REPORT

Hydrogeological Assessment of Proposed ICW Development, South Dublin

Comhairle Contae Átha Cliath Theas
South Dublin County Council

29 September 2020

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Document Control Sheet

Client	South Dublin County Council
Project	Dublin Urban Rivers Life Project
Project No:	251416
Report	Petrifying Springs, Dodder Valley Park Hydrogeological Assessment of Proposed ICW Development
Document Reference:	251416/40/DG/01

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1	Philip Schuler	Conor McCabe	Henning Moe	25 August 2020
2	Philip Schuler	Henning Moe	Ruairi O'Carroll	9 September 2020
3	Philip Schuler	Henning Moe	Ruairi O'Carroll	17 September 2020
FINAL	Philip Schuler	Henning Moe	Ruairi O'Carroll	18 September 2020
Revised FINAL	Philip Schuler	Henning Moe	Ruairi O'Carroll	29 September 2020

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List of Abbreviations

CSM	Conceptual Site Model
CTD	Conductivity, Temperature, Depth
EC	Electrical conductivity
EPA	Environmental Protection Agency
GSI	Geological Survey Ireland
ICW	Integrated Constructed Wetland
ITM	Irish Transverse Mercator
OSI	Ordnance Survey Ireland
SAC	Special Area of Conservation
SPR	Source-Pathway-Receptor
SDCC	South Dublin City Council
T	Temperature
WFD	Water Framework Directive
ZOC	Zone of Contribution

Executive Summary

A hydrogeological assessment of a proposed integrated constructed wetland (ICW) development in the Dodder Valley Park, South Dublin. The ICW development, located in the green park space north west of the River Dodder, near Seskin and Bawnville housing, was carried out to identify potential impacts of the ICW on a set of spring along the river which includes three EU Habitats Directive Annex I Priority Habitat 'Petrifying Springs'.

The assessment was undertaken as part of the Dublin Urban Rivers Life (DURL) Project, which is a collaboration between South Dublin County Council (SDCC) (as the lead authority) and the Dún Laoghaire-Rathdown County Council. The DURL Project aims to address pollution in urban rivers using techniques with proven results relating to domestic misconnection sources and ICW development.

Approach

The assessment included a desk-level review of publicly available information on the hydrogeological setting of the proposed ICW development, and was supplemented by location-specific information provided by SDCC. The latter included a recent ecological survey of the springs, water quality of a dominant spring (referred to as D02), trial pit logs from the ICW area, and layouts of pipe infrastructure near the Dodder Valley Park.

The assessment also included two site visits in August 2020 to: a) confirm the locations of the springs; b) measure their approximate discharge rates; and c) deploy a pressure transducer at spring D02 to record temperature (T) and electrical conductivity (EC) over a 2-week period.

Based on the data and information that were collated, a conceptual site model (CSM) was generated as a basis for the hydrogeological assessment. The CSM was guided by the source-pathway-receptor (SPR) model of environmental risk assessment and describes SPR linkages between the ICW (source) and petrifying spring (receptor) locations.

Key Findings

The petrifying springs along the River Dodder are inferred to discharge groundwater from a limestone bedrock aquifer. At the dominant spring referred to as D02, groundwater visibly discharges from bedrock fractures, and the available field measurements and groundwater quality data are consistent with a bedrock provenance.

In the area of the proposed ICW development, groundwater flow is conceptually from west to east, towards the River Dodder (which receives groundwater baseflow).

Spring D02 is located hydraulically downgradient of the proposed ICW development. However, it is not expected that it would be impacted by the development, for the following reasons:

- The proposed ICW construction is very shallow (<0.5 m below ground surface) whereas the underlying subsoils are thick (several metres, based on observations along the river embankment and GSI data sources at nearby locations).

- During ICW operations, leakage from the ICW basin(s) will conceptually migrate towards the River Dodder via shallow groundwater pathways and discharge as diffuse seeps along the river embankment.
- Even if the ICW leakage water was to discharge at D02, the estimated leakage rate from the ICW represents only approximately 1.7% of the estimated total discharge at spring D02.

The anticipated diffuse seeps along the river embankment would enter the river via runoff (overland flow). This implies that some water may flow across tufa deposits at or near D02.

Springs D01 and D03 to D08 are located upstream from the proposed ICW development. In the groundwater context, these springs are located hydraulically upgradient or sidegradient of the proposed ICW development. They are also more distant, and thus highly unlikely to be influenced by the proposed ICW development.

Mitigation Measures

During construction, standard best practice methods apply. Excavation activity could result in sediment transport to the river, but this can be mitigated using silt fences. The greater risk is associated with potential spills of fuel or other chemicals, but this too can be mitigated with simple measures.

Construction should be carefully supervised to ensure that the ICW is built to specification and that the correct materials are used (especially liner materials).

During operations, potential overflows from the ICW basin(s) would affect the surrounding land, which is a public park. Thus, provision for overflow diversion should be made in the design.

Recommendations – Environmental Monitoring

Although potential impacts are considered unlikely, a precautionary environmental monitoring programme is recommended: a) to build up a broader dataset of discharge characteristics and water quality; and b) to document seasonality and responses to storm events.

In the context of environmental monitoring for the proposal by the DURL Project, specific recommendations are as follows:

- Periodic observation and estimation of spring discharges following storm events, especially at D02.
- Periodic observation of seepages along the river embankment following storm events.
- Deployment of a CTD sensor to record T and EC at D02 Primary, preferably over several weeks, transitioning into and out of the winter season.
- Quarterly sampling of springs (especially D02) for laboratory analyses of physico-chemical, nutrient, and microbiological parameters.

An adaptive approach to monitoring is recommended, whereby the scale and timing of monitoring is amended and possibly reduced following periodic review of findings. The petrifying springs would also be surveyed periodically by a suitably qualified ecologist.

Because the construction of the proposed ICW is not predicted to impact on the bedrock aquifer or the petrifying springs, construction is not contingent or dependent on the environmental monitoring.

Section 1 Introduction

1.1 Background

South Dublin County Council (SDCC) intends applying for Part 8 planning approval for the construction of Integrated Constructed Wetlands (ICWs) at the Dodder Valley Park, Kilnamanagh and Griffeen Valley Park. Planning and design work are currently being undertaken as part of the Dublin Urban Rivers Life (DURL) Project (Agreement number: LIFE17ENV/IE/000281), which is a collaboration between SDCC (as the lead authority) and the Dún Laoghaire-Rathdown County Council.

The DURL Project aims to address pollution in urban rivers using techniques with proven results relating to domestic misconnection sources and Integrated Constructed Wetland (ICW) development.

The current report addresses the proposed ICW within the Dodder Valley Park, consisting of two basins, each covering an area of approximately 2,000 m^2 with an estimated additional project boundary of 1,000 m^2.

Work previously undertaken for SDCC by Denyer Ecology (2020) identified 8 petrifying springs/seepages along the Dodder River valley as features of interest in connection with the proposed ICW development. Petrifying springs are lime-rich water sources that deposit tufa, a porous calcareous rock (Lyons and Kelly, 2016). Denyer Ecology (2020) placed the 8 springs/seepages into 3 different categories, as follows:

- EU Habitats Directive Annex I Priority Habitat 'Petrifying Springs' (3 no.);
- Non-Annex springs with tufa (3 no.); and
- Non-Annex springs without tufa (2 no.).

SDCC subsequently engaged CDM Smith to conduct a hydrogeological assessment of potential impacts of the proposed ICW development on the petrifying springs. The DURL project is particularly interested to know if the construction of the ICW would reduce the volume of water currently discharging from the Annex I Priority Habitat Petrifying Springs D02, which is the closest one to the ICW (approximately 50 m away), as this might have negative impacts on the ecology of the Annex I spring. This report aims to determine the potential volumetric impact of the construction of the proposed ICW, of approximate 2,000 m^2 area, D02 spring, and the potential impact on other springs and seepages in the area.

The DURL Project (Agreement number: LIFE17 ENV/IE/000281) has received funding from the European Union. The report reflects only the author's view and that the Executive Agency for Small and Medium-sized Enterprises is not responsible for any use that may be made of the information it contains.

1.2 Objectives

The objectives of the hydrogeological assessment are to:

1. Describe the hydrogeological settings of the springs in context of the proposed ICW development;
2. Characterise the springs;
3. Assess the impact (or possible impacts) of the proposed ICW on the petrifying springs identified in the Denyer Ecology report entitled "Petrifying Spring Survey and Assessment Dodder Valley Park, South Dublin, Draft Baseline Report";
4. Identify possible and relevant mitigation measures to eliminate or lessen impact; and
5. Prepare an assessment report which is technically suitable for the Part 8 Planning Process.

1.3 Scope of Work

To achieve the project objectives, the following task were carried out:

1. Desk study;
2. Walkover survey;
3. Spring monitoring;
4. Conceptual site model (CSM) development; and
5. Technical Assessment.

1.3.1 Desk Study

The site and associated features were researched and reviewed using publicly available data and information sources, as well as relevant materials provided by SDCC. Topics covered were:

- Physiography and topography;
- Climate (Met Eireann);
- Soil cover (GSI *et al.* 2006)
- Location-specific soil properties (IGSL, 2020);
- Quaternary sediments (GSI, 2016);
- Bedrock and Quaternary geology;
- Groundwater vulnerability;
- Groundwater resources;
- Surface water features and flows/discharges;
- Surface water quality and EPA WFD status;
- Baseline ecology; and
- Water, wastewater infrastructure.

1.3.2 Walkover Survey

The walkover survey involved the ground-truthing of springs/seeps and becoming familiar with the general landscape, its physiography, and features.

Each spring/seep was surveyed, confirming locations and assessing the nature of groundwater discharge locations (e.g. consolidated bedrock vs. unconsolidated sediments). Coordinates were recorded in the field using a Garmin GPSmap 60CSx global positioning system (GPS) device. All coordinates are reported in Irish Transverse Mercator (ITM) throughout this report.

Two site visits were carried out, on 4 and 18 August 2020.

1.3.3 Monitoring

Spot measurements of spring discharges, specific electrical conductivity (EC) and temperature (T) were taken during the study period. EC and T measurements were recorded using a Schlumberger DI263 probe (Schlumberger Water Services, BC, Canada).

Two conductivity-temperature-depth (CTD) sensors (Schlumberger DI271) were deployed at select locations, for 2 weeks each, recording data in 15-minute intervals.

Both CTD sensors were calibrated on 2 August 2020, using a 1,413 µS/cm calibration standard for a one-point calibration. A subsequent comparison of EC records showed an average deviation of 3.4% between the two sensors, which is considered acceptable.

1.3.4 CSM Development

Based on the findings and observations from Tasks 1 through 3, a conceptual site model was developed, focussing on the possible hydrogeological relationships between the proposed ICW, the Dodder River, and the petrifying springs.

