table 3. In an Irish context, pH ranges from 7 to 8.47, with high concentrations of calcium and alkalinity occurring. The concentrations of nitrates and phosphorus were generally low. Any measurements which fall outside of these ranges are likely to indicate springs that are under chemical pressure/stress.

Table 3 Summary of results of key water chemistry parameters recorded from Irish springs (Lyons, 2015)

Units	**mg/l HCO_3**	**pH units**	**mg/l NO_3**	**µg/l PO_4**	**mg/l Cl**	**mg/l**
Sample ID	Alkalinity	pH	Nitrate	Phosphate	Chloride	Calcium
Irish Mean	293.7	7.88	5.09	16	24.2	87.8
Irish Median	292.8	7.97	1.56	13	14.6	84.5
Irish range	109.1 - 644.2	7 - 8.47	<0.07 - 44.05	2 - 140	6.98 -131.89	19.08 -181.2

2.7 Assessing potential hydrogeological impacts to petrifying springs

The key vectors for hydrogeological impacts on petrifying springs are via water quality and quantity. An assessment of potential impacts on existing petrifying springs firstly requires suitable hydrogeological characterisation (as described above) and the creation of a CSM supported by available data. As stated previously the quantity and types of data required will depend on the certainty required for the desired assessment.

Proposed project-related assessments should include construction phase, operational phase and cumulative impact assessments. An assessment of a likely decommissioning phase may also be necessary depending on the project type.

Examples of how water quantity (in terms of groundwater flow and discharge) can be altered:

- Dewatering (temporary dewatering during a construction phase may have limited temporary impacts, but permanent dewatering during an operational phase is likely to have a significant adverse impact).
- Diversion of shallow and/or deep groundwater flows.
- Shallow and deep drainage works.
- Significant alteration of prevailing recharge patterns within the ZoC.

Examples of how water quality can be altered:

- Changes to recharge type from drainage proposals.
- Surface Water and Ground Water discharges during construction and operational phases.
- Earthworks and silt/sediment generation during the construction phase.
- Use of concrete and hydrocarbons during the construction phase.

- Use of fertilizers (*e.g.* at golf courses or intensive agricultural developments) during the operational phase.

The above lists are not exhaustive, and each project type may have other potential elements that may affect water quantity and quality that need to be defined and assessed.

Where possible, hydrogeological assessments should be quantitative. For example, if there is a proposed abstraction in the ZoC of a known petrifying spring, then this abstraction (annual quantity) should be expressed as a percentage of the annual water balance of the ZoC to the spring.

2.8 Petrifying spring hydrogeology summary

The hydrogeological mechanisms that drive tufa spring formation are complex. In an era where certainty of assessment is becoming increasingly onerous, it is critically important to understand that there is no fixed hydrogeological recipe to characterise an individual spring location. Each spring site may have its own specific characteristics. It is also important to highlight that invasive investigation and monitoring can be damaging to these sensitive tufa sites, so any applied approach needs to be considered carefully when planning fieldwork and data collection. We have outlined above some approaches taken during previous hydrogeological studies. The local geological structure and likely sources of calcium carbonate need to be considered when developing ZoCs for petrifying springs. In addition, a sound basis for assessment is to develop a written and graphical CSM based on acquired site specific hydrogeological data. The scale and expanse of such data acquisition are dependent on the required assessment outcome. The quantum and quality of data acquired can reduce uncertainty, and where there is residual uncertainty, mitigation to protect water quality and groundwater flow regimes may be considered. It is also important that the hydrogeological characterisation and assessment is completed by an experienced hydrogeologist or ecohydrologist.

3 Ecological assessment

This section provides updated criteria and additional guidance on the assessment and evaluation of Annex I priority petrifying springs. It is based on existing national guidance (Section 1.2) and only includes sections which have been revised, or which are additional to the guidance in these publications. It includes:

- Details of current guidance documents.
- Required ecologist surveyor expertise.
- Updated lists of indicator species and recommended species nomenclature.
- Identification of Annex I priority (*7220) petrifying springs from non-Annex I petrifying springs.
- Conservation Score calculation and national ranking.
- Notes on the ecological evaluation of Annex I priority petrifying springs.

3.1 Required surveyor expertise

An ecological surveyor undertaking detailed survey and assessment of potential or confirmed Annex I petrifying springs must be both an experienced wetland botanist and bryologist. In addition, the surveyor should be familiar with a range of spring sites and types across Ireland, to be competent at undertaking petrifying spring assessment and evaluation.

Botanical skills should include locating and identifying common and rare wetland forbs, grasses and sedges. In addition, the identification of charophytes is often required and this frequently requires sample collection and microscope identification by an experienced botanist.

Identification of bryophytes is a core requirement. Bryophytes are a very large and cryptic group and can pose a challenge to the uninitiated. Whilst, with experience, many can be confidently identified in the field, there are some species which can only be identified microscopically. It is important to realise that identification of specimens is only one part of a bryophyte survey and that finding different species in the field (the first stage) also requires experience. If an inexperienced surveyor undertakes a survey, collecting material for a referee or expert to identify, then it is likely that species will be missed in the field and this must be made clear when results are presented.

Petrifying spring surveyors should have skills and experience enabling them to:

- recognise those bryophyte, vascular plant and charophyte species which require microscopic confirmation and also those which require confirmation by a referee;
- recognise that some bryophyte, vascular plant and charophyte species can only be identified when critical identification features (*e.g*. fruiting material) are present and that this may affect optimal survey timing of certain habitats;
- prepare collected material for the microscope;
- use the most appropriate identification floras and guides for species identification and recognise that, for some species, reference literature in addition to the standard floras may be required for accurate identification;
- recognise spring sites (*e.g*. Sligo and Leitrim limestone uplands) where rare bryophyte and vascular plant assemblages may occur; and,
- determine appropriate spatial scoping for fieldwork.

A surveyor needs to recognise their level of attainment in botanical and bryophyte identification. Those without the relevant breadth and depth of the knowledge, skills and experience, should always work with, or seek advice from, an adequately experienced individual.

3.2 Vascular plant and bryophyte nomenclature

Vascular plant nomenclature follows that of the New Flora of the British Isles 4th Edition (Stace, 2019). Bryophyte nomenclature follows the updated Checklist for Britain and Ireland (Blockeel *et al.* 2021). Recent changes to indicator species names are highlighted in Section 3.3.

3.3 Updated indicator species lists

The monitoring guidelines for the assessment of petrifying springs in Ireland (Lyons & Kelly, 2016) identifies species that can be used to indicate the ecological value and condition of petrifying springs. These include vascular plants, bryophytes (mosses and liverworts) and charophytes (algae). The indicator species lists included in Lyons & Kelly (2016) have been reviewed and updated based on additional petrifying spring data and ecological knowledge and nomenclature changes.

The groups of indicator species and any changes made to the lists in Lyons & Kelly (2016) are described in the sections below.

3.3.1 High quality indicator species

There are nine high quality indicator species (one vascular plant, two liverwort and six moss species) (Table 4). These are all relatively rare and often restricted to upland and north-western areas. These indicate highly ecologically significant examples of petrifying springs. One species has been added to the list included in Lyons & Kelly (2016). This is the liverwort *Moerckia flotoviana,* which was found in a petrifying spring system in the Leitrim uplands in 2020. There are no other records of this species from petrifying springs in Ireland and it was not recorded in a survey of 110 petrifying springs across Ireland (Lyons, 2015). It is easily overlooked however, and an indicator of high quality spring/fen habitat. Ecological information on these species is provided in Lyons & Kelly (2016) and Lockhart *et al.* (2012; for bryophytes).

Table 4 Updated list of high quality indicator species of petrifying springs.

Species name	Group	Comment
Saxifraga aizoides	Vascular plant	-
Mesoptychia bantriensis	Liverwort	Previously *Leiocolea bantriensis*
Moerckia flotoviana	Liverwort	Addition to list
Catoscopium nigritum	Moss	-
Hymenostylium recurvirostrum var. *insigne*	Moss	-
Orthothecium rufescens	Moss	-
Seligeria oelandica	Moss	-
Seligeria patula	Moss	-
Tomentypnum nitens	Moss	-

3.3.2 Positive indicator species

These are generally common species and many will also be found outside of petrifying spring systems. Within petrifying spring systems however they are typical of good condition spring habitat. There are twenty-six high quality indicator species (12 vascular plants, one algae, three liverworts and ten moss species) (Table 5). Three moss species and two vascular plant species have been added to the list included in Lyons & Kelly (2016). The mosses are *Hymenostylium recurvirostrum* var. *recurvirostrum* and *Plagiomnium elatum*, which both occur in good condition petrifying springs. Lyons (2015) recorded *H. recurvirostrum* var. *recurvirostrum* from 4% and *Plagiomnium elatum* from 9% of surveyed petrifying springs in Ireland. The third moss species (species pair) is *Fissidens crassipes/F. rufulus* (not always possible to separate unless fertile). Lyons (2015) did not record either of these species in petrifying springs. However, they are often present in stream/spring systems and can be a useful indicator in these systems, where conditions do not suit many other positive indicator species (due to variable water flow and periodically high velocity). The additional vascular plants are *Carex hostiana* and *Eleocharis quinqueflora* (recorded from 3% and 11% of petrifying springs respectively).

