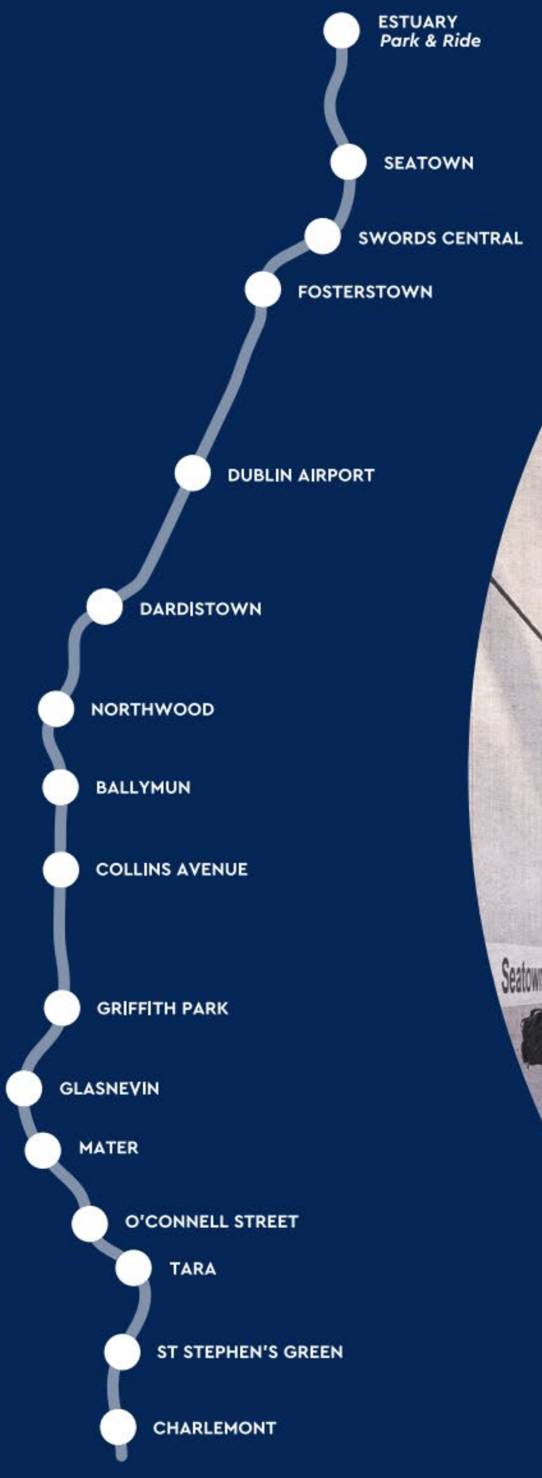

19 Hydrogeology

Contents

Table of Abbreviations

Acronym	Meaning
BOD	Biochemical Oxygen Demand
CEMP	Construction Environmental Management Plan
CSM	Conceptual Site Model
Ch.	Chainage
CIRIA	Construction Industry Research and Industry Association
COD	Chemical Oxygen Demand
DANP	Dublin Airport North Portal
DASP	Dublin Airport South Portal
DCC	Dublin City Council
DCU	Dublin City University
EC	Electrical Conductivity
EIAR	Environmental Impact Assessment Report
EIS	Environmental Impact Statement (former definition)
EMT	Element Materials Technology
EPA	Environmental Protection Agency
EU	European Union
FEM	Finite Element Method
GIR	Ground Investigation Report
GSI	Geological Survey of Ireland
GTV	Groundwater Threshold Value (EU)
IFI	Inland Fisheries Ireland
IGV	Interim Guideline Value (EPA)
IGI	Institute of Geologists of Ireland
IW	Irish Water
Km	Kilometre
LI	Locally Important
LOD	Limits of Deviation
LOD	Limits of Detection
m	Metre
MDL (LOD)	Method Detection Limit (also Limit of Detection)
mgl	Milligrams per litre
mBGL	Metres below ground level
MOD	Metres (above) Ordnance datum (Malin Head)
MRP	Molybdate Reactive Phosphorus
MTBE	Methyl tertiary-butyl ether
NIS	Natura Impact Statement
NPWS	National Parks and Wildlife Service
NRA	National Roads Authority
OPW	Office of Public Works
OSi	Ordnance Survey Ireland

Acronym	Meaning
P&R	Park and Ride
PCB	Polychlorinated biphenyls
PVC	Polyvinyl chloride
PFAS	Per- & poly-fluor alkylated substances, Total Oxidizable Precursor (PFAS TOP Assay)
RBMP	River Basin Management Plan
SAC	Special Area of Conservation
SPA	Special Protection Area
SuDS	Sustainable Drainage Systems
SVOC	Semi-volatile organic substance
TBM	Tunnel Boring Machine
TDS	Total Dissolved Solids
TII	Transport Infrastructure Ireland
TOC	Total Organic Carbon
TOR	Top of rail (MetroLink)
TPH CWG	Total Petroleum Hydrocarbons, Criteria Working Group
TSS	Total Suspended Solids
UKAS	United Kingdom Accreditation Service
ug/l	Micrograms per litre
VOC	Volatile organic substance
WFD	Water Framework Directive
WHO	World Health Organisation
ZOC	Zone of Contribution
ZOI	Zone of Influence

19. Hydrogeology

19.1 Introduction

This Chapter of the Environmental Impact Assessment Report (EIAR) assesses the impact of the MetroLink Project (hereafter referred to as the proposed Project), on hydrogeology during the Construction Phase and Operational Phase.

This chapter describes and assesses the likely direct and indirect significant effects of the proposed Project on Hydrogeology, in accordance with the requirements of Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment (i.e. the EIA Directive) (European Union, 2014a). This Chapter also provides a characterisation of the receiving hydrogeological environment within the proposed Project and within a wider study area in the vicinity of the proposed Project.

This Chapter should be read in conjunction with the following key Chapters, and their Appendices, which present related impacts arising from the proposed Project and proposed mitigation measures to ameliorate the predicted impacts:

- Chapter 15 (Biodiversity);
- Chapter 18 (Hydrology); and
- Chapter 20 (Soils & Geology).

Limits of deviation have been set for the proposed Project and this is addressed in the Wider Effects Report annexed at Appendix A5.19.
The assessment is based on identifying and describing the likely significant effects arising from the proposed Project as described in Chapters 4 to 6 of this EIAR. The proposed Project description is based on the design prepared to inform the planning stage of the project and to allow for a robust assessment as part of the Environmental Impact Assessment (EIA) Process.
Where it is required to make assumptions as the basis of the assessment presented here, these assumptions are based on advice from competent project designers and are clearly outlined within the Chapter.

19.2 Outline Project Description

A full description of the proposed Project is provided in the following chapters of this EIAR:

- Chapter 4 (Description of the MetroLink Project);
- Chapter 5 (MetroLink Construction Phase); and
- Chapter 6 (MetroLink Operations & Maintenance).

Table 19.1 presents an outline description of the key proposed Project elements which are appraised in this Chapter. Table 19.1 presents an outline of the main elements of the proposed Construction Phase that are appraised in this Chapter and Diagram 19.2 presents an outline of the main elements of the Operational Phase of the proposed Project that are appraised in this Chapter.

Table 19.1: Outline Description of the Principal Project Elements

Project Elements	Outline Description
Permanent Project Elements	
Tunnels	It is proposed to construct two geographically separate, single-bore tunnels, using a Tunnel Boring Machine (TBM). Each section of tunnel will have an 8.5m internal diameter and will contain both northbound and southbound rail lines within the same tunnel. These tunnels will be located as follows:

Project Elements	Outline Description
	▪ The Airport Tunnel: running south from Dublin Airport North Portal (DANP) under Dublin Airport and surfacing south of the airport at Dublin Airport South Portal (DASP) and will be approximately 2.3km in length; and ▪ The City Tunnel: running for 9.4km from Northwood Portal and terminating underground south of Charlemont Station.
Cut Sections	The northern section of the alignment is characterised by a shallow excavated alignment whereby the alignment runs below the existing ground level. Part of the cut sections are open at the top, with fences along the alignment for safety and security. While other sections are "cut and cover", whereby the alignment is covered.
Tunnel Portals	The openings at the end of the tunnel are referred to as portals. They are concrete and steel structures designed to provide the commencement or termination of a tunnelled section of route and provide a transition to adjacent lengths of the route which may be in retained structures or at the surface. There are three proposed portals, which are: ▪ DANP; ▪ DASP; and ▪ Northwood Portal. There will be no portal at the southern end of the proposed Project, as the southern termination and turnback would be underground.
Stations	There are three types of stations: surface stations, retained cut stations and underground stations: ▪ Estuary Station will be built at surface level, known as a 'surface station'; ▪ Seatown, Swords Central, Fosterstown Stations and the proposed Dardistown Station will be in retained cutting, known as 'retained cut stations'; and ▪ Dublin Airport Station and all 10 stations along the City Tunnel will be 'underground stations'.
Intervention Shaft	An intervention shaft will be required at Albert College Park to provide adequate emergency egress from the City Tunnel and to support tunnel ventilation. Following the European Standard for safety in railway tunnels TSI 1303/2014: Technical Specification for Interoperability relating to 'safety in railway tunnels' of the rail system of the European Union, it has been recommended that the maximum spacing between emergency exits is 1,000m. As the distance between Collins Avenue and Griffith Park is 1,494m, this intervention shaft is proposed to safely support evacuation/emergency service access in the event of an incident. This shaft will also function to provide ventilation to the tunnel. The shaft will require two 23m long connection tunnels extending from the shaft, connecting to the main tunnel. At other locations, emergency access will be incorporated into the stations and portals or intervention tunnels will be utilised at locations where there is no available space for a shaft to be constructed and located where required (see below).
Intervention Tunnels	In addition to the two main 'running' tunnels, there are three shorter, smaller diameter tunnels. These are the evacuation and ventilation tunnels (known as Intervention Tunnels): ▪ Airport Intervention Tunnels: parallel to the Airport Tunnel, there will also be two smaller diameter tunnels; on the west side, an evacuation tunnel running northwards from DASP for about 315m, and on the east side, a ventilation tunnel connected to the main tunnel and extending about 600m from DASP underneath Dublin Airport Lands. In the event of an incident in the main tunnel, the evacuation tunnel will enable passengers to walk out to a safe location outside the Dublin Airport Lands. ▪ Charlemont Intervention Tunnel: The City Tunnel will extend 360m south of Charlemont Station. A parallel evacuation and ventilation tunnel is required from the end of the City Tunnel back to Charlemont Station to support emergency evacuation of maintenance staff and ventilation for this section of tunnel.
Park and Ride Facility	The proposed Park and Ride Facility next to Estuary Station will include provision for up to 3,000 parking spaces.

Project Elements	Outline Description
Broadmeadow and Ward River Viaduct	A 260m long viaduct is proposed between Estuary and Seatown Stations, to cross the Broadmeadow and Ward Rivers and their floodplains.
Proposed Grid Connections	Grid connections will be provided via cable routes with the addition of new 110kV substations at DANP and Dardistown. (Approval for the proposed grid connections to be applied for separately, but are assessed in the EIAR).
Dardistown Depot	A maintenance depot will be located at Dardistown. It will include: ▪ Vehicle stabling; ▪ Maintenance workshops and pits; ▪ Automatic vehicle wash facilities; ▪ A test track; ▪ Sanding system for rolling stock; ▪ The Operations Control Centre for the proposed Project; ▪ A substation; ▪ A mast; and ▪ Other staff facilities and a carpark.
Operations Control Centre	The main Operations Control Centre (OCC) will be located at Dardistown Depot and a back-up OCC will be provided at Estuary.
M50 Viaduct	A 100m long viaduct to carry the proposed Project across the M50 between the Dardistown Depot and Northwood Station.
Temporary Project Elements	
Construction Compounds	There will be 34 Construction Compounds including 20 main Construction Compounds, 14 Satellite Construction Compounds required during the Construction Phase of the proposed Project. The main Construction Compounds will be located at each of the proposed station locations, the portal locations and the Dardistown Depot Location (also covering the Dardistown Station) with satellite compounds located at other locations along the alignment. Outside of the Construction Compounds there will be works areas and sites associated with the construction of all elements of the proposed Project, including an easement strip along the surface sections.
Logistics Sites	The main logistics sites will be located at Estuary, near Pinnock Hill east of the R132 Swords Bypass and north of Saint Margaret's Road at the Northwood Compound. (These areas are included within the 14 Satellite Construction Compounds).
Tunnel Boring Machine Launch Site	There will be two main tunnel boring machine (TBM) launch sites. One will be located at DASP which will serve the TBM boring the Airport Tunnel and the second will be located at the Northwood Construction Compound which will serve the TBM boring the City Tunnel.

Enabling Works
- Pre-construction surveys and monitoring
- Site establishment and erection of temporary fencing
- Establishment of construction compounds, site office and security
- Site preparation
- Utility diversions
- Vegetation clearance
- Invasive species clearance
- Installation of monitoring systems
- Demolition
- Heritage surveys and preservation
- Establishment of temporary traffic measures

Main civil engineering works
- Excavation, earthworks and construction of structures including stations, tunnels, intervention shafts, cuttings, embankments, bridges and viaducts
- Construction of new roads and access routes
- Road realignments and modifications

Railway systems installation
- Installation of railway track, overhead line equipment, train controls and telecommunication systems
- Installation of mechanical, electrical and operating equipment
- Construction of power supply infrastructure and connection to the electricity transmission grid

Site finalisation works
- Removing construction compounds
- Land reinstatement, such as agricultural land and parks
- Planting, landscaping and erection of permanent fencing

Systems testing & commissioning
- Testing the railway systems
- Commissioning the railway
- Trial running

Diagram 19.1: Summary of Key Activities during the Construction Phase of the Proposed Project

Operational Strategy
- Fully Automated Rolling Stock
- Designed for a maximum of 20,000 passengers per hour per direction
- Minimum possible headway at 100 seconds
- Train will accommodate 500 passengers
- Operational Hours from 05:30 until 0:30

Operational Systems
- Operational Control Centre at Dardistown
- 40 High Floor Vehicles
- Power Systems to supply power to vehicles and stations
- Communication Systems including Radio, WiFi, CCTV, Public Address and Voice Alarm (PAVA), public mobile network and Emergency Telephones
- Ventilation and Air Conditioning Systems
- Emergency Evacuation and Fire Fighting Systems

Maintenance Systems
- Vehicle Maintenance at Dardistown Depot
- Maintenance of Operational Corridor outside of Operation Hours (0:30 until 5:30)
- Maintenance of Power systems, Communication Systems and Ventilation and Air Conditioning Systems

Station Operation
- Access via Escalators, Stairs and Lifts
- Signage
- Ticket Machines
- Lighting
- Back of House
- CCTV and Security

Diagram 19.2: Summary of Key Activities during the Operational Phase of the Proposed Project

19.2.1 Scope

This Chapter describes and evaluates the existing hydrogeological environment that is likely to be impacted by the proposed Project. Section 39(2)(b) of the Transport (Railway Infrastructure) Act, 2001 specifies that an EIAR must contain a description of the aspects of the environment that are likely to be significantly impacted by a proposed Project. This Chapter of the EIAR has been prepared in order to fulfil the requirement to address the hydrogeology aspect of the environment.