The development of the CSM informed about knowledge gaps and risks of impacts, both during ICW construction and operations.

1.3.5 Impact Assessment

Potential impacts and mitigation measures were examined in context of the Source-Pathway-Receptor model of environmental risk assessment. Knowledge gaps were factored into the assessment, which also guided recommendations.

1.4 Sources of Data and Information

Key sources of relevant data and information are the Environmental Protection Agency (EPA), Geological Survey Ireland (GSI), Office of Public Works (OPW), National Parks and Wildlife Service (NPWS), and the SDCC. Data and information related to the topics covered by the desk study were accessed using online web-viewers, and the following reports or publications:

- Blake, S. (2016): A multi-disciplinary investigation of the provenance, pathways and geothermal potential of Irish thermal springs. PhD thesis, National University of Ireland, Galway.
- Denyer Ecology (2020). Petrifying spring survey and Assessment Dodder Valley Park, South Dublin.

- Hennessy, R., Meehan, R., Parkes, M., Gallagher, V., Gatley, S. (2014). The Geological Heritage of South Dublin County - An audit of County Geological Sites in South Dublin County.
- IGSL (2020). Trial pit results of soil properties, Dodder Valley Park. August 2020.
- Lerner, DN. (1990). Groundwater recharge in urban areas. Atmospheric Environment. Part B. Urban Atmosphere, 24, pp. 29-33.
- Lyons, MD., Kelly, DL. (2016). Monitoring Guidelines for the Assessment of Petrifying Springs in Ireland.
- South Dublin City Council. (2020). GIS coverages and CADD drawings of the proposed ICW and topographic surveys.
- Tedd, K., Coxon, C., Misstear, B., Daly, D., Craig, M., Mannix, A., Hunter Williams, T. (2017). Assessing and Developing Natural Background Levels for Chemical Parameters in Irish Groundwater. GSI publication.

Section 2 Site Setting

2.1 Location and Topography

The proposed ICW is located within the Dodder Valley Park, South Dublin. The ICW site extends between approx. 709,901 (X) and 726,755 m (Y) in the north, and between 709,881 (X) and 726,653 m (Y) in the south (Figure 1). Surface elevations range between 90.8 in the NW and 88.4 m OD in the E, with a gentle SE slope towards the River Dodder. The river flows from SW to NE.

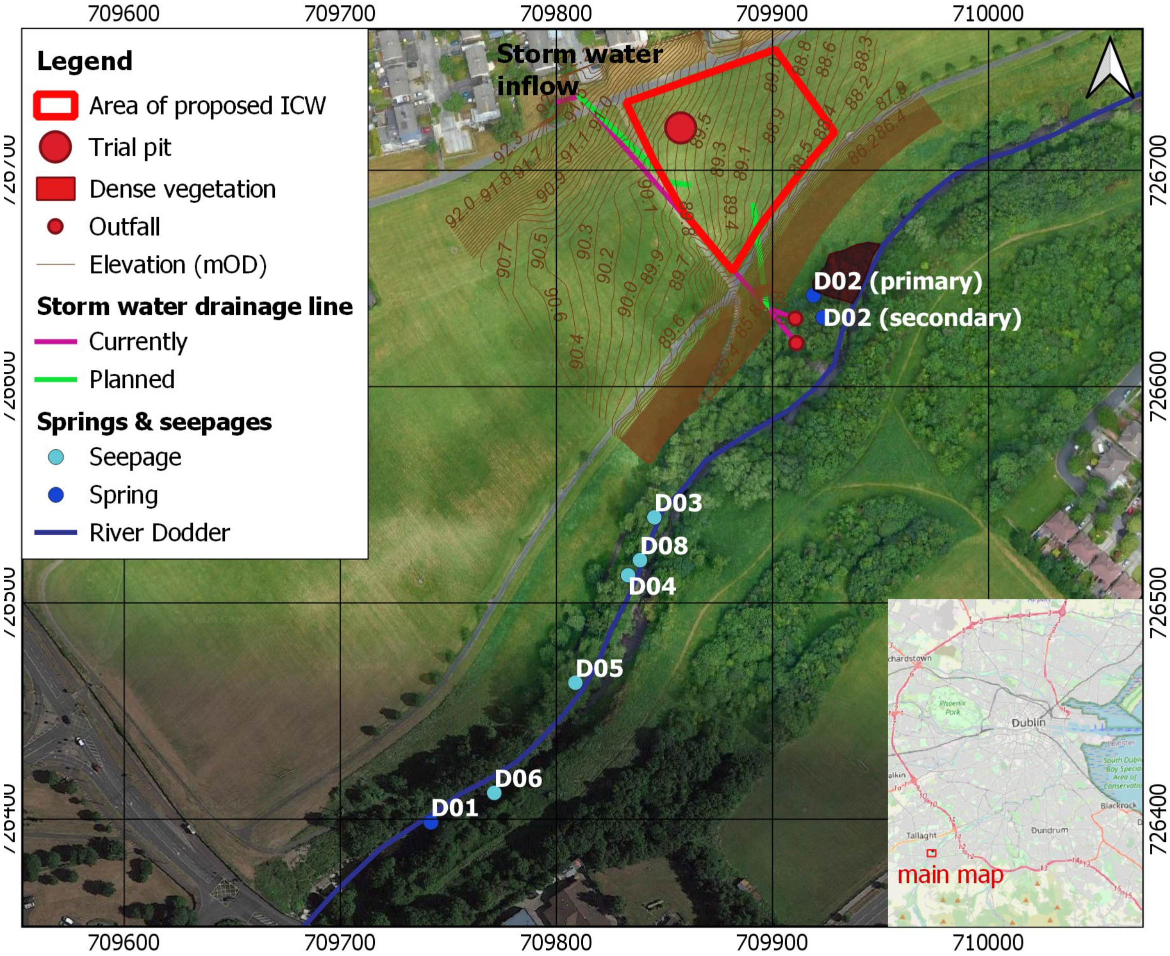


Figure 1: Site Location and Topography

The proposed ICW is located on the northern bank of the river. The current land use at the site is park/grassland. Towards the river, the topography steepens, where land is also covered by dense brush and trees.

The topography of the Dodder Valley and associated terraces are linked to glaciation. The area to the south of the River Dodder opposite the proposed ICW site is considered a site of geological/geomorphological interest (Hennessy *et al.*, 2014). The area north of the river appears to have been heavily modified in the past, both with regards to the course of the river and its embarkment. The modifications become apparent when comparing current and historical topographical OSI maps.

The petrifying springs are located to the south and south-west of the proposed ICW site, along the banks of the River Dodder. The springs/seeps are groundwater discharge locations.

As indicated in Figure 1, stormwater discharges permanently through an outfall located south of the proposed ICW. This storm water includes a small contribution of grey water (dishwashers/sinks/showers) from households' misconnections, which will be treated by the ICW in the future, before being diverted into the River Dodder. There are two outfall pipes: a main pipe and an overflow pipe 9 m to the NNE. These outfalls remain in place, and are planned to discharge the treated water discharged from the ICW.

2.2 Climate

For climatic reference, monthly mean ambient air temperature (T) and rainfall (P) records were collated for the Met Eireann station at Phoenix Park (Figure 2). The mean annual air temperature between Augsut2018 and July 2020 was 10.43 °C, and total monthly rainfall ranged from <10 mm/month (May 2020) to 157 mm/month (November 2019).

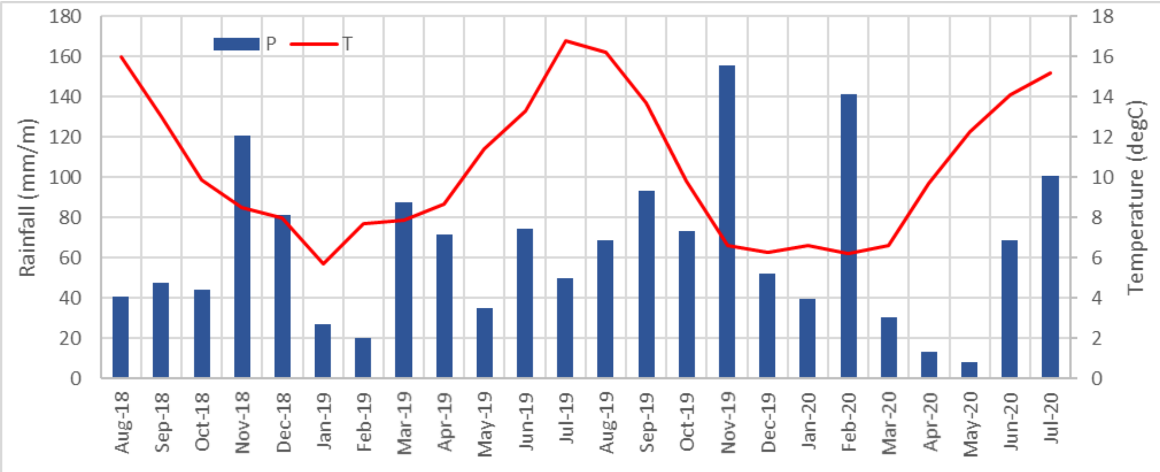


Figure 2: Monthly rainfall and mean temperature, Phoenix Park station, August 2018 to July 2020

2.3 Soils and Subsoils

The distribution of regionally mapped soils and subsoils are presented in Figures 3 and 4, respectively. Across the proposed ICW site, soils are mapped as 'made ground', reflecting the combination of urban/disturbed conditions along the west side of the river. Subsoils (Quaternary sediments) are mapped as glacial till and 'gravelly' alluvial sediments, and a boundary between the two subsoil types passes across (*i.e.* beneath) the proposed ICW area.

The GSI has assigned a 'Low' subsoil permeability across the entire ICW area. The basis for this is not known, and a higher permeability can (conceptually) be expected where alluvial type sediments are present. It should be noted that GSI maps are regional maps. They are not intended to (and cannot) capture local-scale details. As such, they provide indicative information.