Only one stonewort *Chara vulgaris* is included on the positive indicator species list. This was found in 10% of sampled petrifying springs by Lyons (2015). Three additional species have been recorded more rarely from petrifying springs (less than 0.5% of sampled springs), including *Chara curta* and *C. virgata* (Lyons, 2015) and *C. globularis* (George Smith pers. comm., Abbeyleix Bog Project). If a *Chara* species other than *C. vulgaris* is recorded from a petrifying spring, then expert judgement should be used to decide whether to include it as a positive indicator (*e.g*. based on the species' ecology and distribution within the spring/fen system).

Scorpidium scorpioides is typically a species of transition mire and low alkaline fen, rather than highly alkaline petrifying spring habitat. It was recorded from 5% of sampled petrifying springs by Lyons (2015) and included as a positive indicator species in Lyons & Kelly (2016). It is unlikely to occur at the springhead of a petrifying spring, but may be present where it spring grades into fen or flush vegetation. For this reason it has been retained on the updated positive indicator list, but it should be noted that petrifying springs are atypical habitat for this species.

Table 5 Updated list of Positive Indicator Species of petrifying springs

Species name	Group	Comment
Carex hostiana	Vascular plant	Addition to list
Carex lepidocarpa	Vascular plant	-
Carex panicea	Vascular plant	-
Chrysosplenium oppositifolium	Vascular plant	-
Crepis paludosa	Vascular plant	-
Eleocharis quinqueflora	Vascular plant	Addition to list
Equisetum telmateia	Vascular plant	-
Equisetum variegatum	Vascular plant	-
Eriophorum latifolium	Vascular plant	-
Festuca rubra	Vascular plant	-
Lysimachia tenella	Vascular plant	Previously *Anagallis tenella*
Parnassia palustris	Vascular plant	-
Pinguicula vulgaris	Vascular plant	-
Selaginella selaginoides	Vascular plant	-
Schoenus nigricans	Vascular plant	Addition to list
Chara vulgaris	Algae	See note on other *Chara* species
Aneura pinguis	Liverwort	-
Jungermannia atrovirens	Liverwort	-
Mesoptychia turbinata	Liverwort	Addition to list (previously listed as an Accompanying Species) Previously *Leiocolea turbinata*
Pellia endiviifolia	Liverwort	-
Bryum pseudotriquetrum	Moss	-
Campylium stellatum	Moss	-
Didymodon tophaceus	Moss	-
Eucladium verticillatum	Moss	-
Fissidens adianthoides	Moss	
Fissidens crassipes/F. rufulus	Moss	Addition to list
Hymenostylium recurvirostrum var. *recurvirostrum*	Moss	Addition to list
Palustriella commutata	Moss	-
Palustriella falcata	Moss	-
Philonotis calcarea	Moss	-
Plagiomnium elatum	Moss	Addition to list (previously listed as an Accompanying Species)
Scorpidium cossonii	Moss	-
Scorpidium scorpioides	Moss	-

3.3.3 Negative indicator species

Negative indicator species are grouped into general negative indicator species (Table 6), invasive species (Table 7) and woody species in unwooded springs (Table 8). There are no additions to these lists, but nomenclature has been updated where relevant.

Table 6 Updated Negative Indicator Species of petrifying springs

Species name	Group	Comment
Acer pseudoplatanus	Vascular plant	In wooded habitats only
Dactylis glomerata	Vascular plant	
Epilobium brunnescens	Vascular plant	-
Epilobium hirsutum	Vascular plant	-
Helosciadium nodiflorum	Vascular plant	Previously *Apium nodiflorum*
Heracleum sphondylium	Vascular plant	-
Juncus effusus	Vascular plant	-
Petasites hybridus	Vascular plant	-
Phragmites australis	Vascular plant	-
Rumex obtusifolius	Vascular plant	-
Ulex europaeus	Vascular plant	In wooded habitats
Urtica dioica	Vascular plant	-
Brachythecium rivulare	Moss	-
Cratoneuron filicinum	Moss	-
Rhynchostegium riparioides	Moss	Previously *Platyhypnidium riparioides*

Table 7 Updated Invasive Species of petrifying springs

Species name	Group	Comment
Acer pseudoplatanus	Invasive	In unwooded habitats only
Prunus laurocerasus	Invasive	

Table 8 Updated Negative Woody Species of open (unwoody) petrifying springs

Species name	Group	Comment
Calluna vulgaris	Vascular plant	-
Fraxinus excelsior	Vascular plant	-
Hedera hibernica	Vascular plant	Previously listed as *Hedera helix*
Heracleum sphondylium	Vascular plant	Addition to list
Lonicera periclymenum	Vascular plant	-
Rubus fruticosus agg.	Vascular plant	-
Salix cinerea	Vascular plant	-
Ulex europaeus	Vascular plant	-

3.3.4 Typical accompanying species (Neutral Indicator Species)

Accompanying species (or neutral indicator species) are generalist wetland species that are characteristic of petrifying springs (Table 9). They are not used directly in the assessment and evaluation of springs, but can be useful for monitoring general wetland species diversity. The list (Table 9) includes the most frequently recorded wetland species within petrifying springs. There may be additional, less frequent species, that can be typical of a spring system and expert judgement can be used to add these to a site monitoring list where relevant. In some atypical spring types, where positive indicator species number may be low but the spring is in good condition, expert judgement can be used to assess whether any of these species should be used as an additional positive indicator species. For instance, this situation could arise where natural seasonal water fluctuations limit petrifying spring bryophyte species diversity.

Table 9 Updated typical accompanying species (neutral indicators) of petrifying springs

Species name	Group	Comment
Agrostis stolonifera	Vascular plant	-
Angelica sylvestris	Vascular plant	Addition to list
Asplenium scolopendrium	Vascular plant	Addition to list
Bellis perennis	Vascular plant	-
Caltha palustris	Vascular plant	Addition to list
Cardamine pratensis	Vascular plant	-
Carex flacca	Vascular plant	-
Carex pulicaris	Vascular plant	Addition to list
Carex remota	Vascular plant	Addition to list
Cirsium palustre	Vascular plant	-
Epilobium parviflorum	Vascular plant	-
Eriophorum angustifolium	Vascular plant	-
Filipendula ulmaria	Vascular plant	-
Geranium robertianum	Vascular plant	-
Hypericum tetrapterum	Vascular plant	-
Juncus articulatus	Vascular plant	-
Juncus inflexus	Vascular plant	-
Mentha aquatica	Vascular plant	-
Nasturtium officinale agg	Vascular plant	-
Poa trivialis	Vascular plant	-
Primula vulgaris	Vascular plant	-
Prunella vulgaris	Vascular plant	-
Ranunculus flammula	Vascular plant	-
Ranunculus repens	Vascular plant	-
Sagina nodosa	Vascular plant	Addition to list
Samolus valerandi	Vascular plant	Addition to list
Scorzoneroides autumnalis	Vascular plant	Previously *Leontodon autumnalis*
Sesleria caerulea	Vascular plant	-
Succisa pratensis	Vascular plant	-
Triglochin palustre	Vascular plant	Addition to list
Tussilago farfara	Vascular plant	-
Veronica beccabunga	Vascular plant	-
Riccardia chamedryfolia	Liverwort	-
Breutelia chrysocoma	Moss	-
Calliergonella cuspidata	Moss	-
Ctenidium molluscum	Moss	-
Pohlia wahlenbergii	Moss	-
Trichostomum crispulum	Moss	-

3.4 Identification of Annex I priority springs

The European Habitats manual (Commission of the European Communities, 2013) gives the following description for *7220: ‘Hard water springs with active formation of travertine or tufa. These formations are found in such diverse environments as forests or open countryside. They are generally small (point or linear formations) and dominated by bryophytes (*Cratoneurion commutati*)[1].

There is currently no ‘standard’ interpretation of Annex I priority petrifying springs in an Irish context. The work on petrifying springs by Lyons (2015) was not restricted to the Annex I priority habitat (*7220) and a broader range of springs and other wetland habitats was included in this work. Therefore, additional clarification is required to help identify examples of Annex I priority petrifying springs.