This Chapter assesses the potential effects of the proposed Project on the following topics:

- Superficial hydrogeology;
- Bedrock hydrogeology;
- Groundwater resources and groundwater quality;
- Aquifer dewatering and zone of influence of same; and
- Groundwater barrier effects.
- As detailed in Section 19.1 separate assessments have been conducted for some topics which have inter-relationships with hydrogeology including hydrology, biodiversity and Soils & Geology.

19.3 Methodology

19.3.1 Study Area

The geographical scope defined for this assessment comprises all groundwater bodies located within the area occupied by the proposed alignment as well as the lands within ca. a 500m buffer either side of the centre line of the proposed Project alignment. The geographical extent of the proposed Project is shown on in Figure 4.1; the main drawing entitled 'Key Plan' also presents the full alignment.

19.3.2 Relevant Guidance

The hydrogeological baseline assessment has been carried out in accordance with the following guidance and established best practice:

- Environmental Protection Agency (EPA) Advice notes on current practice in the preparation of Environmental Impact Statement (EPA, 2003) and Guidelines on the Information to be contained in Environmental Impact Statements (EPA, 2022a).
- TII/National Roads Authority Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes (TII/formerly NRA, 2009).
- Water Framework Directive (WFD) - Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy. This relates to the improvement of water quality across Ireland including rivers and groundwater bodies.
- River Basin Management Plan 2018-2021 (including regional plans by Local Authority Waters Programme (Waters and Communities 2020)). Draft River Basin Management Plan 2022-2027.
- Institute of Geologists Ireland (IGI) -Geology in Environmental Impact Statements, a guide (IGI, 2002) and Guidelines for the Preparation of Soils, Geology and Hydrogeology Chapters of Environmental Impact Statements (IGI, 2013).

Water resource management in Ireland is dealt with in the following key pieces of legislation and guidelines:

- European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010).
- European Communities Environmental Objectives (Groundwater) Amendment Regulations 2016 (S.I. No. 366 of 2016); European Communities Environmental Objectives (Groundwater) (Amendment) Regulations 2022 S.I. No. 287 of 2022.
- Part IV of the First Schedule of the Planning and Development Act 2000, as amended.
- European Communities (Water Policy) Regulations 2003 (S.I. No. 722 of 2003)
- Environmental Protection Agency 'Towards Setting Guideline Values for the Protection of Groundwater in Ireland Interim Report', (EPA 2003).
- European Union (Drinking Water) Regulations 2014 (S.I. No. 122/2014).
- European Union (Drinking Water) (Amendment) Regulations (S.I. No. 464 of 2017).

In line with the above guidance, the assessment considers the existing hydrogeological regime in the vicinity of the proposed Project. Baseline desk top data was collated from the EPA and Geological Survey of Ireland (GSI) on-line sources, among other sources of information as indicated in Section 19.3.3 below. Site-specific data (water quality, water level data) was also collated from historical and new monitoring boreholes along the alignment. Additional information on aquifer characteristics collected in areas of planned construction dewatering was added to the baseline and subsequent assessment.

- Note: The Impact Assessment follows the EPA guidelines for the EIAR process as outlined in Chapter 2 (Methodology in Preparation of the EIAR). Consideration of the TII/NRA impact significance and rating of significance has also been considered.

19.3.3 Data Collection and Collation

19.3.3.1 Sources of Information

The following list of data sources was reviewed as part of the baseline assessment for hydrogeology:

- Ordnance Survey Ireland:
  - Discovery Series Mapping (1:50,000); Six Inch Raster Maps (1:10,560), Six Inch and 25inch OS Vector Mapping, Orthographic Aerial Mapping (GeoHive).
- Environmental Protection Agency (EPA):
  - Teagasc Subsoil Classification Mapping, Water Quality Monitoring Database and Reports, Water Framework Directive Classification, EPA on-line mapping.
- Dublin City Council/Fingal County Council:
  - Dublin City Development Plan (2016 - 2022), Draft Dublin City Development Plan, 2022-2028, Dublin Airport Local Area Plan (January 2020), Fingal Development Plan 2017-2023, [DRAFT] Fingal Development Plan 2023-2029.
- National Parks and Wildlife Service (NPWS):
  - Designated Areas Mapping
- Geological Survey of Ireland (GSI):
  - Aquifer Characteristics, Vulnerability, Recharge, Subsoils, Well Search, GSI on-line mapping.
- Other sources:
  - Local Authority Waters Programme (2020), [Eastern] River Basin Management Plan 2018 -2021 Ground investigation Reports -historical available data and contemporary database from Ground Investigation Works completed between 2019-2021; Metro North EIS.

19.3.3.2 Baseline Data Collection

The geographical scope defined for this assessment comprises all groundwater bodies located within the area occupied by the proposed alignment as well as the lands within ca. a 500m buffer either side of the centre line as outlined above. Information and data were collected and collated for this study area by way of a desktop data review, field surveys and ground investigations (GI).

19.3.3.3 Desktop Data Review

AWN undertook an extensive desktop review in order to establish baseline conditions along the proposed alignment corridor. The baseline study included reference to historical ground investigation data including the 2007 IGSL investigation borehole dataset (IGSL 2008) and data from Norwest Holst (2008) as well as information from contemporary (2019-2021) ground investigations specific to the proposed Project. Key baseline data reviewed for this Chapter is summarised in Table 19.2 below. The aspects of the attributes considered herein are:

- Classification (i.e. regionally important, locally important poor) and extent of aquifers underlying Project area and increased risks presented to them by the proposed development associated with aspects for example removal of subsoil cover, removal of aquifer (in whole or part), drawdown in water levels, alteration in established flow regimes, change in groundwater quality;
- Aquifer vulnerability in terms of protection to underlying aquifer and assessment of known soil cover in order to identify any areas of higher permeability which could result in high inflows during construction;
- Presence of high-yielding water supply wells/springs and in particular public water supplies (with potential for impact defined by source protection areas) in the vicinity of the proposed Project and the potential for increased risk presented by it;
- Water Body Status (high, good, moderate, poor, and bad) and whether the aquifer is at risk or not at risk. This includes water bodies identified by the EPA as at risk of not achieving Water Framework Directive (WFD) objectives due to industrial influences.
- Natural hydrogeological /karst features in the area and potential for increased risk presented by the proposed Project;
- Groundwater-fed ecosystems, presence of any pathway linkage to same and as such any increased risk presented by the proposed Project; and
- Landfills in the vicinity of the site and the potential risk of encountering contaminated ground. (This is being assessed in Chapter 20 (Soils & Geology) and some reference will be included here, where relevant).

Table 19.2: Survey Criteria and Baseline Data for Groundwater

Information Required	Survey Criteria	Data Source
Aquifer Characteristics	Depth to groundwater table Regional direction of groundwater flow Aquifer hydraulic conductivity Water bearing strata Nature and thickness of overlying strata/depth to bedrock	GSI Well Card Data (GSI). GSI on-line database including karst mapping. Hydrogeological Profiles for MetroLink. Historical ground investigation reports for Metro North. *Factual Ground Investigation Report. Dublin Metro North Ground Investigation.* Prepared for Rail Procurement Agency (IGSL Ltd., 2008). Norwest Holst, *Dublin Metro North MGI - Sections 6 & 7,* (2007), *Factual Report* (GDR) Ground Investigation Reports (Phase 1-5).by Causeway Geotech Ltd., 2019- 2022 Discovery Series Maps, Sheet 50 – Dublin (OSI). Other resources including independent assessments as referenced in this Chapter (Hydrogeological Review for Tara Street and Swords Central, Appendix A19.11)
Aquifer Importance (in terms of water supply and habitats)	Aquifer classification Aquifer productivity Presence of linkage to groundwater dependent ecosystems	National Draft Bedrock Aquifer Map (GSI). Groundwater abstraction yields in Well Card Data (GSI). Source protection zones (EPA on-line mapping). Special Areas of Conservation and National Heritage Areas (EPA; NPWS).
Groundwater Quality	Potential for groundwater contamination from historical activities Potential for groundwater contamination from current activities	WFD Groundwater Body Risk Scores, and Waterbody Status (EPA). IPPC Facilities and IED Industries (EPA). Report *Identification of Possible Areas of Contamination and Proposals for Location of Soils and Groundwater Monitoring Points for Metro North,* (AWN Consulting Ltd., 2007).
Aquifer Sensitivity	Aquifer vulnerability Source Protection Zones (SPZ) Depth to groundwater table Nature of subsoils overlying the aquifer Groundwater quality	Groundwater Vulnerability Mapping (GSI). Source Protection Zone/mapping (GSI, EPA). Well Card Data (GSI). Ground Investigation Reports (as above) including on historical contamination. Hydrogeological Profiles for MetroLink (IDOM).

19.3.3.4 Field Surveys

A number of field surveys and walkover assessments were carried out to add to existing assessment of long-term trend analysis for water quality undertaken by the EPA. Specifically, static water level monitoring and well sampling was undertaken in October/November 2018 and March/April 2019 at historical monitoring well locations identified along the proposed alignment. The available boreholes followed completion of a desk review of existing boreholes identified as possibly viable well points for on-going monitoring.

Further to this, a more comprehensive groundwater quality monitoring programme was undertaken in January 2021 and again in March 2021. This programme included a select number of contemporary (2019-2020) drilled boreholes (>50 no.) spatially located along the full alignment with screened sections in varying geological settings comprising both overburden and bedrock monitoring wells; collection of *in-situ* ground gas measurements at targeted sites was also included. Monitoring of water quality included newly drilled wells located at key locations for example at proposed deep excavations and retained cuts where short-term construction dewatering of local groundwater will occur with subsequent final [treated] discharge off site as part of water management proposals. A key aim of the monitoring completed in 2021 was the requirement to sample at identified representative (i.e. contemporary drilled and well-designed) boreholes ideally during a low water seasonal period and a high-water seasonal period. It is noted however that the wider Dublin area experienced drier than average weather between the summer of 2020 and that of 2021 with limited rainfall recorded. On this basis, the sampling period was undertaken as long as practicable between the first (January 2021) and the second (March 2021) sampling dates in 2021. Monitoring in 2021 included at boreholes newly drilled as part of the Phase 1-4 ground investigation but also for some boreholes completed as part of Phase 5 investigative works which included the Dardistown Depot area for example.

In summary, ascertaining the 'current' existing water levels/quality of groundwater at approximately 54 no. key indicative borehole locations along the alignment and within the four geographical split areas AZ1 – AZ4 has facilitated the assessment of the potential groundwater quality and groundwater level impacts associated with the construction and Operational Phases of the MetroLink project and has informed the corresponding EIAR.

A database of baseline groundwater quality data has been compiled for the identified monitoring wells generally crossing the proposed alignment; this includes water quality data collected as part of historically installed monitoring wells but more importantly at recently completed ground investigation boreholes installed along the alignment. Field works included the collection of representative water quality samples in addition to recording specific field parameters including ground gas (for use in Chapter 20, Soils & Geology).

Representative groundwater sampling was undertaken to support the existing baseline dataset but also to provide adequate information for the preparation of discharge permits/licenses for the proposed development - for which pH, hydrocarbons and suspended solids will possibly represent the more significant impacts from the Construction Phase related works. Water quality sampling followed good practice guidelines as *EN ISO 5667-2 Water Quality - Sampling Part 1: Guidance on design of sampling programmes and sampling techniques; Part 3: Guidance on preservation and handling of water samples; Part 10: Guidance on sampling of waste waters; and BS 6068-6.14 (BS ISO 5667-14:2014) Water Quality, Section 6.14: Guidance on quality assurance and quality control of environmental water sampling and handling. BS5930 Code of Practice for Site Investigations, Section 3: Field Investigations was also referenced.*

Further to the above, representative groundwater sampling and testing of purged groundwater collected from newly installed pumping test wells and monitoring wells was undertaken adjacent to stations where temporary dewatering is anticipated as a requirement during the Construction Phase mainly. In general, the analytical testing suite followed the list of parameters required as part of Dublin City Council's temporary discharge permit requirements. Representative sampling completed as part of the hydraulic testing programme was undertaken at boreholes within seven no. areas along the proposed alignment.

Figure 19.7 presents an outline of the proposed Project alignment included in this baseline quality assessment, extending from Charlemont Station in the south to Estuary Station to the north. The historical groundwater monitoring wells used as part of additional baseline water quality programmes are also presented, with the tabulated results shown in Appendix A19.1 (October/November 2018) and (March/April 2019) together with summary text. Figure 19.8 presents the pumping test areas along the proposed alignment, with a summary of laboratory test results provided in Appendix A19.2. Finally, the tabulated results for all groundwater monitoring completed in 2021 are presented as Appendix A20.8 – Land Contamination Interpretive Report and include summary comparisons with threshold/guideline values where available for certain parameters.

19.3.3.5 Commissioned Ground Investigations

A number of intrusive ground investigations were commissioned for the proposed Project. These investigations included primarily the drilling of shallow and deep boreholes, and excavation of trial pits, which are described further within Chapter 20 (Soils & Geology). The ground investigations also included groundwater level monitoring and water quality testing programmes. To date, the following has been completed with specific reference to groundwater:

- >126 no. Groundwater monitoring wells (single and dual well installations; Phase 1-4); 30 no. for Phase 5;
- 24 no. Groundwater (continuous) level monitoring wells;
- 55 no. Groundwater quality monitoring wells (in addition to quality sampling during pumping tests);
- 24 no. Pumping tests (Test Areas 1-5 and R132 -North and South areas);
- 76 no. Packer tests;
- 55 no. Small scale variable head permeability tests; and
- 3 no. Infiltration tests.

All ground investigation exploratory boreholes for Phase 1 to 5 were located based on the design of the proposed development. A programme of continuous groundwater level monitoring, aquifer testing and groundwater quality monitoring was devised with focus on key well locations along the alignment including at deep station excavations, proposed cuttings, portal sites for the installation of TBM, structures including overpasses and spanning bridges, areas of historical contamination and where key environmental receptors were identified.

19.3.4 Analysis Methods

The laboratory analysis was completed by United Kingdom Accreditation Service (UKAS) laboratories (i.e. EMT and Chemtest) and this ensured consistency with earlier stage laboratory testing for the proposed Project. Locally, Irish National Accreditation Board (INAB) accredited laboratories were also used. All samples were shipped under Chain of Custody quality control sheet to the UKAS accredited laboratory with samples generally arriving at the laboratory the following day. Subsequently, the requisite analysis was scheduled including on the basis that accredited holding times for specific analytes were not compromised. In general, as part of field and laboratory testing, the following parameters were included:

- Major Anions & Cations (including chloride, sulphate, sodium, calcium, potassium, magnesium, fluoride, nitrite, nitrate, ammonia, ammoniacal nitrogen, alkalinity, non-carbonate hardness).
- Metals & other compounds (including aluminum, arsenic, barium, boron, fluoride, cadmium, cobalt, iron, manganese, molybdenum, nickel, antimony, chromium, copper, mercury, lead, selenium, vanadium, phosphorous and zinc).
- Physic-chemical parameters including pH, electrical conductivity, temperature, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Turbidity, Redox, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), fats, oils and grease, colour;
- Volatile Organic Compounds (VOCs) and Semi Volatile Organic Compounds (SVOCs);
- Hydrocarbon compounds including BTEX (Benzene, Toluene, Ethyl Benzene, m/p Xylene, o-Xylene), MTBE, TPH CWG (Aliphatics/Aromatics), Mineral Oil Fraction (aliphatics); and
- PFAS TOP Assay (Dublin Airport area only); PCBs (WHO 12 suite; specific laboratory testing).