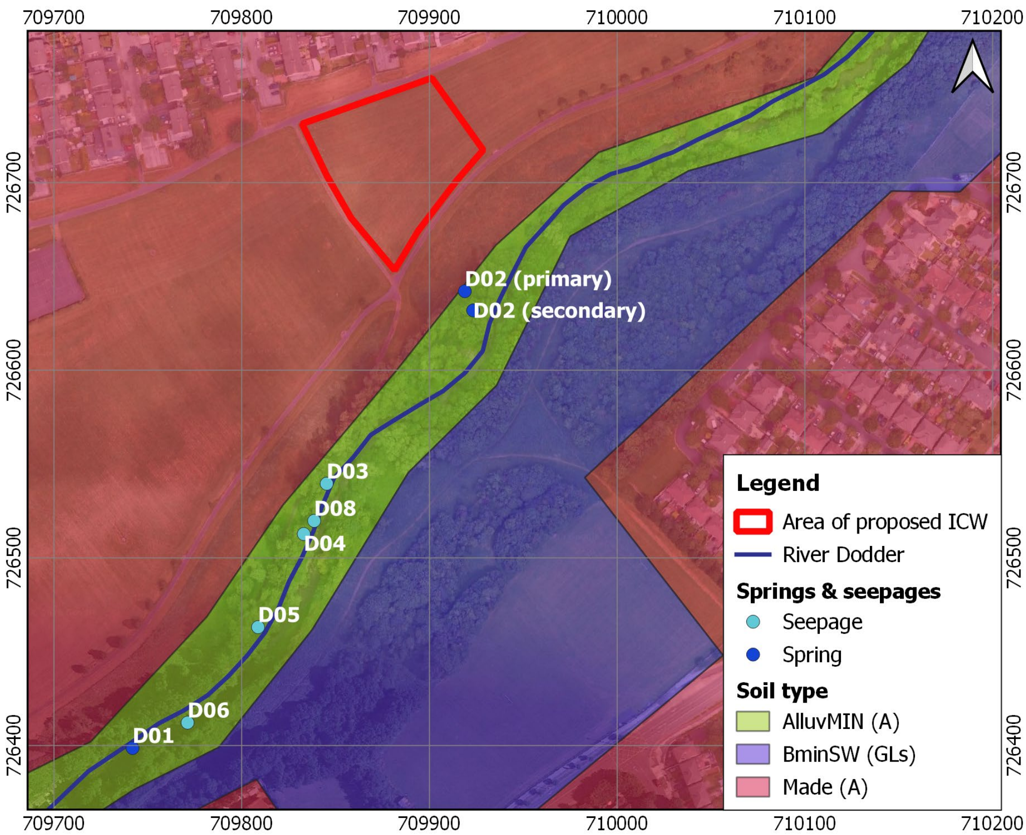


Figure 3: Soil Cover

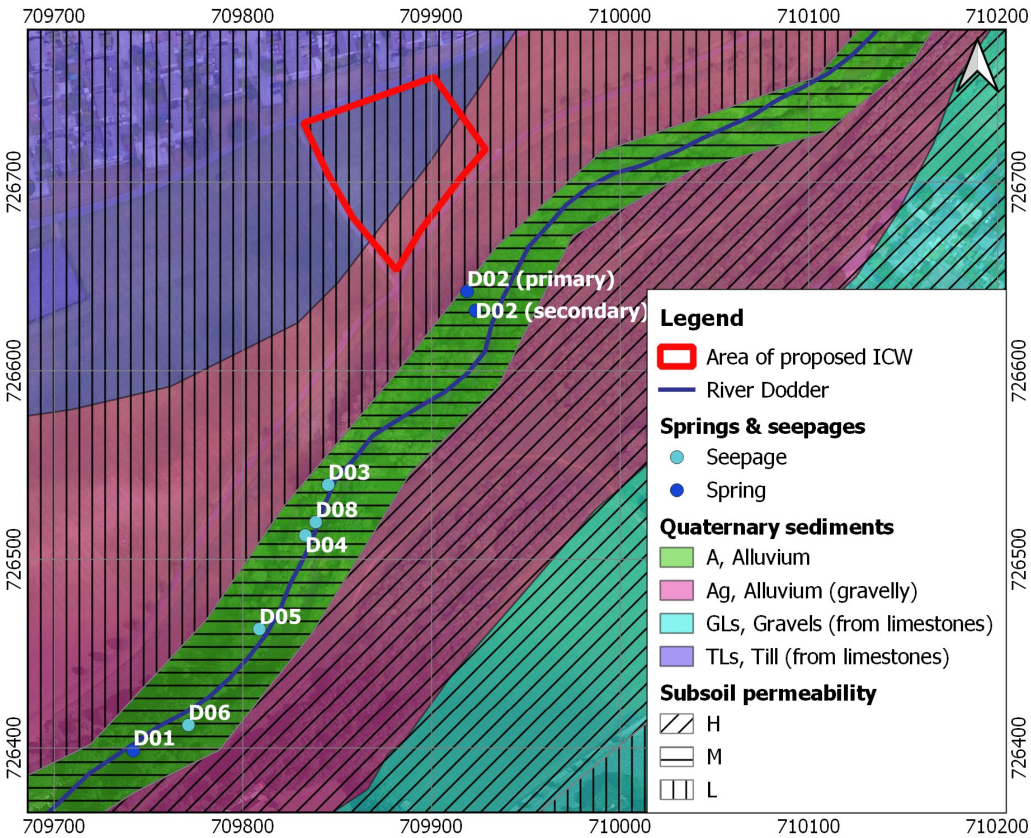


Figure 4: Quaternary Sediments and Subsoil Permeability

As a point of interest, Hennessy *et al.* (2014) described the topographic terraces along the River Dodder as predominantly consisting of well-drained sands and gravels, forming productive grassland.

2.4 Bedrock Geology

The bedrock is mapped by the GSI as the Lucan Formation, which is a dark grey, fine-grained and argillaceous (muddy) limestone. It is commonly referred to as the 'Calp' (GSI 2018b). The Calp can have extensive shale interbeds, and does not tend to be karstified.

A GSI-mapped fault crosses the site, extending NE-SW, broadly following the river valley. The fault trace is inferred at the regional scale, and it is noteworthy that the petrifying springs align with the orientation of the trace (Figure 5). This may indicate a relationship between the fault structure and springs.

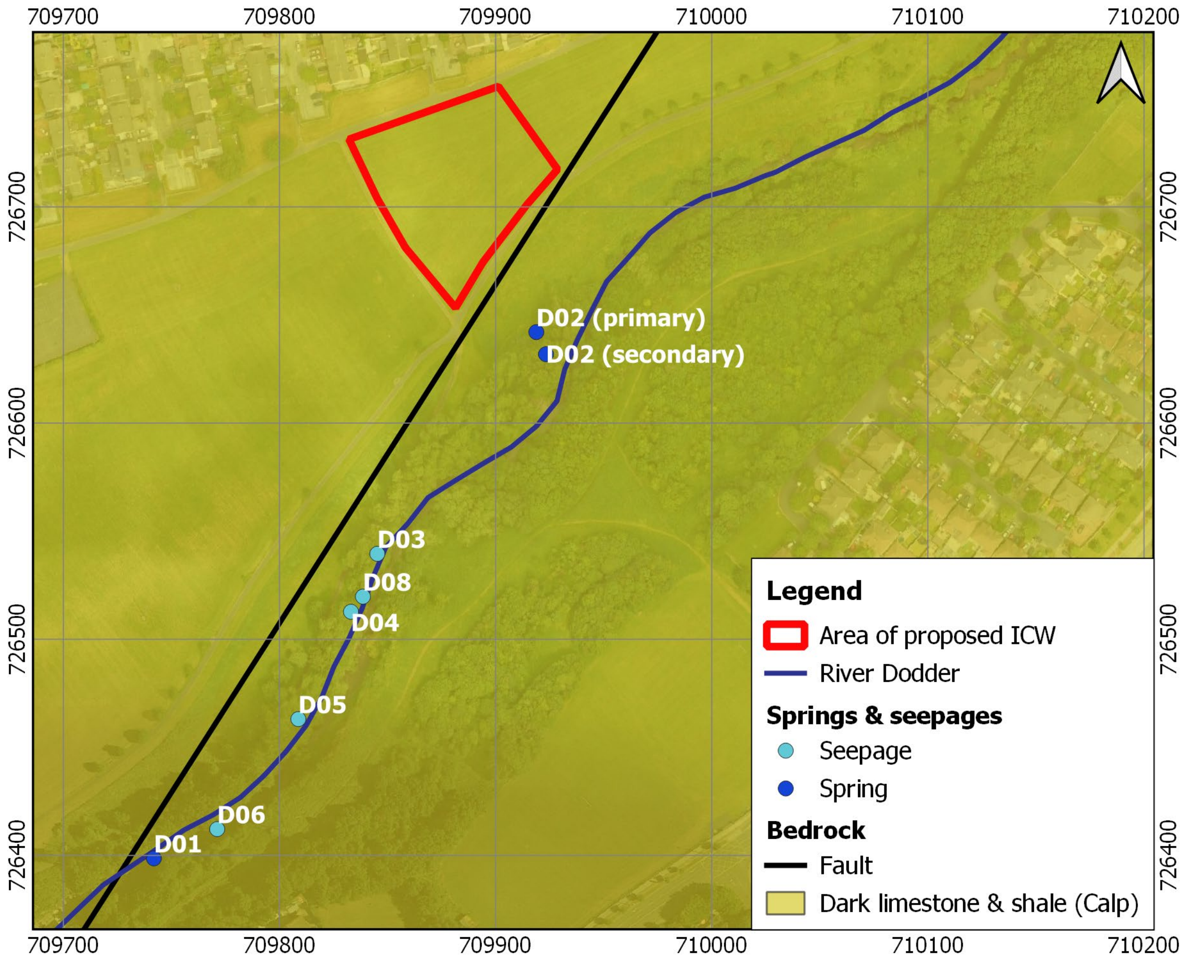


Figure 5: Bedrock Geology

The thickness of the subsoils (*i.e.* depth to bedrock) at the proposed ICW site is not precisely known (see also Section 3.3), but bedrock is expected to be several metres below ground level. This is based on: a) observations from the river looking west onto the embankment; b) GSI mapping of 'Low' groundwater vulnerability (see below); and c) indications of depth of bedrock of more than 8 m near the Old Bawn Road bridge immediately to the southwest of the ICW site (as presented on the GSI Geotechnical web-viewer).

2.5 Groundwater Vulnerability

The GSI-mapped groundwater vulnerability across the proposed ICW site is 'Low' (Figure 6), reflecting a 'Low' subsoil permeability and a deep inferred depth to bedrock.