At its simplest, an Annex I priority petrifying spring should be predominantly groundwater fed, tufa forming (petrifying) and support typical (*Cratoneurion*) vegetation (Lyons, 2015). Lyons (2015) described eight Irish petrifying spring plant communities, which are all considered to be ‘worthy of conservation’ (Lyons, 2015). However not all of these necessarily correspond to the Annex I priority (*7220) habitat type. Good examples of petrifying springs are usually easy to identify as *7220 habitat because of high tufa formation or high species richness. However, tufa formation may be found in the absence of typical petrifying spring indicator species and some weakly tufa forming examples have similar species composition to more strongly tufa-forming springs (Lyons, 2015). In addition, there are situations where a spring has low tufa formation, or a low number of positive indicator species. In these cases, it can sometimes be difficult to decide if a spring is an example of *7220 in poor condition, or whether it is not actually an example of *7220 habitat. Because of the diverse nature of petrifying springs (Lyons, 2015), this decision will not always be clear-cut and expert judgement will be required.

The following criteria should be used to assess whether or not a spring is an example of an Annex I priority petrifying spring. These take into account tufa presence (Section 3.5), positive indicator species (Section 3.3), Conservation score and National ranking (Section 3.5):

1) The definition of a *7220 spring in Ireland includes **springheads**, groundwater **seepage** areas and **watercourses** (streams and rivers) which are predominantly **groundwater fed**. Note that tufa formation can occur in the absence of groundwater supply (e.g. when water flows through limestone gravel or similar) and hydrogeological investigation may be required to determine if there is significant groundwater input.
2) **Tufa formation** must be present for a spring to be considered to be an example of *7220 habitat. This excludes, for instance, springheads dominated by *Palustriella commutata* which have no tufa formation. [This does not imply that these sites/springs are not of conservation importance and they may represent a different Annex I habitat (*e.g.* Alkaline fen 7230/Alluvial woodland 91E0).]
3) At least **three positive indicator** species must be present for a spring to be an example of *7220 habitat (but see point 6 below).
4) If a spring supports at least **three positive indicator** species **and** has at least patchy paludal **tufa formation** then it is usually considered to be *7220. [When assessing the condition of petrifying springs, a minimum of three positive indicator species is required for the spring to pass the Structure and Functions criteria ‘Positive Indicator Species’ (Lyons & Kelly, 2016)].
5) A spring must have at least a **‘Conservation Score’ of three,** which is a national ranking of ‘Moderate’ and above, to be considered as an example of *7220 habitat. This excludes springs that have a national ranking of ‘Low’.

[1] This is a plant community (‘alliance’) first described in 1928. It comprises lime-rich spring communities with tufa formation and a ground flora dominated by mosses. *Cratoneuron commutatum* is a former name for *Palustriella commutata.*

6) **Expert opinion** must be used in conjunction with these criteria. Examples where a spring may not follow the criteria above, but could still be considered an example of *7220 habitat include:

   I. Where a spring has high tufa formation but low number of positive indicator species as a result of groundwater pollution which may be reversible.

   II. Where a spring has experienced recent disturbance, which has temporarily reduced either tufa cover or number of positive indicator species.

   III. Where a stream section has significant tufa formation with less than three positive indicator species, but is part of a *7220 spring complex.

   IV. Where a spring has low tufa formation or low number of positive indicator species but is located within a SAC for which 7220* is listed as a Qualifying Interest (QI).

Such springs should be mapped as *7220 habitat but may not have a high conservation ranking or be considered high quality examples of *7220 in a local or national context (outside of protected sites).

A number of petrifying spring case-studies are presented in Section 4. These have been selected to demonstrate situations where it may not be clear if a petrifying spring is/is not an example of *7220 habitat.

3.5 Conservation evaluation and ranking

3.5.1 Conservation score

Conservation scores are calculated for each spring location, ranging from one (low conservation value for petrifying spring habitats) to ten (highest conservation value) (Lyons & Kelly, 2016). Lyons & Kelly (2016) use four criteria to create a Conservation Score for each particular spring/spring system. These are summarised below, with full details shown in Table 10. It is important to note that these are calculated for the whole spring (not per relevé) (Lyons pers. comm.), as springs are often very small and localised.

- High Quality Indicator species (score 1 for each species)
- Species diversity (positive indicator species) (score 0-4)
- Tufa formation (score 0-4)
- Other positive characteristics (score 1 for each characteristic)

The Conservation Score is calculated as the total scores for each of these criteria (Table 10), up to a maximum of ten.

Table 10 Conservation score criteria and scores

Criteria	Value	Score
High Quality indicator species (refer to updated list in Section 3.3.1)	List if present	1 per species
Species diversity (refer to updated lists in Section 3.3.1 and 3.3.2. This refers to high quality and positive indicator spp.)		0 to 4
Very high	15+ positive indicator species	4
High	10 – 14 positive indicator species	3
Moderate	5 – 9 positive indicator species	2
Low	1 – 4 positive indicator species	1
Absent	0 positive indicator species	0
Tufa Formation		
Very high	Massive, strongly consolidated deposits	4
High	Smaller consolidated deposits or strongly formed paludal tufa	3
Moderate	Patchy paludal tufa	2
Low	Sparse tufa formation	1
Absent	No tufa formation	0
Additional positive characteristics (see list of positive characteristics below)	List if present	1 per spring/ spring system
Total score		Maximum of 10

The monitoring guidelines (Lyons & Kelly, 2016) state that positive characteristics are '*for example, hydrogeological/geological characteristics of merit relevant to the petrifying spring habitat, Score 0 - 1*)'. Positive characteristics included in the relevé data accompanying Lyons (2015) include hydrogeology, landscape, geology and rare species, but do not include a standard list of positive characteristics.

A list of positive characteristics is provided below. This is based on the relevé data accompanying Lyons (2015), with additions from subsequent survey work. Each positive characteristic scores one, with a maximum score of one per spring system (even if additional positive characteristics are present):

- Hydrogeological importance (*e.g*. two separate spring systems at one site).
- Geology (*e.g*. Lakes Marble bedrock in Connemara).
- Karst hydrology (*e.g*. in the Burren).
- Mineral-rich springs present.
- Spring supports, or is associated with, rare or protected flora not otherwise taken into account in the Conservation Score calculation (rarely occurs in practice as most rare/ protected flora species associated with springs will be listed as high quality positive indicator species).
- Ancient woodland indicator species present (Perrin & Daly, 2010).
- Spring associated with (*e.g.* adjacent to/occurs in a mosaic with/or other hydrogeological connection to) another Annex I (*priority) wetland habitat *e.g.* Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* [*91E0}; Turloughs [*3180]; *Molinia* meadows on calcareous, peaty or clayey-silt- laden soils [6410];

Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels [6430]; and, Transition mire and quaking bogs [7140]; Alkaline fen [7230].

- Spring is part of a large spring complex (*e.g*. along a river valley).

This list is based on the survey of over 110 spring systems (Lyons, 2015) and additional petrifying spring data from a range of subsequent surveys. It should cover most situations likely to be encountered in Ireland, but expert judgement may need to be used where it is considered that a site has an additional positive characteristic not listed above.

3.5.2 National ranking

The Conservation Score is used to rank the conservation value of the spring at a national level (Lyons & Kelly, 2016; Lyons, 2015). The conservation value categories are shown in Table 11 with additional information in relation to the Annex I priority habitat status of the spring.

Table 11 National ranking of petrifying springs (percentage figures are from Lyons & Kelly (2016)

Conservation Score	Ranking	% of Irish springs	Annex I priority habitat status
1-2	Low	6%	Not considered to be an example of *7220 unless there is a clear reason (e.g. poor condition) for the low score and a possibility that the score could increase (e.g. with management/ improved water quality). Expert judgement to be used in these cases.
3-4	Moderate	52%	*7220 if tufa present and ≥3 positive indicator species
5-6	High	33%	*7220 if tufa present and ≥3positive indicator species
7-8	Very High	6%	*7220
9-10	Outstanding	3%	*7220

3.5.3 Ecological evaluation

When assessing the ecological value of a spring/spring system there are various factors which need to be taken into account. These include:

- Annex I priority/non-Annex status (See Section 3.4 and Section 3.6.3).
- Ecological condition (Lyons & Kelly, 2016).
- Conservation Score (Section 3.5.2) and National ranking (3.5.3).
- Distribution at a national level (*e.g*. does it alter the national range or distribution of *7220 in Ireland). It may be useful to examine the hectad level (10 km x 10 km) distribution of *7220 springs (*e.g*. from the latest Article 17 report and associated mapping).
- Distribution at a county level (*e.g*. is it located in a county with a high or low number of *7220 springs and does it affect the county range and distribution of *7220).
- Whether the spring is located within, adjacent to, or hydrogeologically connected to an SAC for which *7220 is a Qualifying Interest.
- ‘Naturalness’.
- Whether a petrifying spring is the only example of its vegetation type within a defined area (*e.g.* county).

As an example, the above criteria were used to create a list of ‘priority’ springs in Dún Laoghaire-Rathdown (DLR) (Denyer, 2020). The aim of this exercise was to identify the best examples of this habitat in DLR. The advantage of this type of local area assessment is that it enables the local context to be taken into account when assessing an individual site. This will not always be necessary, but is especially useful for input into policy instruments such as County Development Plans.