The laboratory test results were compared primarily with European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010); European Communities Environmental Objectives (Groundwater) Amendment Regulations 2016 (S.I. No. 366 of 2016), and 2022 (S.I. No. 287 of 2022); and EPA '*Towards Setting Guideline Values for the Protection of Groundwater in Ireland Interim Report*' (EPA 2003).

Appendices A19.1 to A19.2 and A20.8 present details of methods used and results of all testing.

19.3.5 Consultation

The baseline and impact assessment for hydrogeology has included the review of all responses received in respect of stakeholder submissions and concerns, with regard to groundwater. The compiled feedback from both statutory and non-statutory bodies, consultees as well as from engagement with other private individuals and so on, with specific regard to groundwater, has been considered in the overall Project design and reviewed as part of this assessment.

Key concerns from stakeholders included the following (on the basis of geographical area reference):

- General - Effects of construction and possible contamination of the water table (reference is also made to GSI and protection of groundwater as a 'vulnerable' resource);
- AZ4 - Possible changes in local groundwater patterns from station construction at Griffith Park (potential risks to schools and houses in the local area; reference also to potential settlement issues);
- AZ4 - Groundwater and 'rising water table' (refers to the perception of water levels here) in the local area at Glasnevin ('rivers' below ground and the presence of a tributary of the River Wad in the area was also noted);
- AZ4 - Impact on groundwater/changing water table throughout the Dublin area (which has been significantly aggravated by the level of development and construction over recent decades);
- AZ4 - Potential impact on groundwater levels during Construction Phase (and over the long term); and
- AZ4 - Management of groundwater discharges from station dewatering activities from the perspective of water quality (reference also made to IFI comments on ecological importance of receiving water courses) and flood impact potential.

Consultation for hydrogeology was also undertaken with other environmental experts on the proposed Project team to assess the potential impact of the interaction with other environmental factors. This involved discussions on the following:

- Biodiversity: Consultation on the potential impact on groundwater dependent habitats (GWDTE);
- Hydrology: Consultation on the potential impact on surface water systems;
- Land, Soils & Geology: Consultation on geotechnical and contaminated land-related issues;
- Drainage: Consultation on design (construction and operation) of run-off and groundwater management; and
- Material Assets: Consultation on the impact on private wells and/or sensitive structures.

The proposed Project approach to consultation, summary of issues raised during the consultation process, and numerous meetings with stakeholders, is discussed in more detail in Chapter 8 (Consultation). In addition, the summarised questions and comments received from stakeholders and response from the Project Team were reviewed and cross-referenced with this Chapter (refer Appendix A8.18).

19.3.6 Appraisal Method for the Assessment of Impacts

The rating of potential effects from the proposed Project on the hydrogeological environment has therefore been assessed as follows:

- Classifying the importance of the relevant attributes (Table 19.3);
- Quantifying the likely magnitude of any impact on these attributes (Table 19.4); and
- Determining the resultant significance of 'Effects' (Table 19.5). The significance of the environmental effects is determined by cross referencing the magnitude of impact and the identified importance of the attributes impacted).

The attribute importance considers the potential and existing use of the aquifer as a water resource (water supply- public and private) and ecological habitat requirements (groundwater dependent terrestrial ecosystems). The TII criteria for rating the hydrogeological related attributes are presented in Table 19.3.

19.3.6.1 Classifying the Importance of the Relevant Attributes

Table 19.3: Criteria for Rating Site Attributes - Estimation of Importance of Hydrogeology Attributes (TII/NRA, 2009)

Importance of Hydrogeology	Criteria	Typical Examples
Extremely High	Attribute has a high quality or value on an international scale	Groundwater supports river, wetland or surface water body ecosystem protected by EU legislation e.g. SAC or SPA status.
Very High	Attribute has a high quality or value on a regional or national scale	Regionally Important Aquifer with multiple wellfields. Groundwater supports river, wetland or surface water body ecosystem protected by national legislation – e.g. NHA status. Regionally important potable water source supplying >2500 homes. Inner source protection area for regionally important water source.
High	Attribute has a high quality or value on a local scale	Regionally Important Aquifer. Groundwater provides large proportion of baseflow to local rivers. Locally important potable water source supplying >1000 homes. Outer source protection area for regionally important water source. Inner source protection area for locally important water source.
Medium	Attribute has a medium quality or value on a local scale	Locally Important Aquifer Potable water source supplying >50 homes. Outer source protection area for locally important water source.
Low	Attribute has a low quality or value on a local scale	Poor Bedrock Aquifer. Potable water source supplying <50 homes.

The baseline hydrogeological environment along the alignment is also considered under a number of headings including the following:

19.3.6.1.1 Importance:

Aquifers can potentially provide a valuable source of drinking water for the population and industry. The level of importance associated with an aquifer is therefore related to its productivity. The GSI has classified the bedrock aquifers in the Dublin Region according to their productivity. Aquifers can also support groundwater dependent wetlands or surface water ecosystems protected by EU legislation, e.g. SAC or SPA status. These factors are considered in terms of attribute importance characterisation.

19.3.6.1.2 Sensitivity:

Groundwater resources are sensitive to a range of environmental impacts including depletion of the groundwater resource, interference with the natural groundwater flow regime, or contamination of the groundwater through the discharge of polluting substances.

The sensitivity of an aquifer is governed by a number of factors including: the depth to the water table, the nature and thickness of the overlying geological strata (vulnerability), the existing groundwater quality, and aquifer and soil characteristics (transmissivity and storage). These factors are considered in determining areas of potentially higher sensitivity along the alignment.

19.3.6.1.3 Existing Adverse Effects:

Groundwater quality and water body status also needs to be considered when determining baseline assessment. In some cases, the quality of a groundwater resource may have been diminished by historic and/or current impacts such as contamination. The assessment also considers the fact that the quality of aquifers in urban areas with a long history of industrial and urban activity may in some cases have been compromised.

19.3.6.2 Quantifying the Likely Magnitude of Any Impact on these Attributes

Once the importance, value and sensitivity of groundwater bodies and other relevant resources are identified and described to inform the baseline assessment, the magnitude of potential impacts resulting from the proposed development during the construction and Operational Phases are determined (Table 19.1Table 19.4).

Table 19.4: Criteria for Rating Impact Significance at EIA stage – Estimation of Magnitude of Impact on Hydrogeology Attributes (TII/NRA, 2009)

Magnitude of Impact	Criteria	Typical Examples [1]
Large Adverse	Results in loss of attribute and/or quality and integrity of attribute	Removal of large proportion of aquifer Changes to aquifer or unsaturated zone resulting in extensive change to existing water supply springs and wells, river baseflow or ecosystems Potential high risk of pollution to groundwater from routine run-off [2] Calculated risk of serious pollution incident during operation >2% annually [3]
Moderate Adverse	Results in impact on integrity of attribute or loss of part of attribute	Removal of moderate proportion of aquifer Changes to aquifer or unsaturated zone resulting in moderate change to existing water supply springs and wells, river baseflow or ecosystems Potential medium risk of pollution to groundwater from routine run-off [2] Calculated risk of serious pollution incident during operation >1% annually [3]
Small Adverse	Results in minor impact on integrity of attribute or loss of small part of attribute	Removal of small proportion of aquifer Changes to aquifer or unsaturated zone resulting in minor change to water supply springs and wells, river baseflow or ecosystems Potential low risk of pollution to groundwater from routine run-off[2] Calculated risk of serious pollution incident during operation >0.5% annually[3]
Negligible	Results in an impact on attribute but of insufficient magnitude to affect either use or integrity	Calculated risk of serious pollution incident during operation <0.5% annually[3]

Note: 1. Additional examples are provided in the TII/NRA, 2009 Guidance Document;
Note: 2 refers to Method C, Annex 1, Annex 1 of HA"16/06
Note: 3 refers to Method D, Appendix B3/Annex 1of HA216/06

19.3.6.3 Determining the Resultant Significance of Effects

The significance of the environmental effects are determined by cross referencing the magnitude of impact and the identified importance of the attributes impacted (Table 19.5).

Table 19.5: Rating of Significance of Environmental Impacts (TII/NRA, 2009)

		Magnitude of Impact			
		Negligible	Small	Moderate	Large
Importance of Attribute	Extremely High	Imperceptible	Significant	Profound	Profound
	Very High	Imperceptible	Significant/Moderate	Profound/Significant	Profound
	High	Imperceptible	Moderate/Slight	Significant/Moderate	Profound/Significant
	Medium	Imperceptible	Slight	Moderate	Significant
	Low	Imperceptible	Imperceptible	Slight	Slight/Moderate

The quality, magnitude and duration of potential effects are defined in accordance with the criteria provided in the EPA *'Guidelines on the information to be contained in Environmental Impact Assessment Reports'* (2022) as outlined in Table 19.6 below.

The rating of significant environmental effects is also assessed in terms of duration and frequency. With each effect described as being momentary, brief, temporary, short-term, medium-term, long-term, or permanent as defined in Table 19.6 below. The frequency of effects is also described either in terms of reoccurrence or timing (hourly, daily weekly, monthly, seasonally or annually). If an effect is reversible, for example through remediation or restoration, then this is also described. Description of the durations are listed below:

Table 19.6 Description of Effects and Impacts for Hydrogeology Attributes as per EPA Guidelines (EPA, 2022a)

Effect Characteristic	Term	Description
Quality of Effects	Positive	A change which improves the quality of the environment
	Neutral	A change which does not affect the quality of the environment
	Negative/Adverse	A change which reduces the quality of the environment
Describing the Significance of Effects	Imperceptible	An effect capable of measurement but without significant consequences. For example, there is no impact to the nearby watercourse.
	Not significant	An effect which causes noticeable changes in the character of the environment but without noticeable consequences. For example, the Turnapin River will be diverted due to the Dardistown Depot. The diversion will be designed appropriately which will change the watercourse but there will no impact to it.
	Slight Effects	An effect which causes noticeable changes in the character of the environment without affecting its sensitivities. For example, a number of ditches coming from Staffordstown Stream will be diverted due to the Estuary Park & Ride. These diversions will be designed appropriately. However, if not designed appropriately these works may cause localised impacts on the streams which would be classed as a slight effect.
	Moderate Effects	An effect that alters the character of the environment in a manner that is consistent with existing and emerging baseline trends. For example, the Forrest Little Stream will be crossed, and a new culvert will be constructed. If this culvert is not designed appropriately, this may cause downstream flooding with a moderate effect.
	Significant Effects	An effect, which by its character, magnitude, duration or intensity alters a sensitive aspect of the environment. For example, the Broadmeadow River is crossed, and a viaduct will be constructed. This viaduct if not designed appropriately can cause water quality and river

Effect Characteristic	Term	Description
		morphology impacts which could alter this river which is in direct connection with the Malahide Estuary which is a Special Area of Conservation.
	Very Significant Effects	An effect which, by its character, magnitude, duration or intensity significantly alters most of a sensitive aspect of the environment.
	Profound Effects	An effect which obliterates sensitive characteristics
Describing the Extent and Context of Effects	Extent	Describe the size of the area, the number of sites, and the proportion of a population affected by an impact.
	Context	Describe whether the extent, duration, or frequency will conform or contrast with established (baseline) conditions (is it the biggest, longest effect ever?)
Describing the Duration and Frequency of Effects	Momentary Effects	Effects lasting from seconds to minutes
	Brief Effects	Effects lasting less than a day
	Temporary Effects	Effects lasting less than a year
	Short-term Effects	Effects lasting one to seven years.
	Medium-term Effects	Effects lasting seven to fifteen years
	Long-term Effects	Effects lasting fifteen to sixty years
	Permanent Effects	Effects lasting over sixty years
	Reversible Effects	Effects that can be undone, for example through remediation or restoration.
	Frequency of Effects	Describe how often the effect will occur (once, rarely, occasionally, frequently, constantly – or hourly, daily, weekly, monthly, annually).
Probability of Effects	Likely Effects	The effects that can reasonably be expected to occur because of the planned project if all mitigation measures are properly implemented.
	Unlikely Effects	The effects that can reasonably be expected not to occur because of the planned project if all mitigation measures are properly implemented.
Describing the Type of Effects	Indirect Effects (also known as secondary or Off-site effects)	Effects on the environment, which are not a direct result of the project, often produced away from the project site or because of a complex pathway.
	Cumulative Effects	The addition of many minor or insignificant effects, including effects of other projects, to create larger, more significant effects.
	'Do Nothing'	The environment as it would be in the future should the subject project not be carried out.
	`Worst case' Effects	The effects arising from a project in the case where mitigation measures substantially fail.
	Indeterminable Effects	When the full consequences of a change in the environment cannot be described.
	Irreversible Effects	When the character, distinctiveness, diversity, or reproductive capacity of an environment is permanently lost.
	Residual Effects	The degree of environmental change that will occur after the proposed mitigation measures have taken effect.
	Synergistic Effects	Where the resultant effect is of greater significance than the sum of its constituents (e.g. combination of SOx and NOx to produce smog).

19.3.6.4 Water Inflow Assessment & Barrier Effects Modelling

19.3.6.4.1 Water Inflow [Seepage] Assessment

As part of the assessment of potential impact(s) arising from groundwater ingress (for example at deep excavations and where cuttings are proposed for sections of the alignment) a seepage analysis was undertaken by EIS Guia in liaison with Jacobs IDOM. The report entitled '*Seepage Rates Assessment in Stations Executed with Cut & Cover Method (Plaxis2D Modelling)'* was completed with the objective of obtaining potential groundwater ingress ratios to the excavated enclosures assessed; the report is presented as Appendix A19.8.

Plaxis2D software was used to carry out finite element modelling of representative cross sections along the alignment with PlaxFlow (an add-on module to Plaxis2D) used to determine groundwater flow characteristics under both 'steady state' and 'time-dependant' conditions. PlaxFlow incorporates sophisticated models for saturated and unsaturated groundwater flow using well known relationships between pore pressure, saturation and permeability. Initially, a steady state groundwater flow was carried out to determine the water seepage rates into the cut & cover excavations. The flows per linear metre of station box and the total inflow were then calculated.

The calculations of ingress [i.e. seepages] were processed using the Plaxis2D program, incorporating for each station excavation the information gathered from site terrain [2D geometry] models as well as utilising available data collated for the geological, geotechnical and hydrological regime present together with the interpreted results of representative hydraulic testing undertaken in the area(s) of interest. Initially, the overall water ingress was calculated without a grout plug. However, additional calculations were completed for total inflows in the case where a bottom [grout] plug methodology is employed (for example using Jet-Grouting techniques applied in soils and/or 'rock fracture sealing' injection techniques). Details of the specific model, its use and the estimations of potential groundwater inflows are presented in the afore-mentioned report (Appendix A19.8) and further discussed below under Section 19.5.3.4.