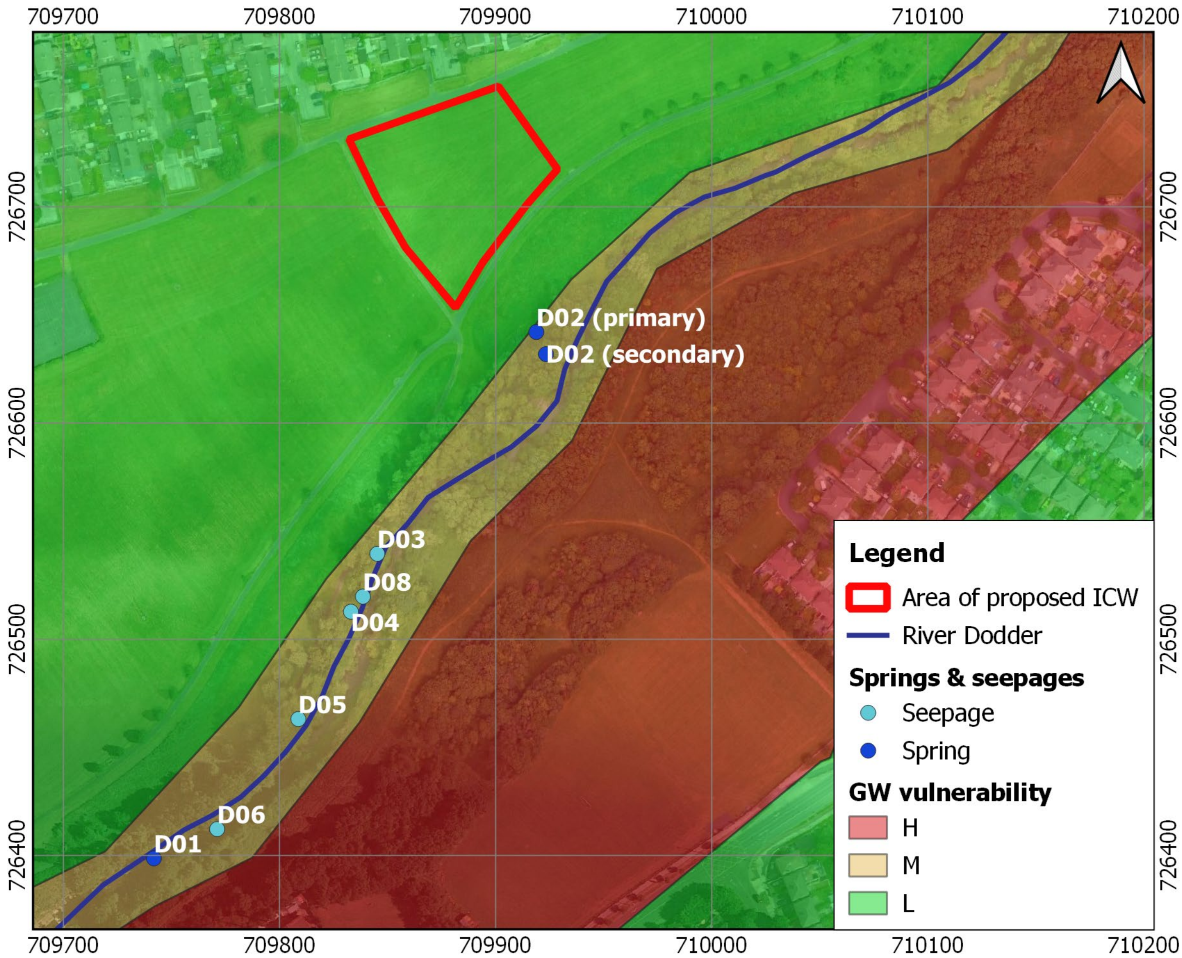


Figure 6: Groundwater Vulnerability

2.6 Groundwater Resources

The principal groundwater resource at the site would be conventionally considered as the underlying bedrock aquifer, *i.e.* the Calp. However, in the context of potential impacts of ICW development on springs/seeps along the river, groundwater flow through the shallow alluvial sediments also has to be factored in.

The Calp bedrock is mapped by the GSI as an 'Ll' aquifer – i.e. locally important and moderately productive only in local zones. In this case, the local zone would be the fault trace along the river as faults sometimes enhance fracture permeability in the rock. Accordingly, groundwater flow and discharge along the fault trace is considered relevant to the conceptual hydrogeological model of the site.

Both the alluvial sediments and bedrock aquifer receive recharge from rainfall. Within the area of interest, a portion of the rainwater infiltrates through the subsoil and into the bedrock aquifer. According to the national map of annual average groundwater recharge (produced by the GSI), approximately 20% of effective annual average rainfall infiltrates the ground across the proposed ICW site. As shown in Figure 7, this equates to an estimated annual average recharge of 83 mm/annum (mm/a). The 20% recharge coefficient reflects the combination of 'made ground' and 'Low' subsoil permeability which has been mapped by the GSI.

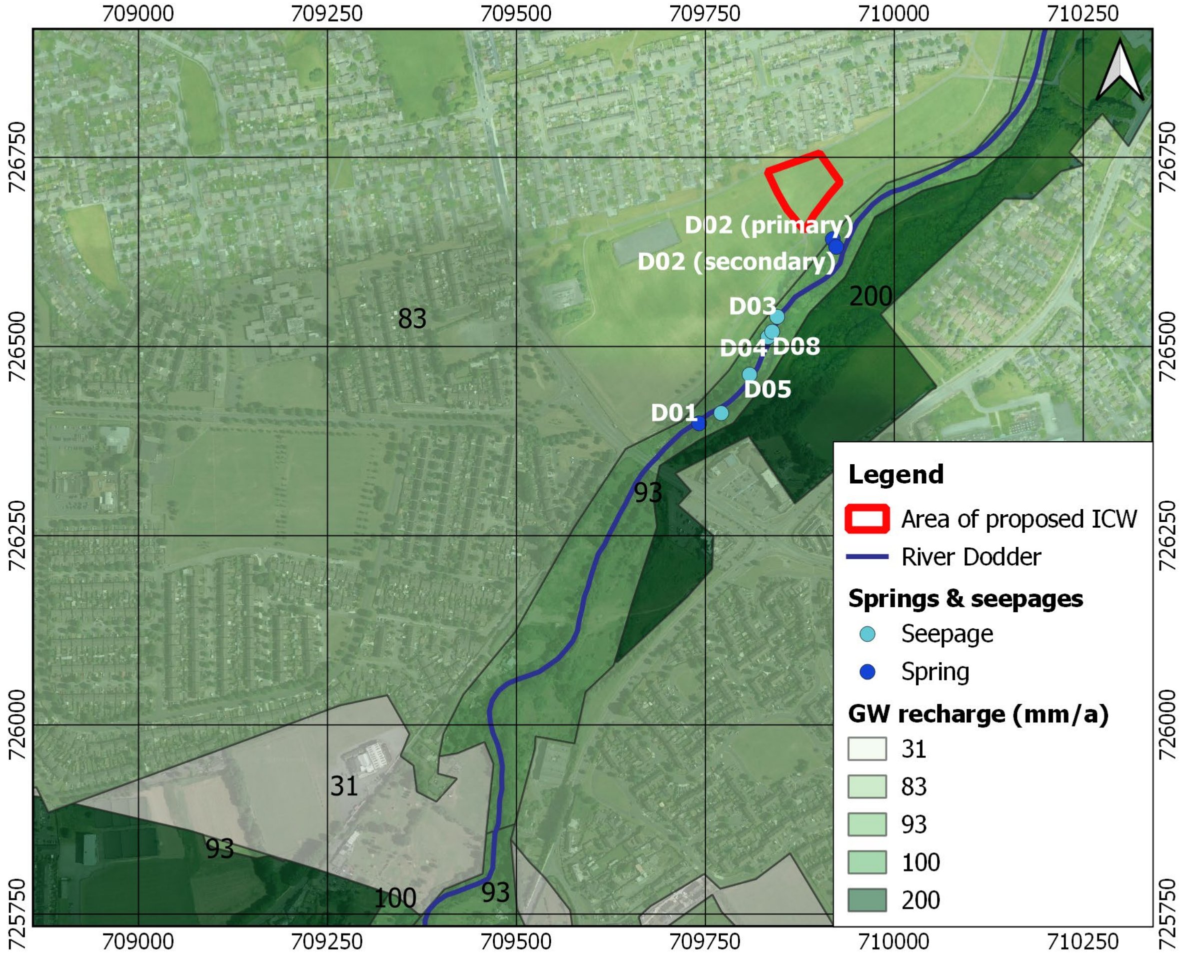


Figure 7: Groundwater Recharge

2.7 Springs and Seeps

The identified petrifying (tufa forming) springs and seeps (Figure 8, Denyer Ecology, 2020) are groundwater discharge locations. Details from site visits to each location are presented in Section 3.

Spring D02 is considered the most relevant to the ICW project, given its proximity to the proposed ICW site and higher discharge compared to the other springs/seeps (Denyer Ecology 2020; personal communication, Ger Staunton, SDCC, 4 August 2020).

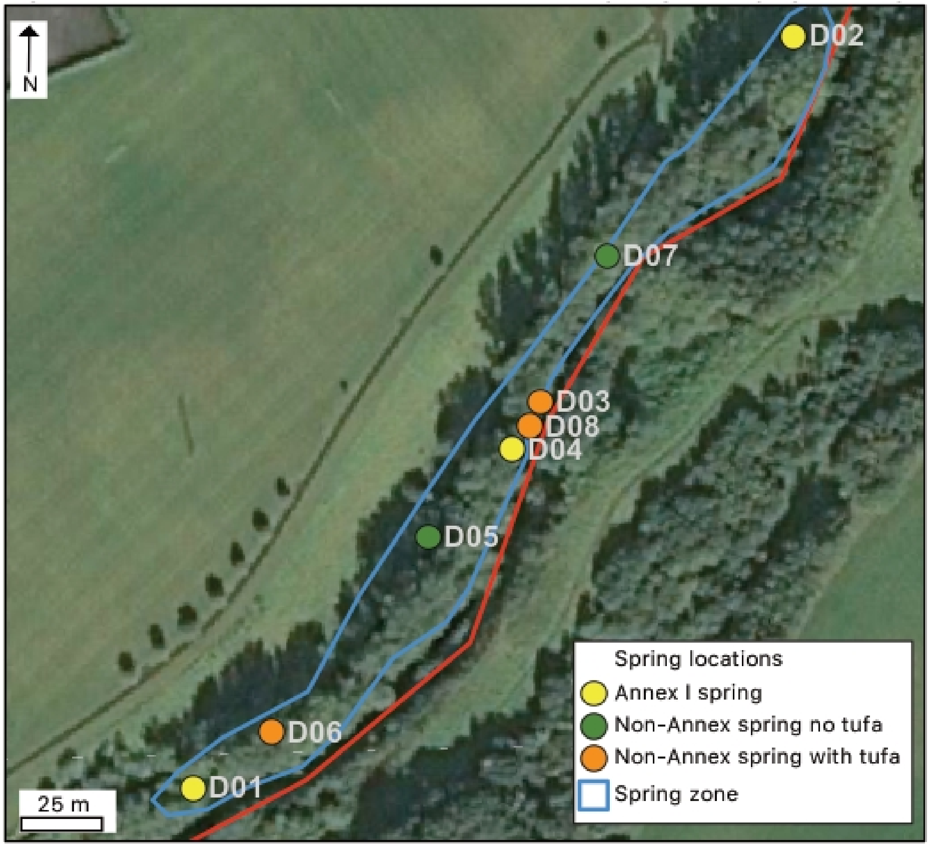


Figure 8: Spring Locations and Types (Source: Denyer Ecology, 2020)

Section 3 Site Investigations

3.1 Site Walkover

The springs were visited on 4 and 18 August 2020. They were ground-truthed in terms of their geographic locations and examined in terms of their discharges, outflow types (springs/seeps) and hydrogeological positions (bedrock/sediment).