The DLR 'priority' springs had to be considered to be an example of * 7220 habitat and fit one of the following criteria:

- Petrifying springs located within a Special Area of Conservation for which 7220* is listed as a Qualifying Interest.
- Petrifying springs located outside of an SAC, but part of a spring complex which is within a Special Area of Conservation (for which 7220* is listed as a Qualifying Interest).
- Petrifying springs which are ranked as having a Very High national ranking (Section 3.5.3).
- Petrifying springs which are ranked as having a High national ranking (Section 3.5.3) and have a 'naturalness' score of A (see below).
- Springs which may have a lower national ranking (Low or Moderate) but which are part of a spring complex with springs that are ranked as High or above conservation value.

'Naturalness' criteria: Petrifying springs can arise in man-made, urban and disturbed habitats and some of these will be examples of *7220. When prioritising *7220 springs of high conservation value, it may be important to distinguish between those that have arisen 'naturally' without significant modification and those which are located in semi-natural habitat, with links to adjacent semi-natural habitat. The following 'naturalness' criteria were used in the DLR assessment:

- 'A' = semi-natural habitat; 7220 spring likely to have arisen 'naturally'.
- 'B' = urban, man-made or modified habitat which has caused 7220 to arise *e.g*. re-profiled land, cattle troughs, water pipes, walls.

In the DLR study, 50 springs at 17 sites were assessed. Of these, seven sites were selected as DLR 'Priority' sites, considered to support the best current examples of Annex I priority petrifying springs in DLR area.

4 Annex I petrifying springs – regulatory context

This section is intended to give general guidance on the regulatory framework within which Petrifying Springs need to be considered for the purposes of conservation evaluation and environmental/ecological assessment. It does not purport to be a legal interpretation and for individual assessments *etc*. independent legal advice should be sought.

Petrifying springs with tufa formation (*Cratoneurion*) [7220] is listed as a priority habitat on Annex I of the EU Habitats Directive (92/43/EEC). The EU Habitats Directive is transposed into Irish law by the European Communities (Birds and Natural Habitats) Regulations 2011 (S.I. No. 477 of 2011), as amended. The main aim of the EU Habitats Directive is to promote the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements. Special Areas of Conservation (SACs) have been designated to restore and maintain threatened natural habitats of Community interest and create a European wide ecological network. Certain natural habitat types, including petrifying springs, have been identified as 'priority' habitats and are considered to be in danger of disappearance. The conservation of these habitats requires the designation of Special Areas of Conservation (SACs). There are 44 SACs in which petrifying springs have been recorded. Of these, 20 SACs (Table 12) have petrifying springs listed as a Qualifying Interest.

When they are located within an SAC for which they are a Qualifying Interest, Annex I petrifying springs are subject to the protective measures set out in Article 6(2), 6(3) and 6(4) of the Habitats Directive. Article 6(2) of the Directive requires that damaging activities that could lead to a deterioration in QI habitats in SACs are avoided. These requirements are reflected in the provisions of Regulation 27 of the European Communities (Birds and Natural Habitats) Regulations, 2011 (as amended) and in Section 177S of the Planning and Development Act, 2000 (as amended). The provisions of Article 6(3) and 6(4) of the Directive require an appropriate assessment of plans and projects be undertaken prior to their authorisation. Consent authorities can authorise a plan or project only having made certain that it will not adversely affect the integrity of a European site.

An appropriate assessment must examine the implications of the plan or project for the QIs of the European site(s) concerned, in view of the site's conservation objectives and in light of the best scientific knowledge. In addition, an appropriate assessment must address the potential impacts of a plan or project on habitats found within a European site that are not listed as qualifying interests for the site and habitats found outside the site, where such impacts may affect the conservation objectives of the site. This requirement applies to any habitats, including Annex I habitats, located within or outside the site, impacts which may affect the conservation objectives, and thus the integrity, of the site concerned. In this context it is important to note that because petrifying springs are a groundwater dependent feature, they may in many circumstances be hydrologically connected to, or otherwise important for, the functioning and conservation of Annex I wetland habitats which are a Qualifying Interest within an SAC. It is important therefore in any ecological assessment of petrifying springs, which are not QI within an SAC, to determine whether there are hydrological connections or ecological dependencies to QI habitats, such as alkaline fens for instance, within SACs.

Where an Annex I petrifying spring is within an SAC but not a Qualifying Interest or where it is located outside the SAC network, it should be considered to be an important groundwater dependent wetland feature. It is likely to be considered of high nature conservation value in an Ecological Impact Assessment or in the context of an Environmental Impact Assessment (EIA). Petrifying springs are also within the remit of the Water Framework Directive (Directive 2000/60/EC) as groundwater-dependent terrestrial ecosystems (Curtis *et al*. 2009, Kimberley *et al*. 2013). Their ecological significance is recognised under this legislation and there is a legal requirement to maintain or improve the status of the groundwaters by which they are fed. In some cases there may be objectives for their protection in the relevant City/County Development Plan.

The aim should always be to retain Annex I petrifying springs wherever possible. The ecological evaluation of petrifying springs is discussed in Section 3.5 of these guidelines and examples of petrifying spring ecological evaluation included in Section 4.

Also relevant is the Environmental Liability Directive (EU Directive 2004/35/CE) which is transposed into Irish Law by the European Communities (Environmental Liability) Regulations 2008 (S.I. No. 547 of 2008). The fundamental objective of the Directive and the Regulations is to prevent and remedy environmental damage. The Environmental Liability Regulations 2008 define environmental damage under three categories: damage to natural habitats and protected species ((*i.e*. those covered by the Habitats Directive (92/43/EEC) and Birds Directive (79/409/EEC)); water damage (*i.e*. waters covered in the Water Framework Directive (2000/60/EC)) and land damage (any contamination that creates a significant risk of adverse impacts on human health). The Regulations place an obligation on an 'Operator' to take preventative measures to dispel any threats of environmental damage, or where damage has occurred to take measures to contain further damage. In addition, an operator must notify the EPA (the Competent Authority) where an imminent threat, or actual case of, environmental damage has occurred. The Regulations require the EPA to direct operators to take measures (preventative or remedial) where there is an imminent threat of, or actual case of, environmental damage. It is an offence if an operator fails to comply with any such direction.

Table 12 Special Areas of Conservation with petrifying springs listed as a Qualifying Interest

Site Code	Site Name
000020	Black Head-Poulsallagh Complex SAC
000054	Moneen Mountain SAC
000163	Lough Eske and Ardnamona Wood SAC
000297	Lough Corrib SAC
000396	Pollardstown Fen SAC
000584	Cuilcagh - Anierin Uplands SAC
000623	Ben Bulben, Gleniff and Glenade Complex SAC
000627	Cummeen Strand/Drumcliff Bay (Sligo Bay) SAC
000713	Ballyman Glen SAC
000725	Knocksink Wood SAC
001021	Carrowmore Point to Spanish Point and Islands SAC
001209	Glenasmole Valley SAC
001398	Rye Water Valley/Carton SAC
001403	Arroo Mountain SAC
001766	Magherabeg Dunes SAC
001926	East Burren Complex SAC
001932	Mweelrea/Sheeffry/Erriff Complex SAC
002147	Lisduff Fen SAC
002162	River Barrow and River Nore SAC
002252	Thomastown Quarry SAC

5 Examples of petrifying spring evaluation

When a petrifying spring has a high number of positive indicator species as well as tufa formation it is generally easy to classify it as an example of an Annex I priority spring (*7220) and to assess its conservation value. However, there are many situations when assessing potential *7220 springs is not clear, such as when they have been modified or are in unfavourable condition.

In this section, twelve examples are presented of petrifying spring evaluations. These have been selected to illustrate a number of potential issues that arise when assessing and evaluating petrifying springs:

- Artificial/modified springs
- Atypical springs
- Invasive species
- Absence of Positive indicator species
- River/stream tufa
- SAC for which *7220 is QI
- Absence of tufa
- Unfavourable condition

The relevant issue(s) are listed at the top of each section. Each example has a short description of the spring, and the spring vegetation community (Lyons & Kelly, 2017) if relevant.

There is a table for each spring which includes information on a number of attributes (Table 13). All of these factors are important to take into account when assessing the ecological value of a spring site. The overall ecological value is not given in these examples. Any assessment of value is dependent on the regulatory context of the assessment and factors such as geographic scale. Each spring description includes the petrifying vegetation group from Lyons and Kelly (2016 and 2017). These are summarised in Table 15.

Table 13 Example spring evaluation criteria

Criteria	Comment
No. of positive indicator species (species diversity)	See Sections 3.3.1 and 3.3.2 for indicator species and Section 3.5.1 for species diversity definition
Tufa formation	See Section Table 14 for tufa types and Section 3.5.1 for tufa formation scoring
Other positive characteristics	See Section 3.5.1 for a list of example positive characteristics
Condition assessment	Refer to Lyons & Kelly (2016) for details
Located within protected site	In these examples this refers only to SACs
Within/adjacent to SAC with *7220 as Qualifying Interest	Only refers to SACs where *7220 is listed as a Qualifying Interest
*7220 petrifying spring	Whether or not the spring is considered an example of *7220, with notes as relevant
Conservation score	See Section 3.5.1 for assessment of Conservation Score. Where no detailed relevé has been undertaken this is estimated if relevant
National ranking	See Section 3.5.2 for assessment of National ranking. Where no detailed relevé has been undertaken this is estimated if relevant. This refers to a national ranking of the spring and not its ecological value (which would take all of the factors in the table into account).