19.3.6.4.2 Barrier Effects Modelling

Barrier effects modelling -which essentially simulates the potential impacts a linear/other deep structure can have on interpreted groundwater flow and anticipated groundwater movement patterns in variable geological settings - was undertaken by EIS Guia in liaison with Jacobs IDOM. The report entitled '*Barrier Effect Assessment -Visual Modflow: Seatown-Fosterstown, Dardistown, & O'Connell Street'* was completed with the objective of assessing the potential impacts on local groundwater flow patterns which could occur where permanent barriers or semi-barriers are created due to the construction of diaphragm walls for proposed station boxes and tunnel sections and/or the linear tunnel alignment itself. The report is presented as Appendix A19.9.

Given the existing hydrogeological subsoil conditions along the alignment and the modifications induced by the construction of the proposed Project, a numerical simulation (incorporating analytical/dimensional calculations) was considered necessary to assess the possible effects and the effectiveness of the corrective/mitigation measures proposed. The model was therefore set up with the aim of assessing impacts from the creation of such barriers/ 'damming effects' defined initially as follows:

- 'Stagnation' effect -An elevation of the piezometric surface occurs up-gradient of the generated barrier or semi-barrier.
- 'Reservoir' effect -this may occur in the case of semi-barriers caused by design proposals.
- 'Lamination' effect -A reduction in the circulation of interpreted groundwater flow down-gradient of the generated barrier or semi-barrier feature. Furthermore, a rise in the piezometric surface is likely to occur in the areas where the flow rate increases.

The lowering of groundwater levels in areas with highly deformable materials can generate significant settlements which may affect the stability of nearby buildings for example -refer to Building Damage Report (refer Appendix A5.17).

Modelling was undertaken using available collated geotechnical and hydrogeological data for a number of representative locations namely, Seatown-Fosterstown, Dardistown and O'Connell Street (where significant gravels are recorded). However, as part of the modelling scope the full alignment was reviewed for the potential of the 'barrier effect' occurring and only the areas with high risk were modelled, i.e. the potential barrier effect will not occur over the remaining sections of the alignment. Details of the specific modelling set-up, its use and the estimations of potential groundwater barrier effects are detailed in the afore-mentioned report and further discussed below under Section 19.5.3.6.

19.4 Baseline Environment

19.4.1 Introduction

The following section describes the hydrogeological environment in relation to the proposed Project. The description is based on the detailed design and engineering documents supplied by Jacobs IDOM for the project (depth of tunnel bore, station boxes and works areas with corresponding groundwater discharge points). The aquifer depth considered is based on the design depth profile for the proposed Project.

This section of the Chapter provides a project description for each of the geographical areas outlined in Table 19.7.

Table 19.7: Proposed Geographical Split for Baseline and Assessment

Reference	Geographical Split	Description
AZ1	Northern Section	Section of the proposed Project from Estuary to north of the DANP. Includes the proposed Park & Ride at Estuary.
AZ2	Airport Section	Section of the proposed Project from the DANP, the tunnel underneath Dublin Airport, Dublin Airport Station and DASP.
AZ3	Dardistown to Northwood	Section of the proposed Project from south of DASP until the Northwood Portal. This section includes the proposed Depot site at Dardistown, the M50 Viaduct and the proposed Construction Compound at Northwood.
AZ4	Northwood to Charlemont	This section includes the underground tunnel between Northwood and Charlemont. All stations along this section are included.

Mapping associated with this chapter is provided in Chapter 19, Figures and comprises the following:

- Figure 19.1: Regional Bedrock Geology;
- Figure 19.2: Aquifer Classification;
- Figure 19.3: Aquifer Vulnerability;
- Figure 19.4: Groundwater Body Status (WFD);
- Figure 19.5: Groundwater Well Search & Karst Features;
- Figure 19.6: Recharge Map;
- Figure 19.7: Baseline Groundwater Quality Monitoring; and
- Figure 19.8: Hydraulic Testing Areas along proposed alignment.

19.4.2 Overview of Regional Geology

Chapter 20 (Soils & Geology) describes in more detail the Soils & Geology along the alignment of the proposed Project. However, an overview of regional superficial and bedrock geology types is provided below (which is relevant to groundwater) and incorporates data primarily sourced from the GSI (2022) on-line mapping database together with the results of extensive ground investigations undertaken to date for the MetroLink alignment.

The lithological units above bedrock together with abbreviations to reference the overburden geology for the proposed Project include the following:

- Made Ground (Qx);

- Alluvial and Fluvio-glacial Sands and Gravels (QAG);
- Pre-Glacial Sands & Gravels (e.g. between chainages 14+500 and 15+800 (QBRs));
- Brown Boulder Clay (QBR) which may also include fluvio-glacial deposits;
- Black Boulder Clay (QBL);
- Base of Drift Deposits (BoD); and
- Upper Weathered Rock (UWR).

Note: The BoD with top of Weathered Rock is the 'contact' between the glacial deposits (Dublin Boulder Clay) and the underlying Carboniferous rocks and includes the basal glacial sediments which is material with a very high porosity and permeability, forming one of the principal aquifers in Dublin.

In terms of the solid geology beneath the full extent of the proposed Project, this can be subdivided into the following main geological units:

- Argillaceous Limestone (CLU), belonging to the Lucan Formation;
- Calcareous Shale Limestone (CTO), belonging to the Tober Colleen Formation;
- Micritic Limestone (CWA), belonging to the Waulsortian Formation; and
- Argillaceous Bioclastic Limestone (CML), belonging to the Malahide Formation.

The geological setting along the full extent of the proposed Project is further summarised below according to the geographical areas AZ1 to AZ4 as defined in Section 19.4.1 above.

The Geological Long Sections (Appendix A19.10), based on extensive ground investigations completed to data (historical and contemporary), provide clear indication of the superficial and solid geology along the full alignment of the proposed Project, as well as interpreted bedding, faults and the potentiometric surface.

19.4.3 Regional Geology and Groundwater

Published GSI (2022) geological mapping indicates the superficial deposits across the study area consist of made ground, encountered mainly in urban areas; glacial till, encountered across the site, alluvium and glaciofluvial sands and gravels, encountered primarily in the Pre-Glacial Liffey channel which runs approximately NW-SE in the vicinity of O'Connell Street. These deposits are all potentially water-bearing by nature and are underlain by limestones and mudstones of the Lucan Formation, the Tober Colleen Formation, the Malahide formation and Waulsortian Limestones which are quite different bedrock units in terms of hydrogeological characteristics. The following subsections describe the geology along the proposed alignment together with some comment on groundwater. This helps in initially defining the hydrogeological setting for the overall scheme as depicted in Diagram 19.3 below, as well as for each section of the alignment.

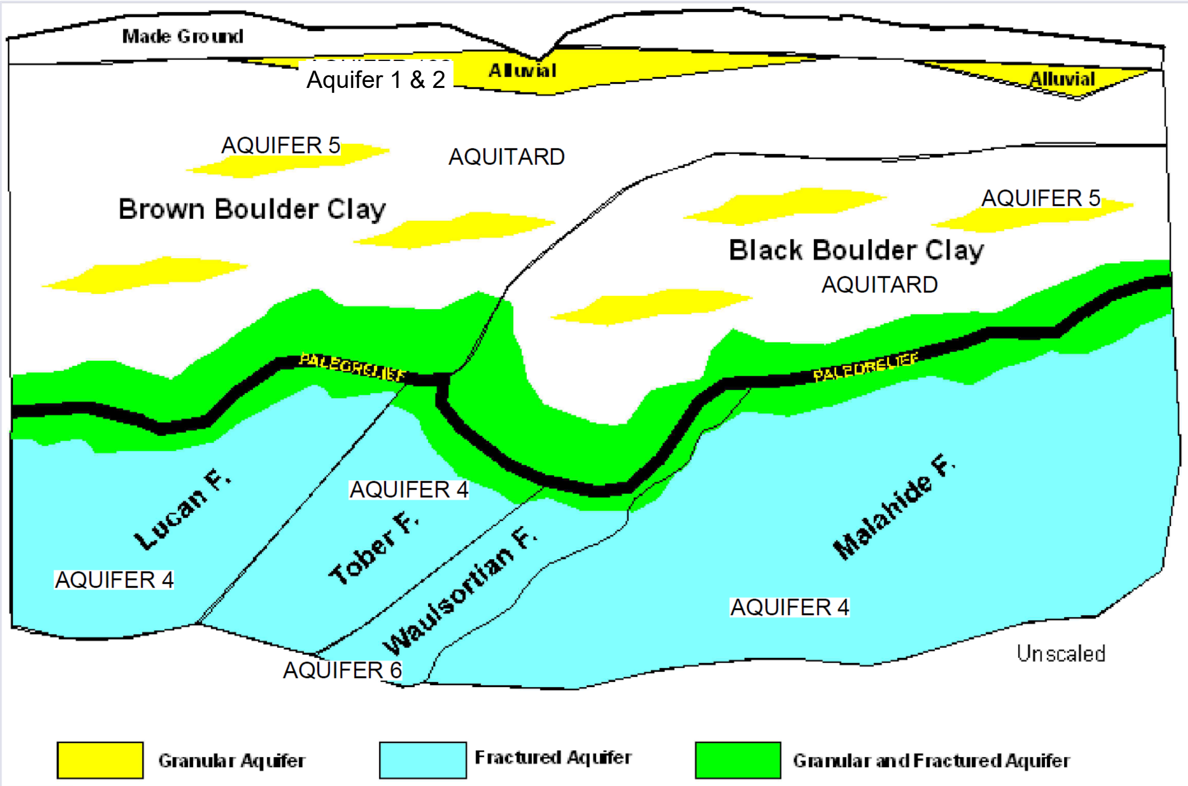

Diagram 19.3: Hydrogeological Section (CSM) for Overall Scheme

Key to Diagram 19.3 Aquifer 1: Actual Fluvial Sand and Gravels (QAG); Aquifer 2: Fluvial Sand and Gravels (e.g. underground rivers) (QAG); Aquifer 3: Free and semi-confined aquifer developed in the Base of Drift by the bottom part of the Dublin Boulder Clay and the upper part of the weathered Carboniferous Sequence. This is the main aquifer involved in the tunnels and deep station construction. Aquifer 4: Bedrock aquifers in fissured Carboniferous Sequence i.e. Upper Member of Malahide Formation (CMUP), Lower member of Malahide Formation (CMLO), Tober Colleen Formation (CTO), Lucan Formation (CLU); Aquifer 5: Semi-confined to confined aquifers developed in granular levels (sands, gravels, cobbles and boulders) in the Dublin Boulder Clay (QBR /QBL); Aquifer 6: Karstic aquifer developed in the Waulsortian Formation (CWA). Aquitard refers to Dublin Boulder Clay (Brown & Black) (QBR/QBL).

The regional bedrock geology in the context of the proposed alignment is presented in Figure 19.1.

19.4.3.1 AZ1 Northern Section

This section of the alignment includes from Estuary to south of Swords Central Station and Dublin Airport boundary north.

19.4.3.1.1 Superficial Geology

Topsoil was encountered across the section with a thickness range of 0.2m-0.4m, and rarely up to 1.5m. Made ground was encountered locally with thicknesses ranging from 0.5m to 3.0m (south-east of Seatown Station).

Alluvial deposits were also encountered in this section including south of Broadmeadow River and can range from 0.5m to a maximum depth of approx. 5.0m; these comprise typically soft to firm sandy gravelly clay/silt or (very loose to dense) occasionally cobbly gravels. Diagram 19.4 below presents these deposits in section view.

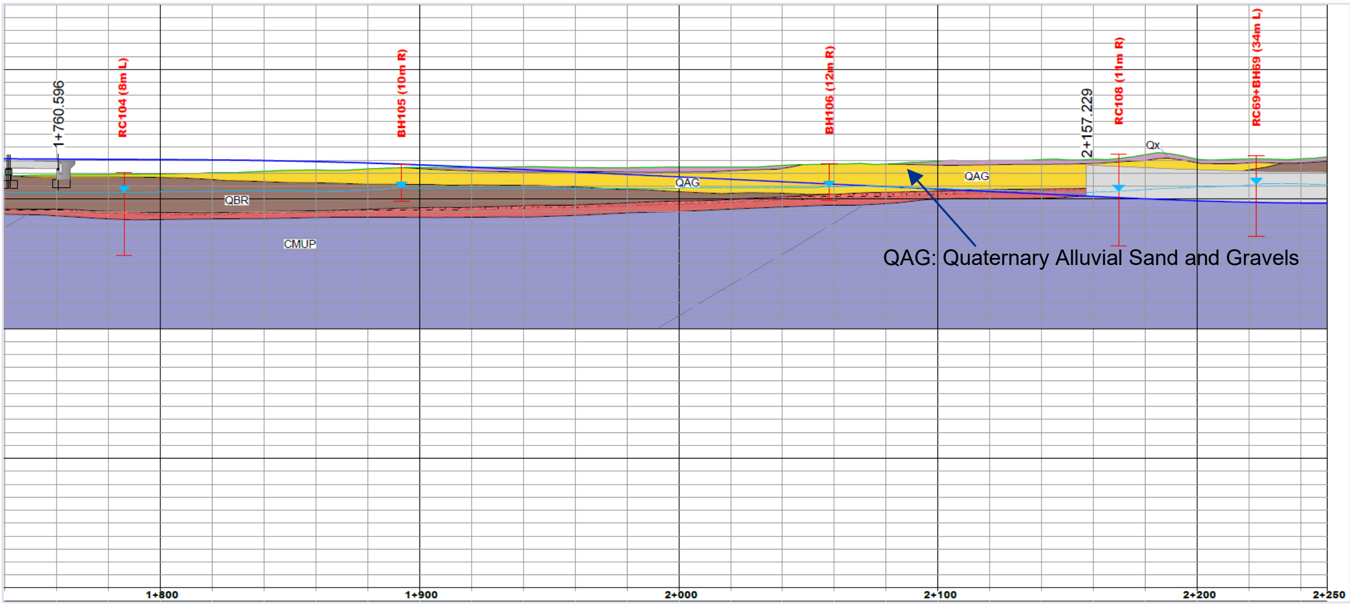

Diagram 19.4: Chainage: 1+800 to 2+400, view: Estuary to Seatown (South of Broadmeadow River)

Alluvial deposits were not identified in any of the exploratory holes undertaken between Swords Central Station and Dublin Airport boundary north. However, the GSI (2022) quaternary geology mapping indicates the presence of alluvial deposits associated with stream courses located close to/crossing the alignment, i.e. such deposits are expected locally, at as yet unidentified locations.

Glacial tills are composed of sandy gravelly clay, occasionally with cobbles and boulders, typically firm to stiff in upper horizons (brown clays), becoming very stiff to hard with increasing depth (black clays); these tills were encountered with a maximum thickness of approx. 11m (brown clays) and approx. 18m (black clays) north of Swords Central Station. Lenses and layers of loose to dense, clayey, sandy, gravel with cobbles were encountered locally within the glacial till with layers/lenses of sand encountered less frequently. Generally, in the area between Swords Central Station and Dublin Airport boundary north, the Glacial Till has been defined exclusively as very stiff to hard, sandy, gravelly, Black Boulder Clay (QBL) with cobbles and boulders and a thickness range of 6.0m to 32m; the Brown Boulder Clay (considered the weathering product of the Black Glacial Till) was not encountered.