All springs described by Denyer Ecology (2020) were found and surveyed, except D07 (Figure 9) which was 'hidden' in dense brush.

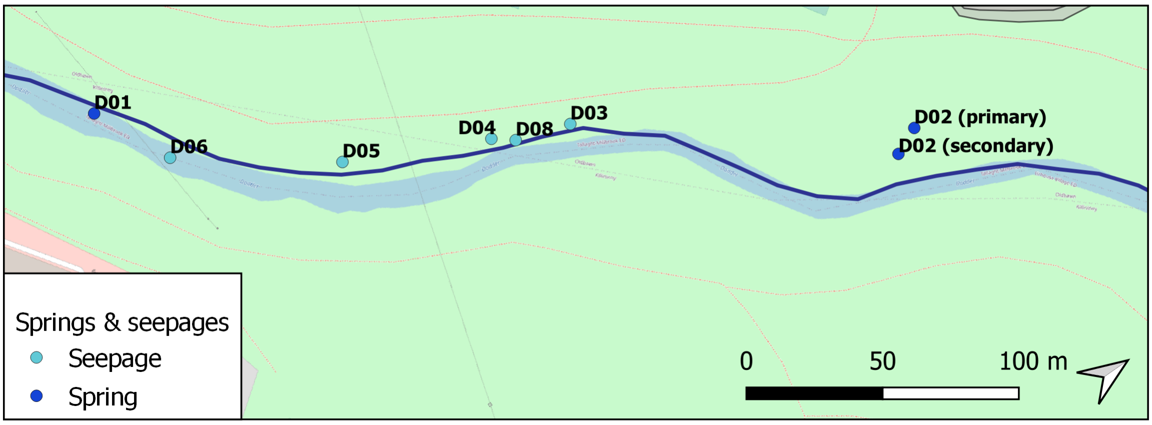


Figure 9: Surveyed Locations of Springs/Seeps

General characteristics of springs and seeps are summarised in Table 1, and photographic documentation is presented in Annex 1 (A 1 to A 8).

Table 1: Summary of Springs and Seeps, Dodder Valley Park

Name	Type	ITM East	ITM North	Elevation (m OD)	Outflow	Discharge (l/s)	Comment
D02 (primary)	Spring	709918.90	726642.17	c. 82.60	Bedrock (gravel contact?)	~1.2	Tufa deposits
D02 (secondary)	Spring	709923.36	726631.96	c. 82.60	Bedrock, distinct fracture	~0.3	Tufa deposits
D07	-	-	-	--	-	-	Not found
D03	Seepage	709845.31	726539.59	80.473	Topsoil	None	Iron staining
D08	Spring	709838.75	726519.72	80.758	Embankment (Bedrock/ topsoil)	0.01	Iron staining, tufa deposits
D04	Seepage	709833.12	726512.77	80.563		None	Iron staining, tufa deposits
D05	Seepage	709808.75	726463.11	81.283		None	
D06	Seepage	709771.19	726412.20	81.431		None	
D01	Spring	709741.91	726398.66	82.101	Bedrock	<0.2	Tufa deposits, multiple outlets

The total discharge from all springs/seeps on both days of visit was estimated to be approx. 2 l/s. Even though a major rain event preceded the second visit, there were no observed changes in discharges along the embankment, and no discernible change in total discharge.

However, anecdotal information indicates that after major storm or rain events, shallow discharges (possibly 'interflow' near the top of bedrock surface) commences along the escarpment, above the petrifying springs. It is possible that such discharges originate from freshly infiltrated water flowing via shallow subsoil/ weathered bedrock pathways (e.g. transition zone).

Spring D02 comprises a 'Primary' and 'Secondary' discharge point. The secondary discharge is from bedrock fractures (only). The primary outlet is inferred to be from bedrock as well, but the presence of sands/pebbles at the outflow location raises a question about possible contribution of shallow groundwater, e.g. from weathered bedrock ('transition zone').

All of the other springs/seeps to the south of D02 emerge along a modified river embankment (see Appendix 1: A 5). Hence, it is not possible to confirm from observation alone whether the corresponding spring discharges/seeps are related to bedrock alone.

Finally, the area to the NE of spring D02 could not be accessed due to very dense vegetation and steep (hazardous) topography (see 'Dense vegetation', Figure 1).

3.2 Spring Monitoring

During the initial site walkover on 4 August 2020, a CTD sensor was deployed at spring D02 Primary for a period of 2 weeks, recording at 15-minute intervals. A second CTD sensor was also used for spot measurements at springs D01 (two locations DO1(1) and D01(2)), springs D02 Primary and D02 Secondary, as well as spring D08. The spot measurements were conducted on 4 and 18 August 2020, and involved reccording EC and T at 10-second intervals for nearly 3 minutes at each measured spring. The data from 4 August 2020 are presented in Figure 10a (EC) and Figure 10b (T). The corresponding data from 18 August 2020 are presented in Figure 11a (EC) and Figure 11b (T).

3.2.1 Spot Measurements

The spot measurements on 4 August 2020 are summarized, as follows:

- The average EC ranged between 742 µS/cm (D02 Primary and secondary) and 892 µS/cm (D08). The data at individual locations are steady (consistent) and only D01(1) shows an increasing trend. The EC values at the two D01 locations are slightly different, 771 and 823 µS/cm.
- The average T values ranged between 11.71 °C (D02 Primary) and and 13.19 °C (D08). Values at D01(1) shows a decreasing trend towards 12 °C. It is possible the sensor may not have been fully submerged, although it is noted that the T values decrease towards what was recorded at the other D01 location (D01(2)).
- Both EC and T values are highest at spring D08.

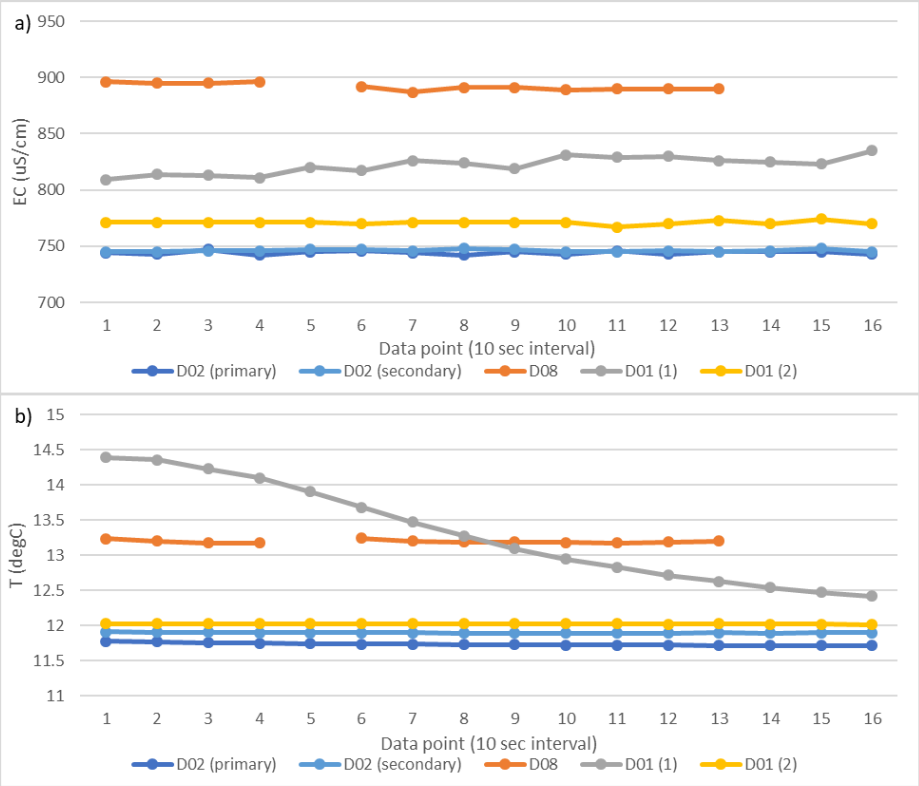


Figure 10: EC (a) and T (b) of Springs D01 (Primary, Secondary), D08 and D01 (1, 2), 4 August 2020

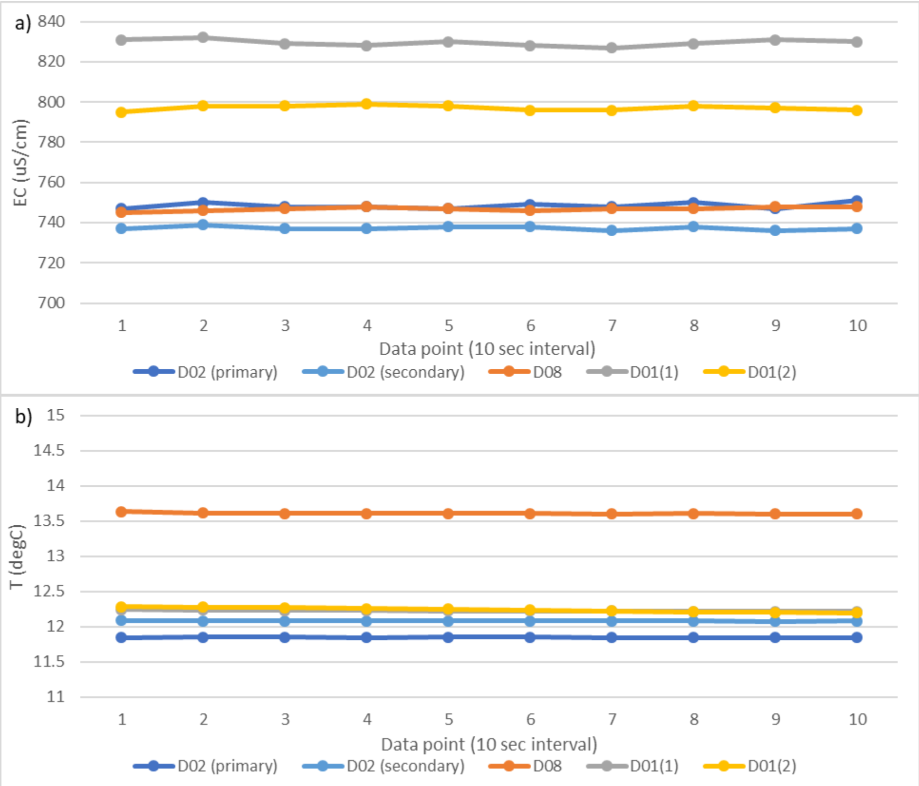


Figure 11: EC (a) and T (b) of Springs D01 (Primary, Secondary), D08 and D01 (1, 2), 18 August 2020

The corresponding spot measurements on 18 August 2020 are summarized, as follows:

- The average EC ranged between 737 µS/cm (D02 Secondary) and 829 µS/cm (D01);
- The average T values ranged between 11.85 °C (D02 Primary) and 13.61 °C (D08); and
- The EC in D08 dropped significantly between 4 and 18 August 2020.