Table 14 Summary of tufa formation types occurring in Ireland (from Lyons and Kelly, 2016)

Tufa category	Description
Cascade	Developing on steep slopes at varying distances from the water source; characterised by massive, frequently complex build-ups.
Dam	Similar to cascades but forming along streams and rivers and causing the impoundment of water behind a tufa crest.
Stream crust	Sheet-like deposits forming in streams of intermediate to low gradient; these may merge with cascades.
Paludal	Formed in low gradient mires where tufa accumulates around the bases of plants, often surrounded by carbonate muds.
Cemented rudites	Gravels etc. cemented by tufa; often found on coasts where spring water seeps onto shingle banks.
Oncoids/ooids	Unattached, coated grains (<1mm up to 30 cm); the cortex may consist of biotic or abiotic particles, such as stones or plant fragments.

Table 15 Summary of petrifying spring vegetation groups (from Lyons and Kelly, 2016 & 2017)

Group	Name and Description
1	*Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades: Bryophyte-dominated, strongly tufa-forming spring communities on steep slopes (both coastal and inland) with low species diversity.
2	*Palustriella commutata-Geranium robertianum* Springheads: Woodland springhead tufa cascades, dominated by *P. commutata*, on moderately steep slopes.
3	*Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes: Woodland communities with flowing water, typically forming in hydrological sequence below Group 2 springheads.
4	*Palustriella commutata-Agrostis stolonifera* Springheads: A group of moderately steep slopes, intermediate between Group 1-3 and Groups 5-8.
5	*Schoenus nigricans* Springs: Springs on level ground forming paludal tufa amongst *Schoenus nigricans* tussocks, with an underlayer of 'brown mosses'.
6	*Carex lepidocarpa* Small Sedge Springs: Weakly tufaceous springs with high species diversity, on level ground, associated with small-sedge fens. *Palustriella falcata-Carex panicea* Springs: Springs of level or gently sloping ground, especially characteristic of karst landscapes, and often with bare, unvegetated tufa or exposed bedrock; *P. falcata*-dominated.
7	*Saxifraga aizoides-Seligeria oelandica* Springs: Species-rich springs with S. aizoides and a suite of rare bryophyte species; weakly tufa-forming, on steep slopes, centred on the Benbulbin Range of NW Ireland.
8	*Saxifraga aizoides-Seligeria oelandica* Springs: Species-rich springs with S. aizoides and a suite of rare bryophyte species; weakly tufa-forming, on steep slopes, centred on the Benbulbin Range of NW Ireland.

5.1 Spring A

Example of: Absence of tufa

This is a spring that arises in wet woodland and has abundant to locally dominant *Palustriella commutata* (Figure 3). This bryophyte species is typical of highly calcareous water and is a strong positive indicator for *7220. The vegetation present best fits the **Group 4** *Palustriella commutata- Agrostis stolonifera* Springheads plant community (Lyons & Kelly, 2017), although it is wooded. This group has variable tufa formation and tufa is sometimes sparse to absent (Lyons & Kelly, 2017). **Group 2** *Palustriella commutata-Geranium robertianum* Springheads have similar vegetation and are wooded, but are generally strongly tufa forming and so not a good fit for this spring (Lyons & Kelly, 2017). As there is no tufa formation, Spring A is **not** considered to be an example of *7220 (Table 16). It is however of high ecological value as a ground-water dependent feature and is associated with wet woodland which has affinity to the Annex I priority habitat *Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* [*91E0]. It is also located within 1 km of an SAC which has *7220 as a Qualifying Interest and potential hydrogeological connections to the SAC should be considered in any assessment.

Table 16 Evaluation criteria for Spring A

Criteria	Value	Comment
No. of positive indicator species (species diversity)	2	Moderate diversity. Minimum of 3 usually required for *7220
Tufa formation	Absent	Some tufa formation required for *7220
Other positive characteristics	Yes	Associated with wet woodland with affinity to 91E0*
Condition assessment	-	Not undertaken, but no obvious impacts
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	Yes	<1 km from SAC
*7220 petrifying spring	No	Does not have tufa formation
Conservation score	-	Not example of *7220
National ranking	-	Not example of *7220

Figure 3 *Palustriella commutata* dominated springhead in wet woodland (Spring A). Photograph Joanne Denyer.

5.2 Spring B

Example of: Positive indicator species absence

This is a small springhead which arises on a wooded bank in a park and subsequently forms a seepage which flows onto a recreational path (Figure 4). Tufa formation is present and frequent (Figure 5), but there are no positive indicator species present (Table 17). There is some trampling near the path but no obvious reason for the lack of positive indicator species away from the path. The vegetation has most affinity to **Group 3** *Brachythecium rivulare-Platyhypnidium riparioides* tufaceous streams and flushes vegetation community (Lyons & Kelly, 2017). As there are no positive indicator species present, this spring is **not** considered to be an example of *7220 (Table 17). It is however part of a complex of springs along a river valley, which includes an SAC for which *7220 habitat is a Qualifying Interest. Potential hydrogeological connections to the SAC should be considered in any assessment.

Table 17 Evaluation criteria for Spring B

Criteria	Value	Comment
No. of positive indicator species (species diversity)	Absent	Minimum of 3 usually required for *7220
Tufa formation	Paludal	Patchy paludal (Moderate tufa formation)
Other positive characteristics	Yes	Part of river valley spring complex
Condition assessment	-	Not undertaken, but no obvious impacts
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	No	<2 km
*7220 petrifying spring	No	Does not have any positive indicator species
Conservation score	-	Not example of *7220
National ranking	-	Not example of *7220

Figure 4 Springhead and seepage (Spring B). Photograph Joanne Denyer.

Figure 5 Tufa formation (oncoids and ooids) (Spring B). Photograph Joanne Denyer.

5.3 Spring C

Example of: Positive indicator species absence

This is a small stream located within a hedgerow (Figure 6). The stream arises as a spring part way along the hedgerow and then flows downhill to join another stream. Tufa formation is locally abundant (Figure 7; Table 18), but there are no positive indicator species present. There is no obvious disturbance and both the spring and hedgerow are shown on historic mapping. It is therefore considered that positive indicator species are unlikely to have ever occurred in this spring. The vegetation does not have affinity to any petrifying spring vegetation community (Lyons & Kelly, 2017). As there are no positive indicator species present, this spring is not considered to be an example of *7220 (Table 18). It would therefore be evaluated as a groundwater dependent feature that is part of an old hedgerow system.

Table 18 Evaluation criteria for Spring C

Criteria	Value	Comment
No. of positive indicator species (species diversity)	Absent	Minimum of 3 usually required for *7220
Tufa formation	Paludal	Patchy paludal (Moderate tufa formation)
Other positive characteristics	Yes	Part of old hedgerow system
Condition assessment	-	Not undertaken, but no obvious impacts
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	No	-
*7220 petrifying spring	No	Does not have any positive indicator species
Conservation score	-	Not example of *7220
National ranking	-	Not example of *7220

Figure 6 Tufa forming spring within old hedgerow (Spring C). Photograph Joanne Denyer.

Figure 7 Tufa formation (oncoids and ooids) in hedgerow (Spring C). Photograph Joanne Denyer.

5.4 Spring D

Example of: Artificial/modified spring

This spring originates from a pipe which flows under a road (Figure 8). As the water emerges from the pipe it forms a waterfall and there is significant tufa cascade formation with a number of positive indicator species (Table 19). The vegetation has most affinity to **Group 4** *Palustriella commutata-Agrostis stolonifera* Springheads vegetation community (Lyons & Kelly, 2017). Although this petrifying spring has a probable artificial origin, it is groundwater fed and fits the criteria for *7220 habitat (Table 19). It has a high national ranking due to high tufa formation and moderate species diversity. When evaluating the ecological value of the site, the artificial origin is irrelevant as the petrifying spring is well developed; but the lack of links to semi-natural habitat may reduce its ecological value. Petrifying springs are well represented in the county in which the spring is located and there are a number of other examples of *7220 within this hectad (10 km x 10 km square). It does therefore not add to the national range of the habitat in Ireland. However, it is located within 1 km of an SAC which has *7220 as a Qualifying Interest and potential hydrogeological connections to the SAC should be considered in any assessment.