The BOD and Top of Weathered Rock has been defined here as 1.0m to 5.5m thick (north of Swords Central) and 2.5m to 7.0m thick (south of Swords Central); this has been described as 'Till with gravel' (the gravel derived from Lower Carboniferous Limestone).

This interface between the BoD and top of weathered rock is defined as the main pathway for groundwater flows. Seepages were often encountered within gravel and sand layers/lenses (within the basal glacial deposits).

19.4.3.1.2 Solid Geology

The regional geology in this section is described as part of the Malahide Formation (GSI, 2022; code CDMALH) which is a limestone composed of calcareous shales, siltstones and sandstones, and occasional thin limestones at its base.

In general, from site investigation works, the bedrock is described as strong to moderately strong grey limestone north of Swords Central Station, with a depth to bedrock range of between 6.0mbgl to 11.0mbgl. To the south of Swords Central Station, the rock is described as strong to very strong, grey limestone with a depth to bedrock range of between 9.5mbgl and 31.0mbgl. For the AZ1 zone, the rock is also recorded with intermittent discontinuities and fresh to weathered rock - discontinuities present some potential for water movement within the rock and less so where the rock shows no/limited signs of any weathering/fracturing effects.

In terms of structural geology, the GSI (2022) records a NW-SE orientated fault (at chainage:3+000) and it is expected to intersect the alignment to the north of Seatown Station. An anticlinal axis running WSW-ENE crosses the alignment close to the N1 trunk road and has been interpreted at chainage: 4+480.

19.4.3.2 AZ2 Airport Section

This section of the alignment includes Dublin Airport boundary north to Dublin Airport boundary south.

19.4.3.2.1 Superficial Geology

The superficial geology encountered in this section comprises mainly topsoil (thickness generally ranged from 0.2m to 0.6m) and made ground (fill -composed of reworked sandy gravelly clay fill extending to a maximum depth of 3.0m). Fragments of concrete, rebar and red brick were also encountered in the made ground material which is described as variable. No alluvial deposits or glacial tills (i.e. brown clays) were encountered in this section. Black Boulder Clay (QBL) generally consists of an upper layer of firm to stiff/hard (occasionally very soft to soft), sandy, gravelly, clay with cobbles and boulders; thickness typically ranges from 2.0m to 34.0m.

The interface between the BOD deposits and Top of Weathered Rock in this section is described as having a thickness range of between 3.0m to 7.5m, with an average thickness of 4.5m.

Groundwater seepage along this interface is frequent within the coarse sandy gravel till soils, and weathered rockhead.

Note: There is also a backfilled quarry (potentially saturated) at the northern end of the Airport Tunnel.

19.4.3.2.2 Solid Geology

The regional geology in this section is described by the GSI (2020) as part of the Malahide Formation (code CDMALH) Waulsortian Formation (code CDWAUL) and Tober Colleen Formation (code CDTOBE). The Malahide Formation is described in Section 19.4.3.1. The Waulsortian Formation is a pale grey, crudely bedded, or massive limestone which is typically 300-500m thick and with shale interbeds; the Tober Colleen Formation is calcareous, commonly bioturbated mudstones and subordinate thin micritic limestones which is 50m -250m thick.

Site investigation works completed across this section describes the limestone bedrock to the north of this section as strong to very strong, grey, fresh to slightly weathered. Bedrock of the Waulsortian Formation has been defined from chainage: 6+800 to chainage: 7+250 and will be the rock support at Dublin Airport Station. This bedrock was encountered at depths of between 3.3mbgl and 22.5mbgl and is generally described as moderately weak to very strong, grey, fresh to slightly weathered limestone. The Waulsortian Formation is more prone to karstification effects than the other limestone formations encountered along the full alignment, however no significant karst (or fault/fracture) features are reported from the exploratory boreholes here (including from Metro North or AGI boreholes) or detected by surface geophysical surveys carried out close to the proposed Dublin Airport Station location (APEX, 2007). However, incipient karstification at sub-vertical joints is reported for boreholes drilled for the Dublin Airport Station. Waulsortian rock has been encountered in the proximity of Dublin Airport Station. As such, there is potential for developed voids (solution features) and associated inflows where this limestone rock type is prone to dissolution and karst development.

In terms of bedrock fracturing, there is limited/unavailable information on public databases and often 'exploratory' boreholes will not intercept major fractures or fissures. Depositional dips (of up to possibly 30°) within the Waulsortian and Tober Colleen Formations are expected. However, apart from the faulted contact between the Waulsortian and Malahide Formations, the geological structure has not been inferred in areas where insufficient ground investigation information is available.

For the faulted contact between the Malahide and Waulsortian Formations and the zone of disturbance or 'fault zone', it is plausible to suggest that fault breccias and clay gouge may be present together with a higher degree of fracturing and associated higher groundwater flows.

19.4.3.3 AZ3 Dardistown to Northwood Section

This section of the alignment includes Dublin Airport boundary south to the south of Northwood Station.

19.4.3.3.1 Superficial Geology

The superficial geology encountered in this section comprises mainly topsoil encountered across the site with a thickness range of 0.1-0.6m. Made ground (fill) was also encountered and is described as [often reworked] firm, sandy, gravelly clay with occasional cobbles, or hardcore and variable in type and depth (maximum 6.0m). Material classified as alluvial deposits was not identified in any of the exploratory holes undertaken here. However, GSI (2022) quaternary geology mapping indicates the presence of alluvial deposits and likely associated with two water courses in the vicinity of the alignment, namely the Mayne River and the Santry River.

Brown Boulder Clay (QBR) [upper glacial till] generally consists of firm to stiff, occasionally soft or very stiff to hard, sandy, gravelly, clay with cobbles and boulders, with a thickness typically ranging from 4.5m to 7m (max of 14.6m). The Black Boulder Clay (QBL) generally consists of very stiff to hard, sandy, gravelly, clay, with cobbles and boulders variable in constituents with layers of gravel encountered locally. Recorded thickness ranges from 2.5m to 28.0m. Fluvioglacial deposits were also encountered overlaying the glacial tills (for example at Portal 2 and Dardistown) which comprise gravelly, silty sand and silty gravels.

The BOD and Top of Weathered Rock in this section is described as having a thickness range of between 2.0m to 6.0m, with an average thickness of 3.0m.

Groundwater seepage and/or moderate inflows were observed within several of the granular layers encountered. Groundwater seepage along the interface between the BoD and Top of Weathered Rock is frequent within the coarse sandy gravel till and weathered rockhead.

19.4.3.3.2 Solid Geology

The regional geology in this section is described by the GSI (2022) as part of the Lucan Formation (code CDLUCN) - which comprises dark grey to black, fine-grained, occasionally cherty, micritic limestones, and the Tober Colleen Formation (code CDTOBE) - described in Section 19.4.3.2 above. The Lucan Formation ranges from 300m to 800m in thickness, is generally not susceptible to karstification and no major voids or cavities have been reported in any of the bedrock exploratory boreholes.

Site investigation works completed across this section generally describes the limestone bedrock encountered as interbedded limestone, shale and calcisiltite limestone. The limestone is generally described as strong to very strong, grey, and fine grained; the shale is generally described as moderately weak to moderately strong, dark grey/black, fine grained and thinly bedded. The GSI (2022) mapping indicates that the stratigraphic boundary between the Tober Colleen Formation and the Lucan Formation occurs just to the north of the M50 motorway. GSI recorded depths to bedrock near Dardistown are shown to lie between 20mgl and 23mbgl, however the exploratory boreholes for the proposed Project indicate that rockhead may be variable in the area where the alignment crosses the M50 motorway which is reflected by the thick sequences of glacial tills discussed above.

In terms of structural geology, the GSI (2022) indicates no significant faulting within this area of the alignment.

19.4.3.4 AZ4 Northwood to Charlemont Section

This section of the alignment includes south of Northwood Station to Charlemont. Given the extent of the geographical area AZ4, a further sub-division of this area is provided in terms of an overview of geology.

19.4.3.4.1 Superficial Geology - South of Northwood Station to Collins Avenue Station

Generally, within the immediate vicinity of the alignment, topsoil and made ground were encountered with a thickness of 0.5 to 4.0m with the composition of the made ground likely to vary and be site specific. Material classified as alluvial deposits was not identified in any of the exploratory holes undertaken here.

Brown Boulder Clay (QBR) generally consists of an upper layer of firm to stiff, brown, sandy, gravelly, clay with occasional to some cobbles with thicknesses ranging from 7.5m to 16m and is described locally as having significant thicknesses of sand and gravel. Black Boulder Clay (QBL) glacial tills were not encountered in this section.

The BOD and Top of Weathered Rock in this section is described as having a thickness range of between 3.0m to 12.0m, with an average thickness of 5.0m.

Groundwater seepage along the interface between the BoD and Top of Weathered Rock is frequent within the coarse sandy gravel till soils, and weathered rockhead.

19.4.3.4.2 Solid Geology - South of Northwood Station to Collins Avenue Station

Bedrock of the Lucan Formation is generally described in the GIR as brown to black fine-grained mudstone with occasional argillaceous limestone inclusions. The top 3.3m of bedrock occurs as layers of mudstone/highly compacted clay, stiff clay and brecciated gravel/cobbles of clay bound mudstone which may indicate that the near surface bedrock is highly to completely weathered, and the possibility of fault disturbance.

In terms of structural geology, a NE-SW trending fault is shown on the GSI (2022) mapping that intersects the alignment approximately 360m to the north of the Collins Avenue Station.

19.4.3.4.3 Superficial Geology - Collins Avenue Station to south of Mater Station

Made ground was encountered in the majority of exploratory holes in this section, with thicknesses of between 0.5 and 6.7m interpreted; composition of the made ground is recorded to vary widely and markedly over short distances. Alluvial deposits were not identified in any of the exploratory holes undertaken here. However, the GSI (2022) mapping indicates the presence of alluvial deposits associated with the course of the River Tolka for example. Deposits are possible at other (as yet unidentified) former stream courses.

Brown Boulder Clay (QBR) generally consists of an upper layer of firm to stiff, occasionally soft, or very stiff to hard, brown, sandy, gravelly, clay with cobbles and boulders, and is described locally as containing pockets of sand and gravel. The thickness of the QBR glacial tills typically ranges from 4.3m to possibly >25.0m. At the Mater Station, a significant thickness of predominantly fluvio-glacial sand and gravel (up to 8.9m thick) occurs within the predominantly clayey glacial till material.

The BOD and Top of Weathered Rock in this section is described as having a thickness range of between 2.0m to 10.5m, with an average thickness of 4.0m.

Groundwater seepage along the interface between the BoD and Top of Weathered Rock is frequent within the coarse sandy gravel till soils, and weathered rockhead.

19.4.3.4.4 Solid Geology - Collins Avenue Station to south of Mater Station

According to the site investigation works, limestone of the Lucan Formation encountered along the alignment in this section is generally described as interbedded limestone, shale and calcisiltite limestone. Generally, the limestone is strong to very strong, locally moderately strong, grey, fine grained, and thinly to thickly bedded. Shale is generally described as weak to moderately strong, dark grey/black, fine to medium grained, thinly to medium bedded and locally thinly laminated, fresh to locally highly weathered.

In terms of structural geology (GSI, 2022), information is sparse for this section with very few faults in this area and in the Dublin City Centre area in general (refer Appendix A19.10).

19.4.3.4.5 Superficial Geology - South of Mater Station

This section of the alignment includes the Dublin City Centre area and proposed Stations located at O'Connell Street, Tara Street, St Stephen's Green and Charlemont after the Grand Canal.

Made ground was encountered in the majority of exploratory holes in this section, with thicknesses of between 0.5m and 5.5m recorded although it is more typically between 1m and 4m, with the thickest deposits generally occurring close to the River Liffey. The composition of the made ground is recorded to vary widely and markedly over short distances. Alluvial deposits were identified in several exploratory hole locations in the vicinity of the River Liffey and only locally elsewhere. The thicknesses are recorded as ranging from 0.50m to >8.40m and can also change markedly over short distances with the possibility of further alluvial deposits present locally for example associated with former stream courses.

The Brown Boulder Clay (QBR) sequence here is complex according to the ground investigation data. The full thickness of this glacial till was proven and ranges from 3.0m to 25.0m, spatially and consists of an upper layer of firm to stiff, occasionally soft or very stiff to hard, brown, sandy, gravelly, clay with cobbles and boulders. Locally, it contains pockets/layers of sand and gravel with thicknesses ranging from 0.3m to 2.7m. *Note: A significant thickness of glacial sands and gravels [with less frequent clayey glacial till] is present in the area near the River Liffey and along O'Connell Street.* Records indicate thicknesses typically vary between 1.0m and 8.0m between the River Liffey and St Stephen's Green to the south, whereas, to the north of the River Liffey the thickness varies between 2.0m and 22.0m (refer to QBR shaded profiles in Diagram 19.5 below). Blowing sands and gravels were observed during historical drilling of exploratory holes in the vicinity of O'Connell Street and St Stephen's Green.

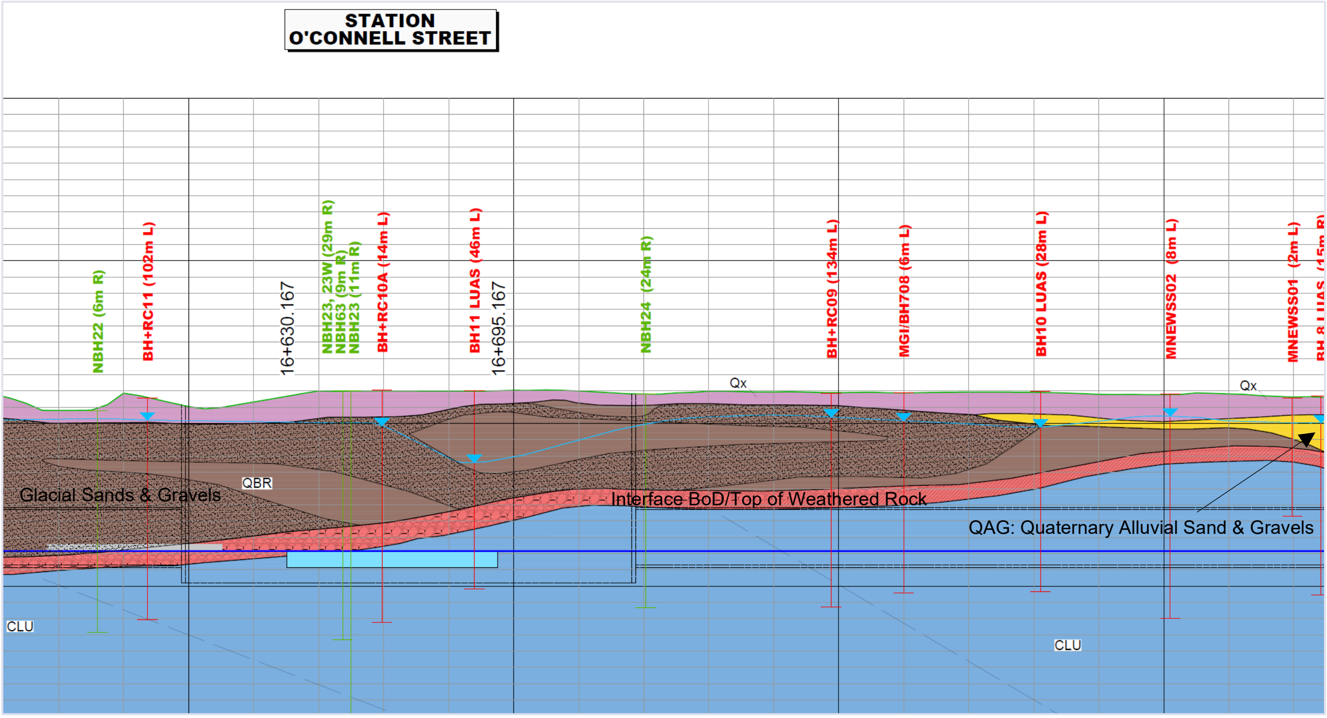

Diagram 19.5: Chainage: 16+540 to 16+950, View O'Connell Street Station southwards to River Liffey Source: IDOM (GDR)

QBL glacial tills (i.e. black clays) were not encountered in this section.