The EC values are generally consistent with limestone source waters. However, the median reference EC value for 'impure limestones' (which includes the Calp) across Ireland is lower, at 554 µS/cm (Tedd *et al.* 2017). This suggests that the springs discharge more mineralized, (and potentially 'older') water, which is indicative of a prolonged residence time in the bedrock aquifer.

The T values generally increased between 4 and 18 August 2020. The records are 1.29 °C higher (4 August) and 1.42°C higher (18 August) than the mean ambient air temperature at Phoenix Park over the previous two years (10.43 °C). Even though there is no universal definition for 'thermal springs' (Blake, 2016), the recorded spring temperatures above the mean annual ambient air temperatures may be related to 'thermal' water (e.g. partial provenance from greater depth in the bedrock). This is a hypothesis only, but it is noted that Spawell House is located less than 3 km to the NE, along the River Dodder.

Table 2 compares all available T and EC records for springs measured between 23 March and 18 August 2020, and includes data received from SDCC and extracted from Denyer Ecology (2020).

Table 2: Summary of Available T and EC Measurements

Spring	23 Mar 2020[1]		20 May 2020[2]		4 Aug 2020[3]		7 Aug 2020[2]		18 Aug 2020[3]	
	T (°C)	EC (µS/cm)	T (°C)	EC (µS/cm)	T (°C)	EC (µS/cm)	T (°C)	EC (µS/cm)	T (°C)	EC (µS/cm)
D02 Primary	11.5	676	12.3	1,210	11.71	742	11.69	655	11.85	749
D02 Secondary	-	-	-	-	11.90	742	-	-	12.09	737
D08	-	-	-	-	13.19	892	-	-	13.61	747
D01	-	-	12.2	1,040	12.02	771/ 823	-	-	12.23	797/ 829

[1]SDCC; [2]Denyer Ecology; [3]CDM Smith

The reported T and EC values on 20 May 2020 at D02 Primary are higher than the apparent, more consistent values recorded between 23 March and 18 August by SDCC and CDM Smith. The reason for this is not known.

3.2.2 High-Resolution Data, D02 Primary

The high-resolution CTD sensor data from D02 Primary are presented in Figure 12a (EC) and b (T), along with daily total rainfall at the Phoenix Park meteorological station. The EC ranged between 717 and 735 µS/cm, and T ranged between 11.94 and 12.12 °C, respectively. Rainfall is low throughout the recording period, although a rain event is captured on 17/18 August.

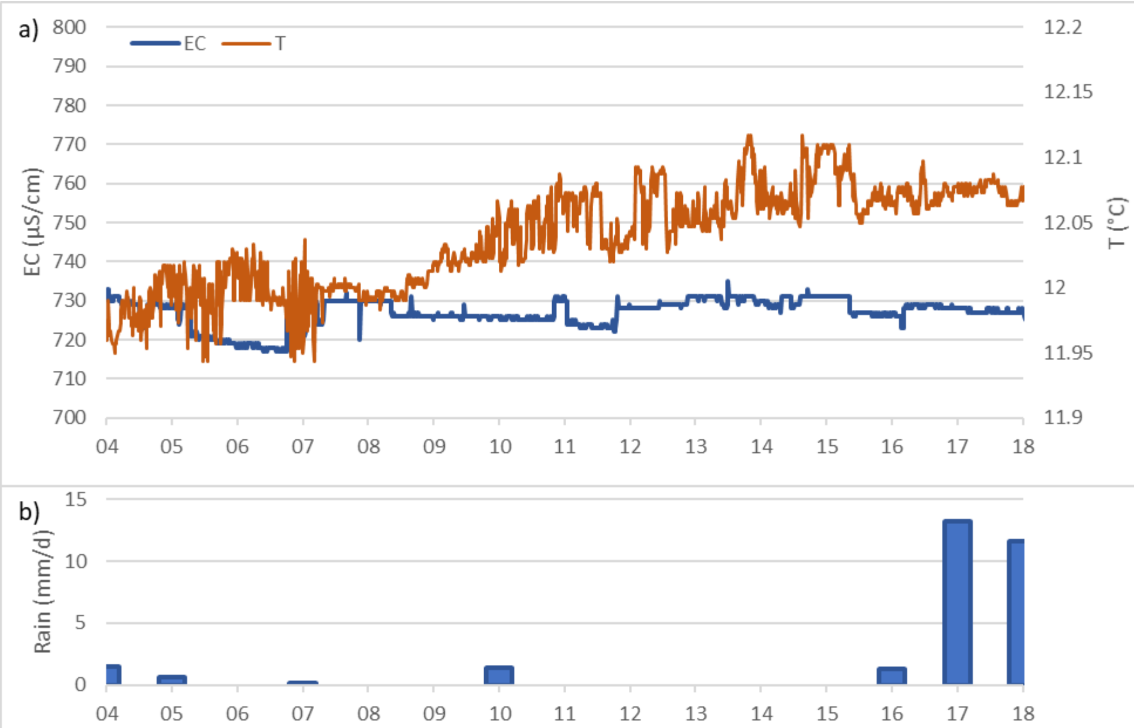


Figure 12: EC and T Data at Spring D02 Primary and Daily Rainfall at Phoenix Park

There is minor noise in the dataset, but diurnal patterns are absent (which would indicate an influence of ambient air temperature on shallow groundwater). Temperature rises slightly and gradually over the 2-week recording period.

3.2.3 Water Quality

Water quality data for D02 Primary in 2020 were provided by SDCC and are presented in Table 3. Nutrient constituents are low there is an apparent absence of coliforms and *E.coli* (both below the reported laboratory count limit of 20 MPN/100 mL). Nitrate is above the median value of 0.003 mg/l for impure limestones (Tedd *et al.*, 2017), but concentrations are still relatively low.

The total hardness and alkalinity values are greater than their respective median values for impure limestones of 250 and 246 mg/l (Tedd *et al.*, 2017).

Concentrations of dissolved oxygen (DO) (3.9 and 2.9 mg/l; 36 and 27% saturation) are low, and below the median value of 7.63 mg/l for impure limestones (Tedd *et al.*, 2017). The recorded values are more consistent with the reported median of 2.5mg/l O_2 for groundwater in 'Low' groundwater vulnerability settings, generally (*i.e.* all aquifer types across Ireland, as reported by Tedd *et al.*, 2017).

The water quality data from D02 Primary is <u>indicative</u> of water that is less influenced by anthropogenic sources of pollution and more influenced by mineralization (*i.e.* longer residence time in the bedrock groundwater flow system).

Table 3: Water Quality, Spring D02 Primary (Source: SDCC)

Parameter	Sample Date	
	23-Mar-20	07-Aug-20
Ammonia (mg/l-N)	<0.01	<0.03
COD (mg/l)	<10	-
EC (µS/cm)	676	655
DO (% Sat.)	36	27
DO (mg/l)	3.9	2.9
E. coli (MPN/ 100 ml)	<20	-
Total Coliforms (MPN/100 ml)	<20	-
Nitrate (mg/l-N)	1.85	2.2
Nitrite (mg/l-N)	<0.005	<0.005
pH	7.2	7.2
Phosphorus (React.) (mg/l-P)	<0.01	<0.03
T (°C)	11.5	11.9
TON (mg/l-N)	1.85	2.2
Total Alkalinity (mg $CaCO_3$/l)	-	310
Total Hardness (mg $CaCO_3$/l)	-	368

Given the urban setting of the springs and the presence of an outfall near spring D02, it was considered that the low DO values in D02 Primary could be indicative of aerobic digestion related to the grey water contributions in stormwater. However, the presence of grey water would be expected to lowered alkalinity and raise the concentrations of nutrient constituents and coliforms. The low concentrations of nutrients (e.g. ammonia) and coliforms suggest that a grey water influence is absent.

3.3 Trial Pits

Two trial pits were excavated by IGSL Ltd within the Dodder Valley park on 29 July 2020, as follows:

- Trial pit TPDD35 (709856.4 E; 726718.9 W) (within the proposed ICW site, see Figure 1).
- Trial pit TPDD33 (710161.0 E; 726929.6 W) (northeast of the proposed ICW site).

The trial pits are 1.5 and 1.8 m, respectively, and their logs are reproduced in Figure 13. The log for TPDD35, within the proposed ICW area, shows ‘made ground’ from 0 to 0.9 m depth, and is described as “firm to stiff, grey/brown, sandy gravelly silty CLAY”. The underlying sediments from 0.9 to 1.5 m are described as “gravelly SAND” and “sandy GRAVEL”, implying permeability. The coarser sediments at depth are likely of alluvial nature.

There were no water strikes recorded over the length of both profiles.