Table 19 Evaluation criteria for Spring D

Criteria	Value	Comment
No. of positive indicator species (species diversity)	7	Moderate diversity
Tufa formation	Cascade	Massive, strongly consolidated deposits (very high tufa formation)
Other positive characteristics	No	-
Condition assessment	-	Not undertaken, but no obvious impacts
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	Yes	<1 km
*7220 petrifying spring	Yes	≥3 positive indicator species with tufa formation
Conservation score	5	Estimated as no detailed assessment undertaken
National ranking	High	Artificial origin, but has moderate species diversity and high tufa formation

Figure 8 Petrifying spring emerging from pipe under a road (Spring D). Photograph

5.5 Spring E

Example of: Artificial/modified spring; SAC for which *7220 is QI

This spring originates from a pipe which discharges into a reservoir (Figure 9). Beneath the pipe there is a narrow strip of cascade tufa formation. It is not possible to safely access the tufa to examine the species. However at least one positive indicator species *Eucladium verticillatum* is abundant. The spring is an example of **Group 1** *Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades vegetation community, which tend to have low species diversity (Lyons & Kelly, 2017). As positive indicator species number is probably low, it may not be an example of *7220 habitat. However, it is predominantly groundwater fed and the pipe is downstream of and likely to be connected to a petrifying spring and flush on a wooded slope above the reservoir edge (Figure 10). This spring has significant tufa formation and sufficient positive indicator species to be an example of *7220 (Table 20). Both springs are located within an SAC for which *7220 habitat is a Qualifying Interest. The spring from the pipe may not fulfil the criteria for *7220 habitat but is hydrogeologically connected to *7220 within an SAC designated for this habitat. A full survey will therefore be needed. Expert judgement may result in a classification of the spring as *7220 even where a minimum of three positive indicator species are not recorded.

Table 20 Evaluation of Spring E

Assessment criteria	**Value**	**Comment**
No. of positive indicator species (species diversity)	1	Estimated to be 1 = Low diversity. Minimum of 3 usually required for *7220
Tufa formation	Tufa cascade	Smaller consolidated deposits or strongly formed paludal tufa (high tufa formation)
Other positive characteristics	Yes	Flows from pipe which discharges from an upstream example of *7220 (hydrogeological connection)
Condition assessment	-	Not undertaken, but no obvious impacts
Located within protected site	Yes	-
Within/adjacent to SAC with *7220 as Qualifying Interest	Yes	Within SAC
*7220 petrifying spring	Yes	Currently does not have 3 positive indicator species. However, it is part of a *7220 spring system and located within an SAC for which *7220 is a QI.
Conservation score	4	Estimated as requires full survey to assess
National ranking	Moderate	Estimated as requires full survey to assess

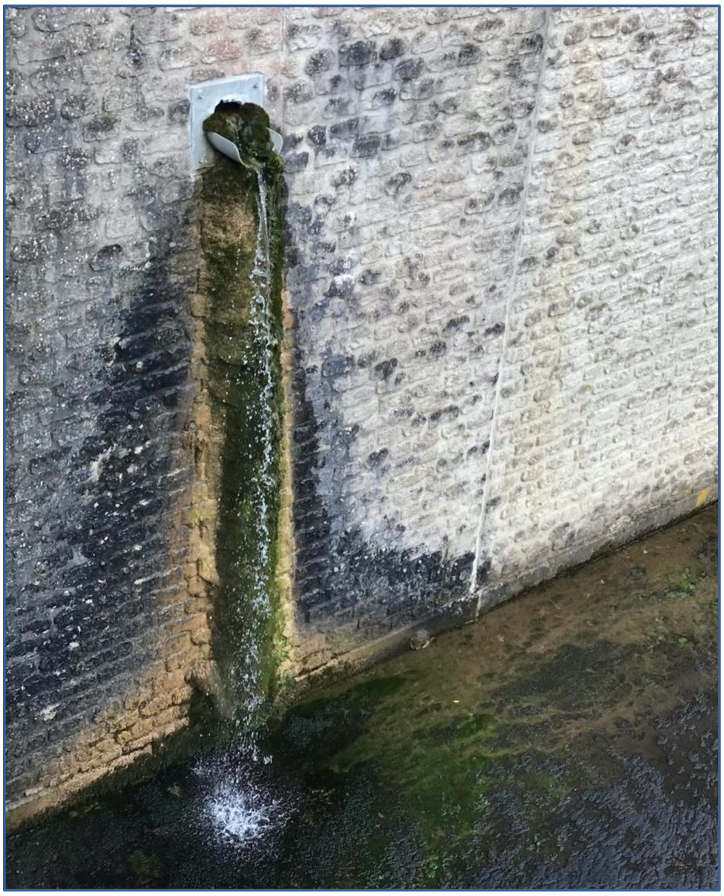

Figure 9 Tufa formation, dominated by *Eucladium verticillatum,* below a pipe outflow (Spring E). Photograph Joanne Denyer.

Figure 10 Petrifying spring and seepage area with abundant *Palustriella commutata* and tufa formation, (upstream of Spring E). Photograph Joanne Denyer.

5.6 Spring F

Example of: Artificial/modified spring; Invasive species

This is one example from a series of highly tufa forming springs and seepages along the edge of a river valley. They are present on both sides of the valley, but appear most developed on the northern side of the river. They arise in residential gardens and have been variously modified historically. However, many still have good flow and/or tufa formation and are groundwater fed. The example below (Figure 11; Table 21) has a relatively natural channel course for much of its length. It has three positive indicator species and significant tufa formation. The vegetation present best fits the **Group 4** *Palustriella commutata- Agrostis stolonifera* Springheads plant community (Lyons & Kelly, 2017), but is locally dominated by the garden plant *Soleirolia soleirolii.* It is considered to be an example of *7220 habitat (Table 5), of high national ranking, albeit in poor condition due to the presence of an invasive species. It is located within 3 km of two SACs for which *7220 is a Qualifying Interest and potential hydrogeological connections to the SACs should be considered in any assessment.

Table 21 Evaluation criteria for Spring F

Criteria	Value	Comment
No. of positive indicator species (species diversity)	5	Moderate diversity
Tufa formation	Cascade	Smaller consolidated deposits (high tufa formation)
Other positive characteristics	Yes	Part of unusual complex of highly tufa forming springs in residential gardens along a river valley
Condition assessment	Unfavourable-Inadequate	Invasive species locally dominant
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	Yes	<3 km from 2 SACs
*7220 petrifying spring	Yes	≥3 positive indicator species with tufa formation
Conservation score	5	Estimated as no detailed assessment undertaken
National ranking	High	Some modification as within a garden setting, but has 3 indicator species and high tufa formation

Figure 11 Petrifying spring in garden (Spring F). Photograph Joanne Denyer

5.7 Spring G

Example of: Artificial/ modified spring

This wet grassland site has a main spring, probably of natural origin, which arises at the top of the field and flows down to a river along the edge of the field. The vegetation within the main spring is an example of **Group 4** *Palustriella commutata-Agrostis stolonifera* Springheads vegetation community (Lyons & Kelly, 2017) and is typical *7220 habitat.

Within the field there are a number of small artificial drainage channels and seven of these have tufa formation within them (Figure 12). There is no obvious springhead and the tufa formation may be due to seepage of groundwater through the exposed banks of the small channels. Aerial photography (www.osi.ie) shows that the area where the channels are located was previously a wetland area with scrub present and no visible channels. At some point post-2005 the scrub, was cleared and presumably the channels were created to drain the wetland vegetation. These now have frequent paludal tufa and a high number of positive indicator species (Table 22). The channel vegetation is an example of **Group 6** *Carex lepidocarpa* Small Sedge Springs vegetation community (Lyons & Kelly, 2017). Although these have an artificial origin and no obvious springhead, they are groundwater fed and fit the criteria for *7220 (Table 22).

Table 22 Evaluation criteria for Spring G

Criteria	Value	Comment
No. of positive indicator species (species diversity)	14	High diversity
Tufa formation	Paludal, cascade, oncoids & ooids	Smaller consolidated deposits or strongly formed paludal tufa (high tufa formation)
Other positive characteristics	Yes	Part of complex of springs within wet grassland, locally grading to fen and associated with a petrifying spring with significant cascade tufa into the adjacent river
Condition assessment	-	No obvious impacts
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	Yes	<1 km
*7220 petrifying spring	Yes	≥3 positive indicator species with tufa formation
Conservation score	5	Estimated as no detailed assessment undertaken in this area
National ranking	High	Estimated as no detailed assessment undertaken in this area

Figure 12 Petrifying spring in drainage channel within wet grassland (Spring G). Photograph Joanne Denyer

5.8 Spring H

Example of: Artificial/modified spring; SAC for which *7220 is QI

Spring H is located within an SAC for which *7220 is a Qualifying Interest. There is a series of springs in the southern part of the site which arise along a (historically) artificially terraced slope. On one terrace there is a 'Roman Bath' made of brickwork into which a pipe discharges. The flow is small but consistent, as the area below it is usually damp even in summer. In 2011 the stonework near the pipe showed some signs of calcium carbonate precipitation (white staining, Figure 13), but there was no tufa formation or tufa vegetation present. By 2019 (Figure 14), it can be seen that the area below the pipe has developed significant tufa formation and vegetation. At least six positive indicator species are present and it is a good example of *7220 habitat within an SAC (Table 23). The spring is an example of **Group 1** *Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades vegetation community (Lyons & Kelly, 2017). This demonstrates that significant tufa formation and petrifying spring species colonisation can occur in less than 10 years, even on artificial surfaces and that *7220 habitat does not need to be old.