The BoD deposits and Top of Weathered Rock in this section is described as having a thickness range of between 2.0m to 6.5m, with an average thickness of 4.0m.

Groundwater strikes, or seepages, between the BoD and Top of Weathered Rock were commonly observed within the granular layers within the Till, as well as at the weathered rockhead.

19.4.3.4.6 Solid Geology - South of Mater Station

According to the site investigation works, bedrock of the Lucan Formation was encountered at depths of between 3.6mbgl and 30.5mbgl. The rock is described as interbedded limestone, shale and calcisiltite limestone. Generally, the limestone is strong to very strong, locally moderately strong, grey, fine grained, and thinly to medium bedded; the shale is generally described as weak to moderately strong, dark grey/black, fine to medium grained, thinly to medium bedded and locally thickly laminated, fresh to locally highly weathered.

In terms of structural geology (GSI, 2022), information is sparse with very few faults in this area and in the Dublin City Centre area in general (refer Appendix A19.10). The proposed Project crosses the axial trace of a syncline at St Stephen's Green and an anticline just to the north of O'Connell Bridge.

Where the glacial sands and gravels are overlain by glacial tills of relatively lower permeability, and ground surface elevation falls towards the River Liffey, the confinement of the groundwater presents the likelihood of artesian water pressure at the base of the glacial till. The occurrence of blowing sands and gravels during the ground investigations is consistent with this phenomenon, particularly at O'Connell Street.

19.4.4 Aquifer Classification and Properties

The GSI has devised a system for classifying bedrock aquifers in Ireland. The aquifer classification for bedrock depends on a number of parameters including the areal extent (km^2), well yield (m^3/d), specific capacity (m^3/d/m), transmissivity (m^2/d) and groundwater throughput/hydraulic conductivity (m^2/sec). There are three main classifications: Regionally Important, Locally Important, and Poor Aquifers. Where an aquifer has been classified as Regionally Important, it is further subdivided according to the main groundwater flow regime within it. This sub-division includes Regionally Important Fissured Aquifers (Rf) and Regionally Important Karstified Aquifers (Rk). Locally Important Aquifers are sub-divided into those that are generally moderately productive (Lm) and those that are generally moderately productive only in local zones (Ll). Similarly, Poor Aquifers are classed as either generally unproductive except for local zones (Pl) or generally unproductive (Pu). The following subsections further describes the aquifer type along the full alignment.

Figure 19.2 presents the aquifer classification in the context of the proposed alignment.

The bedrock underlying the majority of the proposed alignment is classified as a Locally Important Aquifer which is 'moderately productive only in local zones' (Ll) and belongs to the Swords and Dublin Groundwater Bodies (GWB) (refer Figure 19.4). Locally Important Aquifers are generally dominated by poor yielding boreholes with yields less than $40m^3/d$. However, it is noted that yields of up to $393m^3/d$ (for example GSI, 2022 BH: 2923SEW015) are recorded north of the River Liffey.

The aquifer is not considered to have any primary porosity with flow therefore only occurring through fractures and fissures (some of which will have been enlarged by karstification and dolomitisation). These fractures are considered as not well connected, resulting in generally low transmissivities ($1\text{-}10m^2/d$), with a distinct reduction in the permeabilities of the rock type with depth (GSI, 2022). The GSI cites that groundwater flow will predominantly take place close to the surface (i.e. with high velocities possible within the upper weathered and broken rock zone) with additional isolated [possibly conduit] flow commonly recorded along fractures and fissures located at depths of 30mbgl to 50mbgl.

Regionally, the general flow direction of the Swords GWB and Dublin GWB is from west to east towards the coast. Flow paths within the Dublin GWB are also towards the River Liffey and Dublin City. Both aquifer bodies are not expected to maintain regional groundwater flow paths with groundwater circulation from recharge to discharge points more commonly taking place over a distance of less than a kilometre (GSI, 2022).

The southeast of Dublin Airport is reported by the GSI (2022) as underlain by bedrock classified as a Poor Aquifer which is 'generally unproductive except for local zones' (Pl) and belongs to the Dublin GWB described above. This aquifer type is also part of the Industrial Facility (P0480-02) GWB as reported by the EPA (2022) and which is associated with the Dublin Airport facilities.

Aquifer properties spatially along the proposed alignment are further discussed in Section 19.4.4.1 below and under Section 19.4.13.2 (Pumping Tests).

19.4.4.1 Aquifer Properties for Zones AZ1 to AZ4

A summary of the co-efficient of permeability (i.e. rate/ease with which water will move through the matrix) for key subsoil and bedrock types along the proposed Project alignment is provided in Table 19.8 with current values (from field/lab tests) also compared with the (field/lab test) historical values used for Metro North.

Table 19.8: Permeability Values Derived for Subsoil & Bedrock Units Along the proposed Project Alignment

Lithology	Metro North	MetroLink
	Subsoil Permeability Values (m/s)	
Made Ground (Qx)	7.65E-07	7.65E-07
Alluvial and Fluvioglacial Sands and Gravels (QAG)	7.30E-07 *	1.37E-05
Fluvioglacial Sands (14+700 To 16+050) 0-10m	7.30E-07 *	2.90E-06
Fluvioglacial Sands (14+700 To 16+050) >10m	2.90E-04 *	8.59E-06
Upper Brown Boulder Clay (QBR) 0-10m	1.94E-04	7.62E-07
Lower Brown Boulder Clay (QBR) >10m	5.90E-06	6.64E-06

Lithology	Metro North	MetroLink
	Subsoil Permeability Values (m/s)	
Upper Black Boulder Clay (QBL) 0-10m	4.37E-05	7.21E-07
Lower Black Boulder Clay (QBL) >10m	1.18E-06 *	7.15E-07
Interface with BOD soil and Top of weathered rockhead	2.90E-04	2.90E-04
	Bedrock Unit Permeability Values (m/s)	
Micritic Limestone (CLU)	5.64E-06	4.7E-06
Calcareous Shale Limestone (CTO)	2.00E-06	1.40E-06
Micritic Limestone (CWA)	5.69E-07	5.69E-07
Lower Argillaceous Bioclastic Limestone (CMLO)	1.38E-06	1.38E-06
Upper Argillaceous Bioclastic Limestone (CMUP)	5.97E-06	5.97E-06
Upper Weathered Rock (UWR)	-	5.63E-06

*Note: * indicates values had been assumed from bibliography or obtained with limited laboratory or in situ data for Metro North*

Key aquifer properties, which are derived from recently completed field and laboratory tests undertaken for the proposed Project are provided below for each of the areas AZ1 to AZ4. This data has also been used in the assessment of inflows to station boxes as discussed under Section 19.5.3.4.

19.4.4.1.1 AZ1 Northern Section

Superficial Geology:

Permeability values for AZ1 from Estuary to Dublin Airport boundary north are reported for Made Ground (Qx) at 7.65E-07m/s, Alluvial and Fluvioglacial Sands and Gravels (QAG) at 1.37E-05m/s, Upper Brown Boulder Clay (QBR) 0-10m at 7.62E-07m/s, Lower Brown Boulder Clay (QBR) >10m at 6.64E-06m/s, Upper Black Boulder Clay (QBL) 0-10m, at 7.21E-07 m/s, Lower Black Boulder Clay (QBL) >10m, at 7.15E-07 m/s and BOD at 2.90E-04 m/s.

Bedrock Aquifer:

Permeability values derived for the bedrock units in AZ1 include Lower Argillaceous Bioclastic Limestone (CMLO) at 1.38E-06m/s, Upper Argillaceous Bioclastic Limestone (CMUP) at 5.97E-06m/s, and Upper Weathered Rock (UWR) at 5.63E-06m/s.

19.4.4.1.2 AZ2 Airport Section

Superficial Geology:

Permeability values for AZ2 from Dublin Airport boundary north to Dublin Airport boundary south are reported for Made Ground (Qx) at 7.65E-07m/s, Upper Black Boulder Clay (QBL) 0-10m, at 7.21E-07m/s, Lower Black Boulder Clay (QBL) >10m, at 7.15E-07m/s and BOD at 2.90E-04m/s.

The equivalent permeability for subsoils at Dublin Airport Station is 2.35E-06m/s (QBR).

Bedrock Aquifer:

Permeability values derived for the bedrock units in AZ2 include Calcareous Shale Limestone (CTO) at 1.40E-06m/s, Micritic Limestone (CWA) at 5.69E-07m/s, and Upper Weathered Rock (UWR) at 5.63E-06m/s. Locally, the field test data shows a range in hydraulic conductivity in the Waulsortian Limestone at Dublin Airport between 10-3m/s to 10-6m/s. The higher permeability values are likely to be testing fracture flow, whilst the lower permeability values indicate mainly matrix flow where only small-scale fractures are likely intersected in this rock.

The equivalent permeability used for bedrock at Dublin Airport Station is 6.27E-07m/s to 5.40E-07m/s (CWA).

19.4.4.1.3 AZ3 Dardistown to Northwood Section

Superficial Geology:

Permeability values for AZ3 from Dublin Airport boundary south to the south of Northwood Station are reported for Made Ground (Qx) at 7.65E-07m/s, Upper Brown Boulder Clay (QBR) 0-10m at 7.62E-07m/s, Lower Brown Boulder Clay (QBR) >10m at 6.64E-06m/s, Upper Black Boulder Clay (QBL) 0-10m, at 7.21E-07m/s, Lower Black Boulder Clay (QBL) >10m, at 7.15E-07m/s and BOD at 2.90E-04m/s.

The design permeability used for subsoils beneath proposed stations [where available] is as follows:

- Dardistown [proposed depot/future station] at 1.08E-06m/s (QBR), and
- Northwood Station at 1.50E-06 m/s to 2.67E-07m/s (QBR).

Bedrock Aquifer:

Permeability values derived for the bedrock units in zone AZ3 include Calcareous Shale Limestone (CTO) at 1.40E-06m/s, and Upper Weathered Rock (UWR) at 5.63E-06m/s.

The design permeability used for bedrock beneath proposed stations [where available] is as follows:

- Dardistown [proposed depot/future station] at 3.80E-08m/s (CTO), and
- Northwood Station at 7.19E-67m/s (CLU).

19.4.4.1.4 AZ4 Northwood to Charlemont Section

Superficial geology:

Permeability values for AZ4 zone from the south of Northwood Station to Charlemont are reported for Made Ground (Qx) at 7.65E-07m/s, Alluvial and Fluvioglacial Sands and Gravels (QAG) at 1.37E-05m/s, Fluvioglacial Sands (14+700 to 16+050) 0-10m at 2.90E-06m/s, Fluvioglacial Sands (14+700 to 16+050) >10m at 8.59E-06m/s, Upper Brown Boulder Clay (QBR) 0-10m at 7.62E-07m/s, Lower Brown Boulder Clay (QBR) >10m at 6.64E-06 m/s, and BOD at 2.90E-04m/s.

The design permeability used for subsoils beneath proposed stations [where available] is as follows:

- Ballymun and Collins Avenue at 1.94E-04m/s (QBR <10m), 5.90E-06 m/s (QBR >10m) and 2.90E-04m/s (BoD);
- Griffith Park at 1.94E-04m/s (QBR <10m) and 2.90E-04m/s (BoD);
- Glasnevin at 1.94E-04m/s (QBR <10m), 5.90E-06m/s (QBR >10 m) and 2.90E-04m/s (BoD);
- Mater and O'Connell Street at 7.30E-07m/s (QBR <10m), 2.90E-06m/s (QBR >10 m) and 2.90E-04m/s (BoD);
- Tara Street at 7.30E-07m/s (QAG) and 2.90E-04m/s (BoD);
- St Stephen's Green at 1.94E-04m/s (QBR <10m) and 2.90E-04m/s (BoD); and
- Charlemont at 1.94E-04m/s (QBR <10m), 5.90E-06m/s (QBR >10m) and 2.90E-04m/s (BoD).

Bedrock Aquifer:

Permeability values derived for the bedrock units in zone AZ4 include Calcareous Shale Limestone (CTO) at 1.40E-06m/s, Micritic Limestone (CLU) at 4.70E-06m/s, and Upper Weathered Rock (UWR) at 5.63E-06m/s.

The design permeability used for bedrock beneath proposed stations [where available] is as follows:

- Ballymun and Collins Avenue at 2.00E-06m/s (CLU);
- Griffith Park at 2.90E-06m/s (CLU);
- Glasnevin at 1.22E-06m/s (CLU);

- Mater at 1.49E-06m/s to 1.75E-06m/s (CLU); and
- O'Connell Street, Tara Street, St Stephen's Green and Charlemont at 5.64E-06m/s (CLU).

19.4.5 Aquifer Vulnerability

Aquifer vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated generally by human activities. Due to the nature of the flow of groundwater through bedrock in Ireland, which is almost completely through fissures/fractures, the main feature that protects groundwater from contamination, and therefore the most important feature in the protection of groundwater, is the subsoil (which can consist solely of/or of mixtures of peat, sand, gravel, glacial till, clays or silts).

The vulnerability category assigned to a site or an area is thus based on the relative ease with which infiltrating water and potential contaminants may reach groundwater in a vertical or sub-vertical direction. As all groundwater is hydrologically connected to the land surface, it is the effectiveness of this connection that determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is considered to be more vulnerable than groundwater that receives water (and contaminants) more slowly, and consequently in lower quantities. Also, the slower the movement and the longer the pathway, the greater is the potential for attenuation of many contaminants. Table 19.9 presents the vulnerability guidelines and rating according to the GSI (2022).