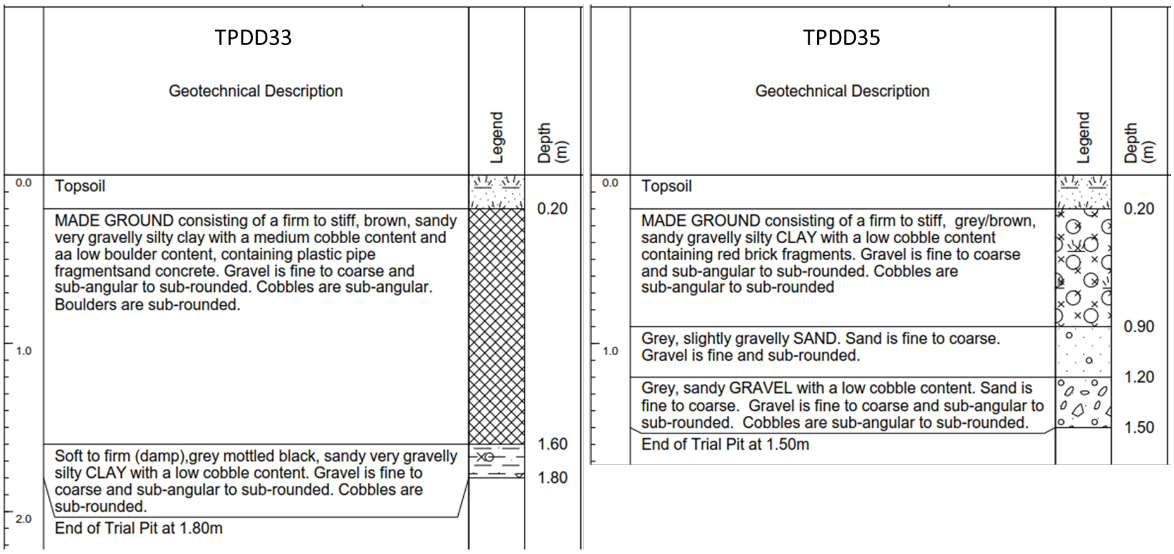
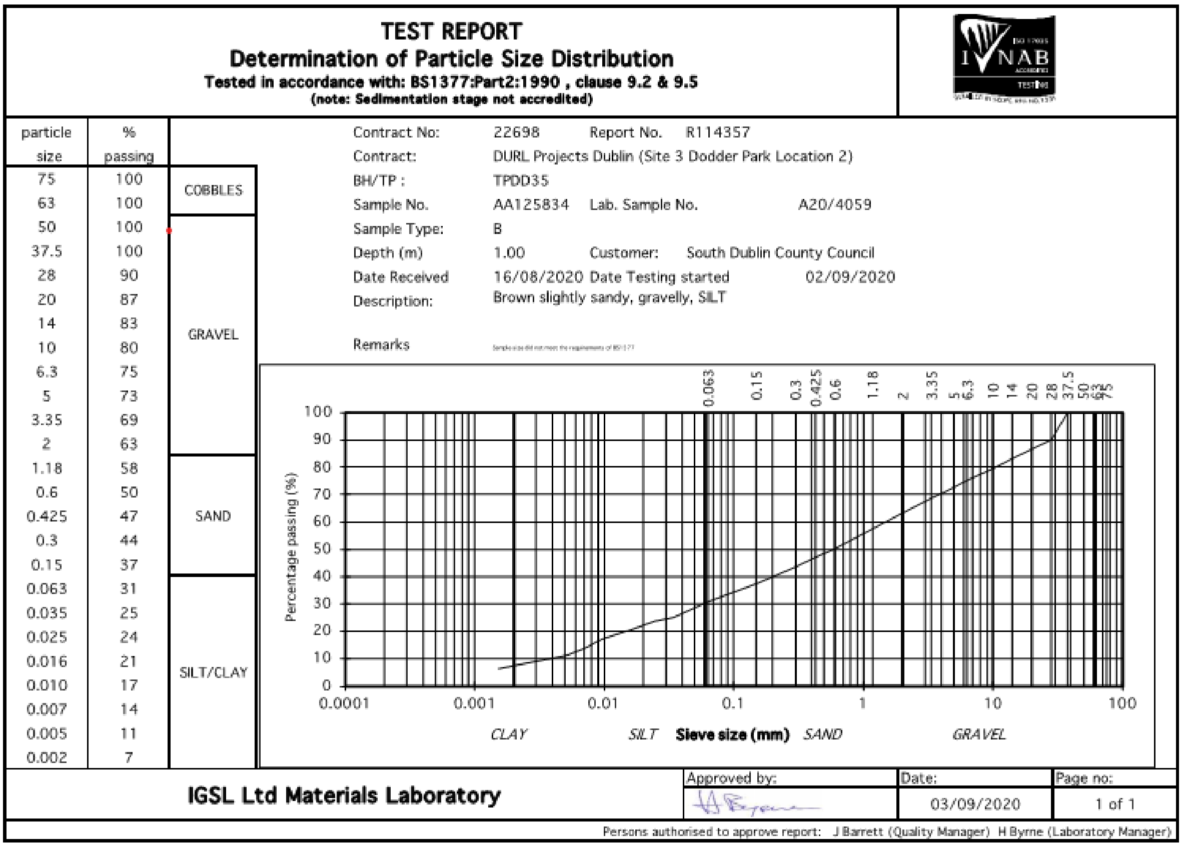


Figure 13: Trial Pit Logs of TPDD33 and TPDD35 (Source: IGSL, 2020)

Subsoil samples from TPDD35 at 0.5 and 1.0 m depths also underwent grain size analysis. The particle size distribution curve of the sample from 1.0 m depth (*i.e.* beneath 'made ground') is reproduced in Figure 14 (Source: IGSL, 2020).



TEST REPORT
Determination of Particle Size Distribution
Tested in accordance with: BS1377:Part2:1990 , clause 9.2 & 9.5
(note: Sedimentation stage not accredited)

Contract No: 22698 Report No. R114357
Contract: DURL Projects Dublin (Site 3 Dodder Park Location 2)
BH/TP : TPDD35
Sample No. AA125834 Lab. Sample No. A20/4059
Sample Type: B
Depth (m) 1.00 Customer: South Dublin County Council
Date Received 16/08/2020 Date Testing started 02/09/2020
Description: Brown slightly sandy, gravelly, SILT
Remarks

particle size	% passing	
75	100	COBBLES
63	100	
50	100	GRAVEL
37.5	100	
28	90	
20	87	
14	83	
10	80	
6.3	75	
5	73	
3.35	69	
2	63	
1.18	58	SAND
0.6	50	
0.425	47	
0.3	44	
0.15	37	
0.063	31	SILT/CLAY
0.035	25	
0.025	24	
0.016	21	
0.010	17	
0.007	14	
0.005	11	
0.002	7	

IGSL Ltd Materials Laboratory Approved by: Date: 03/09/2020 Page no: 1 of 1

Persons authorised to approve report: J Barrett (Quality Manager) H Byrne (Laboratory Manager)

Figure 14: Grain Size Distribution Curve, Trial Pit TPDD35, 1.0 m (Source: IGSL, 2020)

The sample is poorly sorted, as indicated by the broad range of particle sizes and an estimated uniformity coefficient (d_{60}/d_{10}) of approximately 460. The percent passing of SILT grade particles is approximately 30%. Thus, the sample appears to be finer-grained than indicated by the trial pit log at the same depth (Figure 13). Whereas the trial pit log described the sample as a "Grey, slightly gravelly SAND", the description from the grain size analysis is "Brown slightly sandy, gravelly SILT" (Figure 14).

Finally, the sample from 0.5 m depth underwent triaxial cell permeability testing, and the reported value was 6.55×10^{-9} m/s (IGSL, 2020). The sample from 1.0 m depth was not tested.

Section 4 Conceptual Site Model (CSM)

The groundwater which discharges from the spring group along the River Dodder near the proposed ICW site is inferred to originate from limestone bedrock. The largest spring, D02, visibly discharges from bedrock fractures. The measured water temperatures at D02 are above the mean annual ambient air temperature. This suggests a possible (geo)thermal influence on the water. That said, the available dataset is limited and measurements to date were all taken in late spring/summer.

Accordingly, a possible influence of shallow groundwater in overlying sediments and/or a weathered 'transition zone' (at the top of bedrock), cannot be ruled out. Potential influences from shallow 'urban pressures' are, however, not evident.

A conceptual hydrogeological cross-section across the ICW to spring D02 is depicted in Figure 15. Deeper groundwater in bedrock discharges at spring DO2 and into the Quaternary (alluvial) sediments along the river valley.

In the regional context, groundwater flow in bedrock is from west to east, obliquely towards the river, and both flow and discharges from bedrock are expected to be influenced by the NE-SW trending fault which follows the Dodder River valley. An upwards hydraulic gradient from bedrock is inferred based on the position of the site adjacent to the River Dodder (the latter being a receptor of groundwater baseflow). Subsoils are several metres thick, and the bedrock aquifer is likely semi-confined.

In a local (site-specific) context, vertical leakage from the proposed ICW would enter the shallow groundwater environment and flow via shallow groundwater pathways towards the river, emerging as seepages along the river embankment above bedrock.

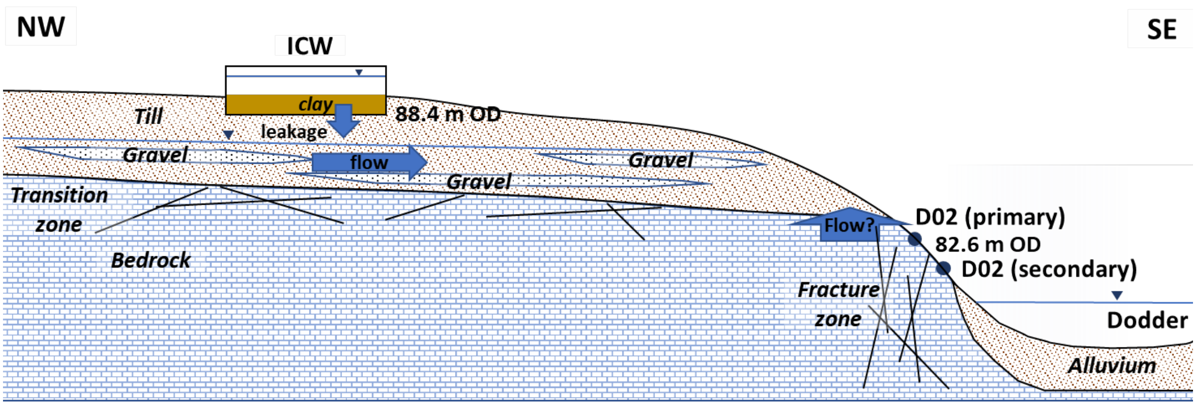


Figure 15: Cross-Section of the CSM

4.1 Zone of Contribution (ZOC)

The estimated total discharge from spring group considered in the current assessment is 2 l/s. The majority of the discharge is attributed to spring D02 which emerges from the limestone bedrock aquifer. Each spring in the spring group has its own zone of contribution (ZOC), within which rainwater infiltrates (*i.e.* recharges) flows as groundwater, and ultimately discharges at the spring location.

Whilst it is not possible to pin-point the precise area where recharge to the springs take place (especially since the bedrock aquifer is buried beneath thick Quaternary sediments), the ZOC is conceptually to the south and west of the spring group (guided by topography), and the shape would likely also be influenced by the linear fault trace along the river valley. The main recharge area of spring D02 could, in fact, be located some distance away from the spring.

In this context, a simplified water balance method was used to estimate the potential size of the ZOC of the spring group, whereby the estimated spring discharge (m^3/day) and groundwater recharge rate (m/day) provide an indication of the area (m^2) that is needed to balance the two, as follows:

- Estimated total discharge = 2 l/s, or 173 m^3/day;
- Estimated annual average recharge = approximately 83 mm/d, or 2.27×10^{-4} m/d; and
- ZOC area = 173 m^3/d / 2.27×10^{-4} m/d = 759,904 m^2, or c. 0.76 km^2

This is reasonably conservative since the recharge coefficient of 20% (see Section 2.6) considers the urban environment (‘made ground’) of the general project area.

It should be noted that the estimated ZOC area applies for steady state conditions. In reality, the extent of the ZOC may vary temporally, in line with rainfall/recharge and spring discharge conditions.

4.2 Knowledge gaps

The present knowledge gaps about the hydrogeological characteristics of the site are:

- Depth to bedrock beneath the proposed ICW area and to the springs/river;
- Local-scale subsoil stratigraphy in the same areas, notably the nature and composition of Quaternary sediments (*i.e.* glacial till and/or alluvial/glacio-fluvial sediments);
- Confirmation of a transition zone at the top of bedrock; and
- Confirmation of groundwater flow directions in bedrock.