Table 23 Evaluation of Spring H

Assessment criteria	Value	Comment
No. of positive indicator species (species diversity)	6	Moderate Diversity
Tufa formation	Tufa cascade	Smaller consolidated deposits or strongly formed paludal tufa (high tufa formation)
Other positive characteristics	Yes	Associated with historic/ cultural feature ('Roman Bath')
Condition assessment	-	Not undertaken. No current obvious impacts to spring, but there is litter dumping within the Roman Bath, graffiti and burning of adjacent grassland
Located within protected site	Yes	-
Within/adjacent to SAC with *7220 as Qualifying Interest	Yes	Within SAC
*7220 petrifying spring	Yes	≥3 positive indicator species with tufa formation
Conservation score	6	Estimated as requires full survey to assess
National ranking	High	Estimated as requires full survey to assess

Figure 13 Roman Bath without tufa formation (2011) (Spring H). Photograph Joanne Denyer

Figure 14 Roman Bath with tufa formation (2019) (Spring H). Photograph Joanne Denyer

5.9 Spring I

Example of: Artificial/modified spring; River/stream tufa; Unfavourable condition; SAC for which *7220 is QI

Spring I is located within an SAC for which *7220 is a Qualifying Interest. It comprises a stream which partially originates from water overflow from an upstream canal, but also receives groundwater inputs from springs which are a feature of this valley. Tufa formation is occasional to frequent along the stream, but is best developed where there is increased water aeration such as at a waterfall several metres in height (Figure 15) and where the stream joins into the main river downstream of the waterfall (Figure 16). The waterfall has significant tufa formation and at least four positive indicator species (Table 24). It does however show signs of nutrient enrichment with frequent filamentous algae and the negative bryophyte indicator species *Brachythecium rivulare* and *Rhynchostegium riparioides.* The lower tufa dam only supports one positive indicator species and again has high cover of filamentous algae. The vegetation present best fits the **Group 3** *Brachythecium rivulare-Platyhypnidium* (now *Rhynchostegium*) *riparioides* Tufaceous Streams and Flushes plant community (Lyons & Kelly, 2017). The stream is considered to be an example of *7220, but in unfavourable condition due to nutrient enrichment. It supports tufa dams within the lower part of the stream. Tufa dams are the least frequent type of tufa formation in Ireland, comprising less than 3% of surveyed tufa-forming springs and watercourses (Lyons 2015). Given that this stream is also located within an SAC for which *7220 is a QI, this makes it of high ecological importance.

Table 24 Evaluation of Spring I

Assessment criteria	Value	Comment
No. of positive indicator species (species diversity)	4	Moderate Diversity
Tufa formation	Tufa cascade	Smaller consolidated deposits or strongly formed paludal tufa (high tufa formation)
Other positive characteristics	-	-
Condition assessment	-	Not undertaken but stream shows signs of nutrient enrichment
Located within protected site	Yes	-
Within/adjacent to SAC with *7220 as Qualifying Interest	Yes	Within SAC
*7220 petrifying spring	Yes	≥3 positive indicator species with tufa formation
Conservation score	5	Estimated as requires full survey to assess
National ranking	High	Estimated as requires full survey to assess

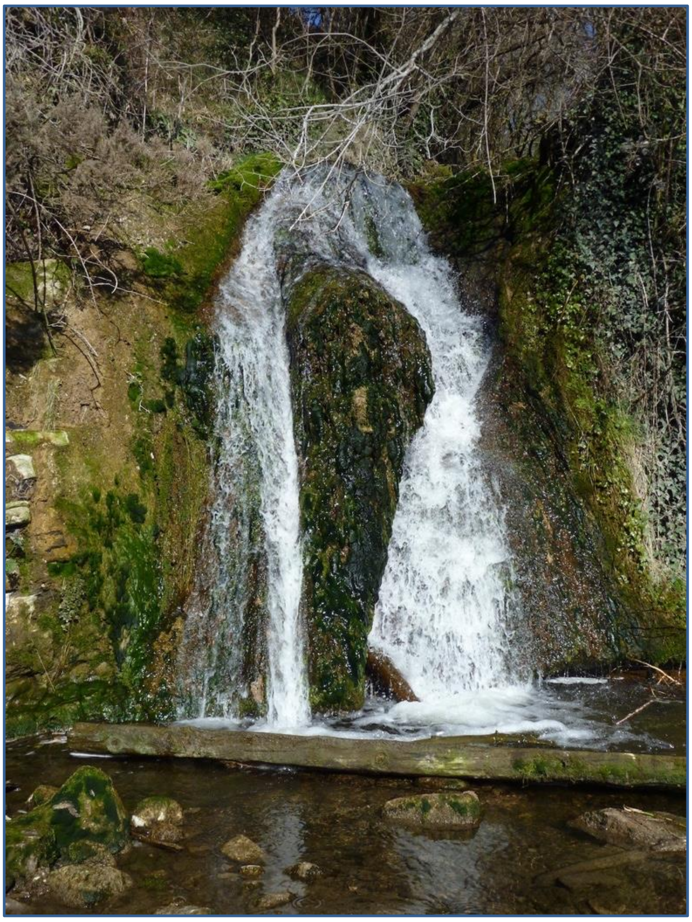

Figure 15 Waterfall with cascade tufa formation (Spring I). Photograph Joanne Denyer

Figure 16 Tufa dam formation where stream (Spring I) joins main river. Photograph Joanne Denyer

5.10 Spring J

Example of: Unfavourable condition

This is a small petrifying spring that arises in an area of wet grassland and scrub within a river valley. It flows down a slope, through an area of marsh and into the river downstream. It is an example of **Group 3** *Brachythecium rivulare-Platyhypnidium riparioides* tufaceous streams and flushes vegetation community (Lyons & Kelly, 2017). An initial survey in 2010 found significant tufa formation (Table 25; Figure 17), but only two positive indicator species were recorded. This was due to scrub encroachment and lack of grazing. In 2019, very little tufa formation was present at the springhead, with no positive indicator species recorded (Table 25; Figure 18). However the spring still had good water flow and there was tufa present under the adjacent scrub downstream of the springhead. This further decline in condition is attributed to changes to water quality in the spring catchment area and continuing lack of management at the site. It is considered that with improvement to water quality in the catchment area and suitable site management (scrub clearance and grazing or mowing), the spring vegetation has the potential to recover. Therefore expert judgement was used to classify the spring as *7220, but in unfavourable condition. This finding can be reviewed after any future surveys. The spring is part of a small complex of springs in this area and associated with two Annex I wetland habitats 'Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*' [*91E0] and 'Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels' [6430].

Table 25 Evaluation of Spring J

Assessment criteria	Value	Comment
No. of positive indicator species (species diversity)	0 (2019)	2 (2010) = Moderate Diversity. Minimum of 3 usually required for *7220
Tufa formation	Paludal tufa	2019 = patchy paludal tufa (low tufa formation) 2010 = strongly formed paludal tufa (high tufa formation)
Other positive characteristics	Yes	Associated with Annex I wetland habitats 91E0 and 6430
Condition assessment	Unfavourable-Inadequate	Fails on positive and negative indicator species due to vegetation succession and nutrient enrichment
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	No	-
*7220 petrifying spring	Yes	Currently no positive indicator species present. Species diversity has declined due to the poor condition of the spring. This is potentially reversible and so expert judgement is used to still assess as *7220.
Conservation score	2	-
National ranking	Low	Usually springs with 'Low' ranking are not considered to be *7220 but expert judgement is used to classify as *7220 (see above).

Figure 17 Petrifying spring with abundant tufa (2010) (Spring J). Photograph Joanne Denyer

Figure 18 Petrifying spring with little tufa (2019) (Spring J). Photograph Joanne Denyer

5.11 Spring K

Example of: Unfavourable condition

This spring is located on a slope within a river valley. The spring was surveyed in 2010 and found to be an example of *7220 habitat, with six positive indicator species and paludal tufa present (Table 26; Figure 19). It was an example of the **Group 4** *Palustriella commutata-Agrostis stolonifera* Springheads vegetation community (Lyons & Kelly, 2017). The spring was accidentally damaged in 2016 with complete removal of the spring vegetation (Figure 20). Groundwater however was still emerging in the area of the former spring. The spring was re-surveyed one year later and petrifying spring vegetation was regenerating and there was some tufa formation present (Table 26; Figure 21). Expert judgement was used to classify the spring as *7220, but in unfavourable condition. The petrifying spring was re-surveyed in 2021, five positive indicator species were recorded and the spring was assessed as being in good condition, five years after the damage occurred (Figure 22). This shows that although the spring vegetation and tufa were damaged, the spring water quality and quantity were not permanently impacted. The spring is part of a complex of springs in this area which adds to its ecological value.