Table 19.9: GSI Groundwater Vulnerability Mapping Guidelines

Vulnerability Rating	Hydrogeological Conditions		
	Subsoil Permeability (Type) and Thickness		
	High Permeability (sand/gravel)	Moderate Permeability (e.g. sandy soil)	Low Permeability (e.g. clayey subsoil, clay, peat)
Extreme (E) Note1	0.0 - 3.0m	0.0 - 3.0m	0.0 - 3.0m
High (H) Note1	> 3.0m	3.0 -10.0m	3.0 - 5.0m
Moderate (M) Note1	Not applicable	>10.0m	5.0 - 10.0m
Low (L) Note 1	Not applicable	Not applicable	>10m

Note 1. - Release point of contaminants is assumed to be 1 - 2m below ground surface

Aquifer vulnerability will vary depending on the whether the proposed works areas/station locations are at grade or underground, in addition to the deeper tunnelling works.

In the following subsections, a summary of the subsoil thickness (metres) using data collected from site investigation works is presented for each of the geographical areas AZ1 to AZ4. The data is presented in the context of the [current] GSI (2022) vulnerability classification also for the extent of the proposed alignment within these four geographical areas along with additional comments on vulnerability class as 'assessed at the local scale'. Additional focus is on the proposed station/works areas for each AZ with a reference chainage indicated – i.e. not specifically for the areas between these reference station/works areas for which the GSI classification is generally applied. Reference is also made to the data collected on subsoil type and thicknesses for the proposed Project as discussed under Section 19.4.4.1.1 above.

Figure 19.3 presents the aquifer vulnerability in the context of the proposed alignment and for each of the assessment zones AZ1-AZ4.

19.4.5.1 AZ1 Northern Section

The GSI (2022) vulnerability classification for the extent of the proposed alignment within AZ1 is generally shown as M-L. Table 19.10 summarises the predominant subsoil type/thickness recorded for the proposed stations within zone AZ1 in the context of this current vulnerability class.

Table 19.10: AZ1 Northern Section -Summary of Recorded Subsoil Thickness

Reference Station/Works Area	Ref. Chainage	Predominant Subsoil Type(s)	Depth (thickness) Observed (m)	GSI Vulnerability Class (General Area)	Comments
Estuary Park & Ride	1+250	Brown Boulder Clay (QBR)	0.00-5.00	M	QBR over BoD and CMUP limestone rock; GSI classification is M with H to the west; revised class M-H likely
Seatown	2+850	Black Boulder Clay (QBL)	0.00-7.00	L	QBL over BoD and CMUP limestone rock; GSI classification is L with M to the west; classification acceptable
Swords Central	3+820	Black Boulder Clay (QBL)	0.00-16.00	L	QBL over BoD and CMLO limestone rock (w/thin shale beds); GSI classification is L with M to the west; classification acceptable
Fosterstown	4+780	Black Boulder Clay (QBL)	0.00-21.00	L	QBL over BoD and CMLO limestone rock (w/thin shale beds); GSI classification is L with M to the north; classification acceptable

Note: BoD - Base of Drift over Top of Weathered Rock; GI - Ground Investigation (findings)

19.4.5.2 AZ2 Airport Section

The GSI (2022) vulnerability classification for the extent of the proposed alignment within AZ2 is generally shown as M-H. Table 19.11 summarises the predominant subsoil type/thickness recorded for AZ2 in the context of this current vulnerability class. Additional information is provided given the variable depth to bedrock in the area of Dublin Airport.

Table 19.11: AZ2 Airport Section - Summary of Recorded Subsoil Thickness

Reference Station/Works Area	Ref. Chainage	Predominant Subsoil Type(s)	Depth (thickness) Observed (m)	GSI Vulnerability Class (General Area)	Comments
DANP/north of airport	6+040 & 6+940	Made Ground (Qx) Black Boulder Clay (QBL)	0.00-1.00 1.00-17.00	M-H	Low potential QBL over BoD and CMUP limestone rock; GSI classification is M-H; locally, revised class L likely
Dublin Airport Station area	6+940 & 7+240	Made Ground (Qx) Black Boulder Clay (QBL)	0.00-2.50 2.50-5.00	H - E/X	Correct H-E Hardstanding surface, mainly;

Reference Station/Works Area	Ref. Chainage	Predominant Subsoil Type(s)	Depth (thickness) Observed (m)	GSI Vulnerability Class (General Area)	Comments
					QBL over BoD and CWA limestone rock; GSI classification is H-E/X; classification acceptable
South of Dublin Airport	7+240 & 7+600	Made Ground (Qx) Black Boulder Clay (QBL)	0.00-2.00 2.00-20.00	M-H	Low potential QBL over BoD and CTO shale rock; GSI classification is M-H; locally, revised class L likely
South to DASP	7+600 & 8+480	Made Ground (Qx) Black Boulder Clay (QBL)	0.00-1.00 1.00-30.00	L	Low = Correct QBL over BoD and CTO shale rock; GSI classification is L which correlates to GI; classification acceptable

Note: BoD - Base of Drift over Top of Weathered Rock; GI - Ground Investigation (findings)

19.4.5.3 AZ3 Dardistown to Northwood Section

The GSI (2022) vulnerability classification for the extent of the proposed alignment within AZ3 is generally shown as L. Table 19.12 summarises the predominant subsoil type/thickness recorded for the proposed stations within AZ3 in the context of this current vulnerability class.

Table 19.12: AZ3 Dardistown to Northwood Section - Summary of Recorded Subsoil Thickness

Reference Station/Works Area	Ref. Chainage	Predominant Subsoil Type(s)	Depth (thickness) Observed (m)	GSI Vulnerability Class (General Area)	Comments
Dardistown (Depot and Future Station)	9+040	Made Ground (Qx) Black Boulder Clay (QBL)	0.00-1.00 1.00-16.00	L	QBL over BoD and CTO shale rock; GSI classification is L; classification acceptable
Northwood	10+320	Made Ground (Qx) Brown Boulder Clay (QBR)	0.00-2.00 2.00-12.00	L	QBR over BoD and CTO shale rock; GSI classification is L; classification acceptable

Note: BoD - Base of Drift over Top of Weathered Rock; GI - Ground Investigation (findings)

19.4.5.4 AZ4 Northwood to Charlemont Section

The GSI (2022) vulnerability classification for the extent of the proposed alignment within AZ4 is generally shown as L. Table 19.13 summarises the predominant subsoil type/thickness recorded for the proposed stations within AZ4 in the context of this current vulnerability class.

Table 19.13: AZ4 Northwood to Charlemont Section - Summary of Recorded Subsoil Thickness

Reference Station/Works Area	Ref. Chainage	Predominant Subsoil Type(s)	Depth (thickness) Observed (m)	GSI Vulnerability Class (General Area)	Comments
Ballymun	11+260	Made Ground (Qx) Brown Boulder Clay (QBR)	0.00-2.00 2.00-18.00	L	Significant hardstanding over QBR over BoD and CLU limestone rock; GSI classification is L; classification acceptable
Collins Avenue	12+220	Made Ground (Qx) Brown Boulder Clay (QBR)	0.00-2.00 2.00-12.00	L	Significant hardstanding over QBR over BoD and CLU limestone rock; GSI classification is L; classification acceptable
Griffith Park	13+800	Made Ground (Qx) Brown Boulder Clay (QBR)	0.00-2.00 2.00-8.50	M-H	Significant hardstanding over QBR over BoD and CLU limestone rock; GSI classification is M-H; locally, revised class M likely
Glasnevin	14+850	Made Ground (Qx) Brown Boulder Clay (QBR)	0.00-2.00 2.00-27.00	L	Significant hardstanding over QBR over BoD and CLU limestone rock; GSI classification is L; classification acceptable
Mater	15+640	Made Ground (Qx) Pre-glacial Sands & Gravels within QBR	0.00-2.00 2.00-20.00	L	Significant hardstanding over QBR over BoD and CLU limestone rock; GSI classification is L; classification acceptable
O'Connell St.	16+660	Made Ground (Qx) Pre-glacial Sands & Gravels within QBR	0.00-2.00 2.00-25.00	L	Significant hardstanding over QBR over BoD and CLU limestone rock; GSI classification is L; classification acceptable
Tara St.	17+400	Made Ground (Qx) Alluvial Sands & Gravels (QAG)	0.00-3.00 3.00-8.00	M	Significant hardstanding over QAG over BoD and CLU limestone rock; GSI classification is M; classification acceptable

Reference Station/Works Area	Ref. Chainage	Predominant Subsoil Type(s)	Depth (thickness) Observed (m)	GSI Vulnerability Class (General Area)	Comments
St Stephen's Green	18+480	Made Ground (Qx) Brown Boulder Clay (QBR)	0.00-2.00 2.00-7.00	M	Significant hardstanding/grass over QBR over BoD and CLU limestone rock; GSI classification is M; classification acceptable
Charlemont	19+360	Made Ground (Qx) Brown Boulder Clay (QBR)	0.00-2.00 2.00-12.00	M	Significant hardstanding over QBR over BoD and CLU limestone rock; GSI classification is M; classification acceptable

Note: BoD - Base of Drift over Top of Weathered Rock; GI - Ground Investigation (findings)

The nature and type of subsoil cover determines the likely inflow rates during sub surface construction for the stations primarily, as well as other works areas; this indicates the vulnerability of this material to anthropogenic influences. A review of available ground investigation indicates the presence of Made Ground, which extends to depths of approximately 4mbgl in Dublin City Centre (including up to 3mbgl at Tara Street). This is underlain by sequences of cohesive and/or granular deposits as presented above.

Diagram 19.5 above (chainage: 16+540 to chainage: 16+950) highlights areas where more permeable material is likely to be present in the vicinity of O'Connell Street Station (glacial sands/gravels) and southwards near the River Liffey (alluvial sand & gravels) at shallow depths indicating a greater vulnerability class.

Diagram 19.6 below highlights more permeable material present to the north and south of the River Liffey and to Tara Station; these alluvial deposits are shown to extend to approx. chainage 17+740. The diagram indicates the vulnerability of such deposits in a city centre setting and potential contamination by human activities.

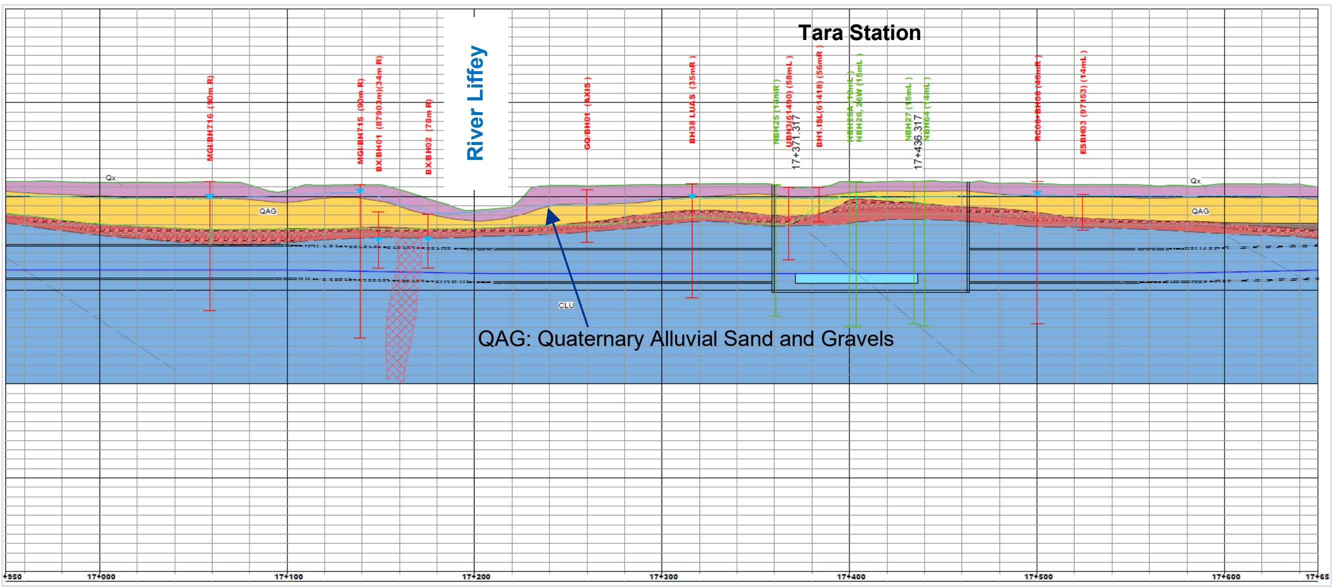

Diagram 19.6: Chainage: 16+950 to 17+650, view southwards to River Liffey and beyond Tara Station

19.4.6 Groundwater Body Status

The European Communities Directive 2000/60/EC established a framework for community action in the field of water policy (commonly known as the Water Framework Directive [WFD]). The WFD required '*Good Water Status'* for all European water, to be achieved through a system of river basin management planning and extensive monitoring. 'Good groundwater status' means both *'Quantitative Status'* and *'Good Chemical Status'* is achieved. To meet the aim of Good Chemical Status, hazardous substances should be prevented from entering groundwater, and the entry of all other pollutants (e.g. nitrates) should be limited. Good Quantitative Status can be achieved by ensuring that the available groundwater resource is not reduced by the long-term annual average rate of abstraction (which is not applicable to the proposed Project).

According to the GSI (2022), if a groundwater body is capable of serving 10m^3/day of sustainable abstraction, it is designated as a groundwater 'waterbody'.

Under the WFD, the GSI (2022) has delineated a number of groundwater bodies in Ireland. The GWBs shown to be traversed by the proposed Project include in the main the Swords GWB and Dublin GWB as discussed in Section 19.4.4 above. There are also the Industrial Facility GWBs delineated within both the Swords GWB and the Dublin GWB. The latter are subsets of the regional GWBs but delineated in relation to specific licenced facilities. These are summarised in Table 19.14 (GSI/EPA, 2021) together with current WFD Status (period: 2013-2018) and WFD Risk Score (third cycle) which means the risk for each waterbody of failing to meet their WFD objectives by 2027.

Table 19.14: Groundwater Bodies Crossed by the Proposed Alignment

Geographical Reference Area	Groundwater Body	EU Groundwater Body Code	Flow Regime (bedrock)	WFD Status Classification (overall)	WFD Risk Score
AZ1	Swords GWB/ Dublin GWB/ Industrial Facility (P0014-03) Industrial Facility (P0480-02)	IE_EA_G_011/IE_EA_G_008/ IE_EA_G_062 IE_EA_G_086	Moderately productive Moderately productive Moderately productive Moderately to poor productive	Good Good Poor Poor	Not at risk Review At risk At risk
AZ2	Industrial Facility (P0480-02) Dublin GWB	IE_EA_G_086 IE_EA_G_008	Poorly productive Poorly productive	Poor Good	At risk Review
AZ3 to AZ4	Dublin GWB	IE_EA_G_008	Poorly to moderately productive	Good	Review

The principal GWBs traversed by the proposed Project are mostly at Good Status, presently. However, localised areas of known contamination exist within the vicinity of Dublin Airport and within the Swords waterbody farther to the west of the R132 (e.g. Watery Lane). Both 'industrial' referenced GWBs are directly related to point sources at these particular locations, however only the Industrial Facility GWB (ref. P0480-02) at Dublin Airport is crossed directly by the proposed Project.