Other knowledge gaps are:

- Seasonal changes in spring discharges or water quality; and
- Response of springs to significant storm events.

Despite these knowledge gaps, sufficient information is available to conclude about possible impacts of the proposed ICW on springs, as presented in Section 5.

Section 5 Impact Assessment

5.1 During Construction

Available information indicates that subsoils across the proposed ICW area may be several metres thick. The base of the ICW will be shallow, only approximately 0.5 m below ground. Accordingly, excavation of ICW basin(s) will not extend to bedrock. This means there no risk of physical damage or other construction-related impact to the petrifying springs (including D02), which discharge from the bedrock aquifer.

Excavation can result in sediment transport via overland flow, but this can be mitigated against using best practice methods (e.g. silt fences).

Potential spills of fuel or other chemicals pose a risk of contamination to soils and shallow groundwater during construction. Associated risks can be mitigated by implementing standard best practice measures, such as bunding of fuel/chemical tanks, re-fuelling at offsite location only, keeping chemicals away from the site, and so forth.

During excavation works, it will be important to record subsurface lithology. Alteration of gravel layers and replacement with clay liner materials can affect leakage fluxes from the ICW to the shallow groundwater environment. It will also be important to ensure that construction is implemented as intended, especially that the designed thickness, composition and permeability of liner materials are achieved.

Precise elevations of key design features (notably the base of liners) should also be achieved and maintained. Thus, high-accuracy elevation surveys will be needed prior to, during and following construction, so that corrective actions can be taken before operations.

Only pre-approved liner materials (source and type) should be used that match technical specifications. Emplacement and installation require supervision by a suitably qualified and experienced individual.

In the worst case, poor construction practice and errors could result in the backing up of water, with potential ponding or flooding of surrounding terrain.

5.2 During Operations

During operations, a proportion of the water in the ICW will leak through the clay liner. The leakage will be proportional to basin areas, liner permeability and the head of water in the ICW basin(s). The leakage water will migrate in the shallow groundwater environment under prevailing hydraulic gradients towards the river.

Leakage will marginally increase the shallow groundwater flux towards the river (see below). Under normal, operations, the water will be relatively free of any pollutants, and any pollutants that may be present will undergo *some* attenuation in the shallow groundwater environment (e.g. mixing/dilution and filtration).

An estimate of the leakage flux that can be expected is provided below, and is based on the existing ICW design.

5.2.1 ICW Design

- Ground level: 88.6 – 90.3 m OD
- Base level (bottom): 88.9m OD
- Design water level (depth): 0.2 m
- Clay liner:
  - Top level: 88.9 m OD
  - Base level: 88.4 m OD
  - Thickness dl: 0.5 m
  - Head difference dh: 0.7 m
  - Permeability K: 1×10^{-8} m/s
- Basin Area (A): 1,500 – 2,000 m^2

5.2.2 Calculated Flux

Leakage was calculated using Darcy's empirical law, where

$$Q = \mathrm{A.K.}\frac{dh}{dl} \qquad \text{Eqn. 1}$$

A is the area of the basins, K is the permeability of the clay liner, and *dh/dl* is the hydraulic gradient across the liner. Assumptions that apply are:

- Vertical flow is laminar (kinetic energy can be ignored) so that the Reynold's number is low (approx. <10);
- Flow is continuous and steady and occurs in saturated medium;
- Fluid is incompressible; and
- The liner/aquifer is isotropic (uniform K into all directions) and homogeneous.

Further, no influence of any nearby pumping is assumed, which would potentially contribute a negative head h_p to the clay liner.

In the calculation, the water levels in the ICW are constant at the (maximum) design depth of water (0.2 m). Under the stated conditions, the estimated flux through the liner is summarised in Table 4 for: a) the ICW; b) natural recharge from rainfall (which is naturally additional to the ICW); c) the difference between a) and b); and d) the sum of a) and b).

Table 4: Estimated Leakage through the Clay Liner

A) Leakage from ICW	Calculated Value
Volume per year (m^3/a), 1,500 m area	662
Volume per year (m^3/a), 2,000 m area	883
Darcy velocity (m/s)	1.40E-08
Leakage rate as mm/a	442
B) Natural Recharge	**Calculated Value**
Recharge (mm/a)	83
Volume per year (m^3/a), 1,500 m area	125
Volume per year (m^3/a), 2,000 m area	166
D) Difference between ICW and Natural Recharge	**Calculated Value**
Volume per year (m^3/a), 1,500 m area	538
Volume per year (m^3/a), 2,000 m area	717
Total Leakage from ICW	**Calculated Value**
A+B, volume (m^3/a) for a 1,500 m area	787
A+B, volume (m^3/a) for a 2,000 m area	1,049

The estimated total leakage flux from the ICW would be up to 1,049 m^3/a, or approximately 2.9 m^3/day. The equivalent hydraulic load across the ICW area is 1.4 $l/m^2/day$, which is small. For this reason, the risk of ponding or flooding under the stated conditions is low.

The hydrogeological setting of the ICW site and petrifying springs makes it unlikely that ICW leakage will enter the bedrock aquifer and discharge from the petrifying springs. Subsoils are thick (affording natural protection of the bedrock aquifer), the bedrock aquifer is considered to be semi-confined, and the thermal and EC characteristics of D02 (dominant spring) are indicative of a bedrock origin.

Even if it was assumed that all of the ICW leakage water would discharge at the petrifying springs, the influence would be minor. This is because the estimated leakage (1,049 m^3/a) represents only c. 1.7% of the total spring discharge (2 l/s, or 63,072 m^3/a).

Accordingly, it is considered unlikely that the bedrock springs, including D02, will be impacted by ICW operations.

Nonetheless, the ICW leakage represents an additional input of water to the local (shallow) groundwater system. Conceptually, the ICW leakage water will migrate towards the river via shallow groundwater pathways and discharge as seeps along the river escarpment, above bedrock. Anecdotally, such shallow seeps can be observed naturally following storm events, and the seeps subsequently flow via surface pathways to the river. There are currently no systematic observations about escarpment seeps (following heavy rains).

Potential overflows from the ICW basin(s) would affect the surrounding land surface, which is a public park. Thus, provision for overflow diversion should be made in the design.

Section 6 Conclusions & Recommendations

6.1 Conclusions

The petrifying springs along the River Dodder are inferred to discharge groundwater from a limestone bedrock aquifer. At dominant spring D02, groundwater visibly discharges from bedrock fractures, and the available field measurements and groundwater quality data are consistent with a bedrock provenance.

Under the conceptual site model, spring D02 is located hydraulically downgradient of the proposed ICW development. However, spring D02 is not expected to be impacted by the development, for the following reasons:

- The proposed ICW construction is very shallow (<0.5 m below ground surface) whereas the underlying subsoils are thick (several metres, based on observations along the river embankment and GSI data sources at nearby locations).
- During ICW operations, leakage from the ICW basin(s) will conceptually migrate towards the River Dodder via shallow groundwater pathways and discharge as diffuse seeps along the river embankment.
- Even if the ICW leakage water was to discharge at D02, the estimated leakage rate from the ICW represents only approximately 1.7% of the estimated total discharge at spring D02.

The anticipated diffuse seeps along the river embankment would enter the river via runoff (overland flow). This implies that some water may flow across tufa deposits at or near D02.

Springs D01 and D03 to D08 are located upstream from the proposed ICW development. In the groundwater context, these springs are located hydraulically upgradient or sidegradient of the proposed ICW development. They are also more distant, and thus highly unlikely to be influenced by the proposed ICW development.

6.2 Recommendations – Environmental Monitoring

Although potential impacts are considered unlikely, a precautionary environmental monitoring programme is recommended: a) to build up a broader dataset of discharge characteristics and water quality; and b) to document seasonality and responses to storm events.

In the context of environmental monitoring for the proposal by the DURL Project, specific recommendations are as follows:

- Periodic observation and estimation of spring discharges following storm events, especially at D02.
- Periodic observation of seepages along the river embankment following storm events.
- Deployment of a CTD sensor to record T and EC at D02 Primary, preferably over several weeks, transitioning into and out of the winter season.

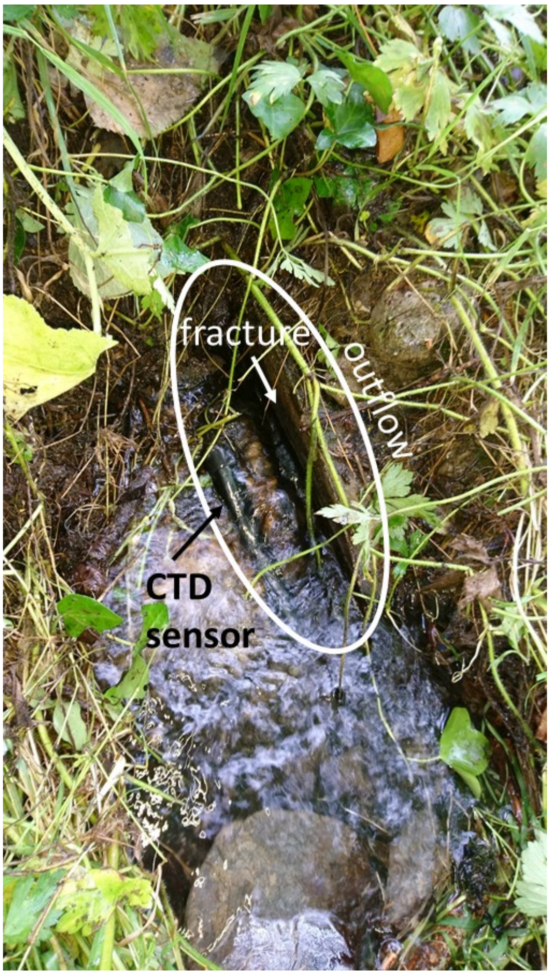
- Quarterly sampling of springs (especially D02) for laboratory analyses of physico-chemical, nutrient, and microbiological parameters.

An adaptive approach to monitoring is recommended, whereby the scale and timing of monitoring is amended and possibly reduced following periodic review of findings. The petrifying springs would also be surveyed periodically by a suitably qualified ecologist.

Because the construction of the proposed ICW is not predicted to impact on the bedrock aquifer or the petrifying springs, construction is not contingent or dependent on the environmental monitoring.

Annex 1: Photos

A 1: Spring D02 Primary



A 2: Spring D02 Secondary

A 3: Seepage D03

A 4: a) and b) Spring D08

A 5: Seepage D04 (a, b), and modified embankment of the River Dodder south of D04, exemplifying the nature/context of spring/seepage locations (c)

A 6: Seepage D05, hidden below vegetation

A 7: Seepage D06

A 8: Spring D01 (a, b)