Figure 19 Abundant *Palustriella commutata* in petrifying spring prior to damage (Spring K). Photograph Joanne Denyer

Figure 20 Petrifying spring with no vegetation due to accidental damage (Spring K). Photograph Joanne Denyer

Figure 21 Recovery of Petrifying spring vegetation one year after accidental damage (Spring K). Photograph Joanne Denyer

Figure 22 Recovery of Petrifying spring vegetation five years after accidental damage with abundant Palustriella commutata (Spring K). Photograph Joanne Denyer

Table 26 Evaluation criteria for Spring K

Criteria	Value	Comment
No. of positive indicator species (species diversity)	1 (2017)	6 positive indicators present in 2010; 0 in 2016; 5 in 2021
Tufa formation	Paludal, oncoids & ooids	Sparse tufa (low tufa formation)
Other positive characteristics	Yes	Part of spring complex which contains a very large tufa mound
Condition assessment	Unfavourable-Inadequate	Spring severely disturbed in 2016
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	No	-
*7220 petrifying spring	Yes	Fails minimum criteria, but expert opinion used to assess as *7220 as recovering from former disturbance
Conservation score	3	-
National ranking	Moderate	The ranking is increased from low, as it is part of a spring complex

5.12 Spring L

Example of: Atypical spring

This spring occurs in the lagg system of a raised bog and is part of a complex of fen/flush vegetation. It is a very wet area with standing water present. The vegetation is dominated by the stonewort *Chara globularis,* with sparse paludal tufa (Table 27; Figure 23). It has most affinity to **Group 6** *Carex lepidocarpa* Small Sedge Springs vegetation community (Lyons & Kelly, 2017). However, it has an unusual combination of species for a petrifying spring, which is probably due to its presence in the lagg zone of a raised bog system. Species of transition mire (*Scorpidium scorpioides* and *S. revolvens*) occur with more typical *7220 species such as *Palustriella falcata* and *Scorpidium cossonii. Chara globularis* was not recorded from Irish petrifying springs in the survey work by Lyons (2015) and it is not listed as a positive indicator species for *7220. *Chara globularis* is generally typical of standing water and water movement may be slow in the spring area. In this case, expert judgement can be used to count *Chara globularis* as a positive indicator species as this is an unusual petrifying spring. As there is tufa formation and eight positive indicator species, it is considered that this is an example of *7220.

Table 27 Evaluation criteria for Spring L

Criteria	Value	Comment
No. of positive indicator species (species diversity)	8	Moderate diversity
Tufa formation	Paludal	Sparse tufa (low tufa formation)
Other positive characteristics	Yes	Occurs in a diverse complex of wetland communities including Annex I habitats 91D0 and 7140
Condition assessment	Favourable	-
Located within protected site	No	-
Within/adjacent to SAC with *7220 as Qualifying Interest	Yes	Within 1 km
*7220 petrifying spring	Yes	≥3 positive indicator species with tufa formation
Conservation score	5	-
National ranking	High	-

Figure 23 Petrifying spring in lagg zone of bog, dominated by *Chara globularis* (Spring L). Photograph George Smith.

Bibliography & Relevant Literature

AWN Consulting (2020). *Soils, Geology, Hydrogeology and Surface Water Assessment. Lands located in IDA Industrial Park, Garrycastle, Athlone, Co. Westmeath*. Technical Report prepared by Jacobs Engineering (pg. 97 of Reports on Westmeath County Council Planning Ref: 207025).

Blockeel, T.L., Bell, N.E., Hill, M.O., Hodgetts, N.G., Long, D.G., Pilkington, S.L. & Rothero, S.L. (2021). A new checklist of the bryophytes of Britain and Ireland, 2020, *Journal of Bryology*, **43**,1, 1-51.

Cantonati, M., Segadelli, S., Ogata, K., Tran., Sanders., D., Gerecke, R., Rott., E., Filippini, M., Gargini, A. & Celico, F. (2016). A global review on ambient Limestone-Precipitating Springs (LPS): Hydrogeological setting, ecology and conservation. *Science of the Total Environment* **568**, 624-637.

Commission of the European Communities (2013). *Interpretation manual of European Union habitats: EUR 28*. Brussels: European Commission DG Environment.

Creagh House Environmental Ltd (2021a). *Dun Laoghaire Gold Club Extension. Environmental Impact Assessment Report.* Unpublished Report.

Creagh House Environmental Ltd (2021b). *Dun Laoghaire Golf Club Extension, Revised EIAR Sections 5,6 and 8 and CEMP*. Unpublished Report.

Curtis, T., Downes, S. & Ní Chatháin, B. (2009). The ecological requirements of water-dependent habitats and species designated under the Habitats Directive. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science*, **109B**, 261-319.

DELG/EPA/GSI (1999). *Groundwater Protection Schemes*. Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland.

Denyer, J. & Long, M.P., (2018). *Backing document – National Conservation Status Assessments (NCAs) for Petrifying Springs with Tufa Formation (Cratoneurion) (7220).* Unpublished Report, National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Dublin.

Denyer, J. (2018). *Petrifying spring survey, Garycastle, Athlone*. (pg. 397 of Reports on Westmeath County Council Planning Ref: 207025).

Denyer, J. (2020). *Dún Laoghaire-Rathdown Petrifying springs review*. Unpublished report, Dún Laoghaire Rathdown County Council, Dublin.

Environment Agency (2009). *Wetland functional mechanisms: a synopsis of WETMECs*. Science Report – SC030232/SR2.

Farr, G & Graham, J. (2017). Survey, characterisation and condition assessment of *Palustriella* dominated springs 'H7220 Petrifying springs with tufa formation (*Cratoneurion*)' in Gloucestershire, England. British Geological Survey, OR/17/020. 141pp

Heery, S. (2007). *Slieve Bloom tufa-forming (petrifying) spring survey (Part 1, Main Report).* Unpublished Report. Offaly County Council and Laois County Council.

HES (2020). *Proposed Housing Development at Kilgarron Hill, Enniskerry, Co. Wicklow – Hydrogeological Assessment Report*. Unpublished Report. Capami Ltd.

Hydro-G (2008). *Hydrological Report for Leixlip Spa, Co. Kildare*. Draft report. Kildare County Council.

IE Consulting (2021). *Proposed extension to Dun Laoghaire Golf Club P/058/21. Response to Request for Further Information: Hydrogeological Report*. Unpublished Report.

JBA (2019). *Tufa Catchment Study*. Unpublished Report. Dun-Laoghaire Rathdown County Council, Co. Dublin.

Kimberley, S., Regan, S., Naughton, O. & Lyons, M. (2013). *Provision of expert assistance on the assessment of groundwater dependent terrestrial ecosystems (GWDTEs)*. Unpublished Report, Environmental Protection Agency, Ireland.

Kimberley, S. (2013). *Conservation status assessments of three fen habitat types*. Unpublished Report, National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Dublin.

Lockhart, N., Hodgetts, N.G. & Holyoak, D. (2012). *Rare and threatened bryophytes of Ireland*. National Museums Northern Ireland, Co. Down.

Lyons, M.D. & Kelly, D.L. (2017). Rapid tufa deposition and bryophyte growth rates in Irish petrifying springs. *Journal of Bryology* **43**,2, 162-174.

Lyons, M.D. (2015). *The flora and conservation status of petrifying springs in Ireland*. Ph.D. Thesis, Trinity College Dublin.

Lyons, M.D. & Kelly, D.L. (2016). Monitoring guidelines for the assessment of petrifying springs in Ireland. *Irish Wildlife Manuals*, No. 94. National Parks and Wildlife Service, Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs, Ireland.

Lyons, M.D. & Kelly, D.L. (2017). Plant community ecology of petrifying springs (*Cratoneurion*) – a priority habitat. *Phytocoenologia* **47** (1) 13–32.

NPWS (2008). *The Status of EU Protected Habitats and Species in Ireland*. Unpublished Report, National Parks and Wildlife Service. Department of Arts, Heritage and the Gaeltacht, Dublin.

NPWS (2013). *The Status of EU Protected Habitats and Species in Ireland*. Unpublished Report, National Parks and Wildlife Service. Department of Arts, Heritage and the Gaeltacht, Dublin.

NPWS (2019). *The Status of EU Protected Habitats and Species in Ireland.* Unpublished Report, National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Dublin.

Pentecost, A. (2005). *Travertine.* Springer-Verlag, Berlin and Heidelberg.

SBEC (2021). *Hydrogeological Risk Assessment of Residential Development, Domville, Cherrywood*. Unpublished Report.

Stace, C.A. (2019). *New Flora of the British Isles*. 4th Edition. C&M Floristics, Stowmarket, UK.

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