Figure 19.4 presents the GWB status in the context of the proposed alignment.

19.4.7 Source Protection Areas and Record of Groundwater Wells

Water supplies refer to any large springs, groundwater abstractions for local authorities, commercial/industrial, holy wells, Group Water Schemes or private well supplies. Source Protection Plans have been published by the GSI or EPA to define the groundwater catchment for some large public water supplies and state appropriate land use practices within the catchment. The Source Protection Areas (SPA) include Inner (SI) and Outer Protection (SO) areas.

The nearest public water supplies and SPAs are located in/beyond north County Dublin (for example Bog of the Ring PWS located 10km north of Estuary Station). Local Authority and the National Federation of Group Water Schemes (NFGWS, 2020) records were also consulted to determine the locations of potential groundwater abstractions. In summary, there are no SPAs identified within the vicinity of the proposed Project study area.

The GSI (2022) Well Card Index is a record of wells drilled in Ireland, water supply sources and site investigation geotechnical boreholes. It is noted that this record is not comprehensive as licensing of wells is not currently a requirement in the Republic of Ireland. It is important to state that the general area in the vicinity of the proposed Project is serviced by public water supply mains. As such, there is no significant density of boreholes anticipated.

Notwithstanding this, the EPA have launched a register of water abstractions in accordance with the *European Union (Water Policy) (Abstractions Registration) Regulations 2018 (S.I. No. 261 of 2018).* People who abstract 25m^3/d (25,000 litres) of water or more per day are required to register their water abstraction. Development of a register of water abstractions is a requirement of the Water Framework Directive (2000/60/EC) and has been signalled in the River Basin Management Plan 2018-2021.

Figure 19.5 shows the locations of all wells presently recorded by the GSI (2022). However, as it is not a requirement for wells to be registered with the GSI the list of wells is not necessarily complete.

Table 19.15 presents additional available details on the groundwater well search in the context of the proposed alignment and specific proposed stations (and therefore the track/tunnel alignment), as well as the geographical reference areas presented as AZ1 to AZ4. Note the degree of location accuracy as provided by the GSI which indicates potential positional variance with the proposed alignment. Furthermore, no information is available on the current 'condition' of the points presented, i.e. 'live', decommissioned, mild steel casing.

Table 19.15: Groundwater Well Search in Vicinity of the Proposed Alignment

Ref Area	Nearest Station Reference	GSI Well Identification	GSI Yield (m^3/d)	GSI Yield Class	GSI location relative to alignment type/structure (approx. only)	Notes (incl. location accuracy)
AZ1	Estuary	2923NEW063	-	-	c. 550m NE from Station	Spring (Sunday Well), Lissenhall Little townland, 10m acc.
	Seatown	2923NEW045	381	Good	c. 850m E from Station	Borehole; Depth 33.5m, 50m acc.
	Seatown	2923NEW044	218	Good	c. 1km E from Station	Borehole; Depth 15.2m, 50m acc.
	Swords Central	2923NEW019	385	Good	c. 500m N from Station	Borehole; Depth 33.5m, 500m acc.
		2923NEW018	110	Good	c. 650m NNW from Station	Borehole; Depth 46.9m, 500m acc.
		2923NEW020	220	Good	c. 590m NW from Station	Borehole; Depth 27.4m, 500m acc.
		2923NEW038	-	-	c. 560m NW from Station	Spring (Slips Well), Forrestfields townland, 20m acc.
		2923NEW039	-	-	c. 300m S from Station	Spring, Crowcastle townland, 20m acc.

Ref Area	Nearest Station Reference	GSI Well Identification	GSI Yield (m^3/d)	GSI Yield Class	GSI location relative to alignment type/structure (approx. only)	Notes (incl. location accuracy)
	Fosterstown	2923NEW021	38.2	Poor	c. 280m SE from Station	Borehole; Depth 36.6m, 200m acc.
AZ2	Dublin Airport	2923NEW034	300	Good	c. 720m SE from Station	Borehole; Depth 13.7m, 500m acc.
		2923NEW042	-	-	c. 1.1km SE from Station	Spring, Toberbunny townland, 20m acc.
AZ3	Dardistown (depot/future Station)	2923NEW061	87	Moderate	c. 80m SE from Station	Borehole; Depth 91.4m, 200m acc.
		2923NEW062	200	Good	c. 80m SE from Station	Borehole; Depth 122m, 200m acc.
		2923NEW036	87	Moderate	c. 80m SE from Station	Borehole; Depth 91.4m, 500m acc.
		2923NEW037	-	-	c. 80m SE from Station	Borehole; Depth 122m, 200m acc.
		2923NEW015	130	Good	c. 400m SE from Station	Borehole; Depth 48.8m, 500m acc.
		2923NEW016	109	Good	c. 700m SE from Station	Borehole; Depth 35.4m, 500m acc.
AZ4	Glasnevin	2923SEW027	300	Good	c. 400m N from Station	Borehole; Depth 90m, 200m acc.
		2923SEW028	482	Excellent	c. 400m N from Station	Borehole; Depth 106m, 100m acc. Production well, 72hr pumping test
	O'Connell Street	2923SEW012	163.6	Good	c. 250m NE from Station	Borehole; Depth 137m, 100m acc.
		2923SEW013	114.5	Good	c. 650m SW from Station	Borehole; Depth 106.7m, 200m acc.
		2923SEW015	393	Good	c. 1km W from Station	Borehole; Depth 30.4m, 500m acc.
	St Stephen's Green	2923SEW014	261.8	Good	c. 1.3km ENE from Station	-
	Charlemont	2923SEW010	109.1	Good	c. 550m SW from Station	Borehole; Depth 39m, 50m acc.

Note: Table 19.15 should be read in conjunction with Figure 19.5.

Other groundwater wells have been recorded in the vicinity/context of the proposed alignment and include the following:

- According to the Estates Office at Trinity College Dublin (TCD), periodic groundwater level monitoring includes regular collection of water levels at the 'extremely sensitive' underground St Patrick's Well (observed by AWN on 11/04/2018). This historical [>200-year-old] well, depth 40ft (12.2m) is located below the present Luas Green line in Nassau Street and approximately 340m to the east of the proposed alignment.
- TCD also have a number of other monitoring wells [existing and proposed] on site and geothermal wells within the college grounds including at the Library and Rubics buildings (communication with the GSI Groundwater & Geothermal Unit, 31-05-2022) at possibly >100m west of the tunnel alignment (but exact location not defined).
- Other Temple Bar well (details on historical well points unknown)
- Additional review by the GSI of their geothermal installation datasets (31-05-2022) indicated the following commercial systems that are in the region of the proposed MetroLink route: Cowper Care Rathmines – (at a distance from the tunnel alignment in Ranelagh), Sean O'Casey Community Centre, East Wall, Wilton Terrace (unspecified building), The Times Building, Dublin 2 (Tara Street), ESB HQ Fitzwilliam St., and IKEA Ballymun -however details on the exact location for each site are not available.
- Historical dug wells including at the National Gallery (dug, stone-lined well in north-east corner of basement at Milltown Wing, subsequently backfilled (with stone) during 2018 upgrade works completed at the National Gallery Ireland site); wells with timber pumps located on the central carriageway of St Stephen's Green North during Luas Cross City (LCC) works; historical water supply wells located along Marlborough St., Parnell Street, and Dawson St.; and dug well near ILAC Centre (approx. 380m to west of alignment).

19.4.8 Karst Features

There are no recorded karst features identified within the vicinity of the study area according to the GSI Karst database (2022). The nearest karst feature as identified by the GSI is a borehole located in Saint Doolagh's church, approx. 4.3km east of Dublin Airport Station.

Notwithstanding the above, in the context of the proposed alignment, locally at Dublin Airport the solid geology consists of massive limestone and mudstone (Waulsortian limestone) which represents bedrock potentially more susceptible to the development of karst features (refer Section 19.4.3.2). The bedrock has been faulted, partly folded, and uplifted with the existence of water and clay-filled voids also previously reported in this area. However, the ground investigation results for boreholes drilled at Dublin Airport within this rock type only indicated 'incipient' epikarst with no significant karst features encountered (Appendix A19.10).

19.4.9 Recharge Map

Related to the groundwater vulnerability mapping is the GSI recharge mapping. Figure 19.6 presents the GSI (2022) recharge map in the context of the proposed alignment from Estuary Station to Charlemont Station. The recharge co-efficient rate (%) is a function of the hydrogeological setting and description, i.e. primarily the subsoil cover, drainage characteristics and the thickness and permeability of that subsoil. The recharge map provides an estimate of the average recharge (mm/yr) to ground for that area and takes account of the effective rainfall for the same area.

The following subsections provide an overview of the GSI (2022) groundwater recharge estimates for the four areas AZ1 to AZ4; reference should be made to Figure 19.6. Recharge estimates will invariably be linked to the degree of groundwater ingress potential for deep excavations for example and consequently on the potential need for dewatering activities.

19.4.9.1 AZ1 Northern Section

The general average recharge for the AZ1 area is shown to range from 0mm/yr-100mm/yr with lower, i.e. <30mm/yr recharge indicated for areas where low permeability subsoil prevails (e.g. Fosterstown) and co-efficient values of ~7.5% to 15% are shown. Areas where made ground is present are represented by slightly higher recharge estimates of between 60mm/yr-70mm/yr, and co-efficient values of ~20% to 25% are shown; this area includes the urban settings around Seatown and Swords (both cut & cover points). To the west of Swords Central, recharge estimates from 75mm/yr-200mm/yr (co-efficient values ~60%) are indicated where well-drained tills are present. Similarly, to the south of Fosterstown (cut & cover), the presence of high permeable subsoil comprising sand & gravels overlain by well-drained soil correlate with greater recharge estimates, i.e. up to 250mm/yr with a comparatively higher recharge co-efficient of ~85% indicating the greater infiltration to ground of effective rainfall. Here, the alignment is generally in open cut/incline/surface.

In general, despite the wider area underlain by a Ll Aquifer, where areas of low permeable subsoil persist, including hardstanding cover, this will also limit the quantity of recharge that can infiltrate to ground. Effective rainfall in this instance will therefore run off to surface water by means of local drains and ditches.

19.4.9.2 AZ2 Airport Section

The general average recharge for the airport section is shown to range from 60mm/yr-80mm/yr and this reflects predominantly low permeable subsoil (QBL) and made ground (QX), irrespective of the area underlain by Ll aquifer to the north and the Pl to the south of AZ2 area. Notwithstanding this, there are [Ll aquifer type] areas shown to be of H-E/X vulnerability, i.e. a recharge co-efficient of 85% (greater if karst present), with average 200mm/yr recharge potential at Dublin Airport Station. The area to the west of Dublin Airport, the airport itself as well as lands farther east crossing the R132 Swords Bypass all correlate to shallow limestone bedrock (i.e. very thin subsoil cover) and it is in these areas where the aquifer has potential for a significantly higher infiltration capacity. In summary, where low permeable subsoils persist, or where thin subsoils are covered by hardstanding, meteoric recharge to ground is expected to be low.

Figure 19.6 indicates potential recharge values of up to 400mm/yr farther to the west and likely hydraulically up-gradient of Dublin Airport. The proposed Project is at tunnel alignment as it crosses area AZ2.

19.4.9.3 AZ3 Dardistown to Northwood Section

The predominant subsoil cover for AZ3 is QBL extending from the south of Dublin Airport to south of the M50 Viaduct and QBR tills from here to south of Northwood Station. This is generally low permeable strata and correlates with the predominantly low recharge coefficient range of 7.5%-20% and mostly average recharge rates of 20mm/yr. AZ3 crosses both a Pl and Ll bedrock aquifer and while the latter may indicate a higher recharge acceptance the GSI do apply a recharge cap to the annual quantity of recharge in this general area.

The proposed Project is at surface alignment from DASP and north of Northwood with a change in elevation to incline at the proposed M50 Viaduct. In summary, where tills persist then meteoric recharge to ground is expected to be low.

19.4.9.4 AZ4 Northwood to Charlemont Section

The recharge coefficient for the area covered by AZ4, i.e. from south of Northwood to Charlemont Station is estimated by the GSI as 20% or less, with an average annual recharge of up to 60mm/yr only. This is based on a hydrogeological setting of made ground typical of an urban setting with intermittent incidences of [exposed] low permeable subsoil (QBR) including below any hardstanding cover all of which limits infiltration potential. Rarely, till overlain by well-drained soil is present, for example near the Tolka River/north of Botanic Gardens, and here a recharge co-efficient of 60% is estimated (i.e. average recharge of <200mm/yr).

The GSI also apply a recharge cap to the annual quantity of recharge in this geographical area and this includes areas where alluvial sands and gravels prevail, i.e. from south of O'Connell Street to south of Tara Station, reflecting the degree of hardstanding which limits the quantity of recharge that can infiltrate to more permeable geology. Effective rainfall in this instance will therefore run off to surface water by means of stormwater drains and/or the combined sewer network to Ringsend Wastewater Treatment Plant.

The proposed Project is at tunnel alignment from Northwood to south of Ranelagh with all stations (apart from Northwood) representing deep excavations with base slab or Top of Rail (TOR) within the underlying (CLU) limestone bedrock. In summary, the recharge within the AZ4 area will typically be low to very low with run-off drainage managed as part of surface water run-off to storm sewers for example.

19.4.10 Groundwater Quality

Reference is made to the long-term trends for groundwater quality which are used to determine groundwater body status by the EPA. The current data on groundwater quality adds to this national understanding of the aquifer water quality and therefore provides a local dataset for assessment in the EIAR process.

Contemporary groundwater monitoring was undertaken at 9-10 no. historical [available] borehole locations (RC, IGSL, BH, AGI, MGI -all associated with the Metro North Project) located by AWN in 2018 along the proposed Project alignment. The main objective of the field work included early recording of baseline water quality and water levels in geological strata representative of the medium through which the alignment will pass (refer also to Section 19.3.3.2 above). In addition, baseline water quality was collected during short-term pumping tests undertaken at locations along the alignment (refer Figure 19.8). Finally, the most recent groundwater monitoring was completed by AWN in January and March 2021 at newly drilled (2019-2020) boreholes designed also for groundwater level and quality monitoring purposes. The data collected from all sampling events was added to the overall database for the proposed Project.

As part of the Phase 5 Ground Investigation works, additional groundwater quality monitoring was undertaken within all areas AZ1 to AZ4. Groundwater sampling and laboratory analysis was undertaken on selected monitoring installations between February and March 2022 (refer Chapter 20 Soils & Geology).

Appendix A19.1 provides a summary of analytical and field monitoring results for the groundwater baseline sampling rounds completed during October/November 2018 and March/April 2019, at historical monitoring wells drilled as part of Metro North. Appendix A19.2 presents the laboratory test results of the groundwater monitoring as part of the recent hydraulic testing programme. Appendix A19.3a to A19.3d present a summary analytical and field monitoring results for the groundwater baseline sampling rounds completed during January 2021 and March 2021 at specific monitoring wells drilled for the proposed Project.

Baseline groundwater quality is further presented in tabular format and discussed under Appendix A19.1, Appendix A19.2 and Appendix A19.3d for each of the geographical areas AZ1 to AZ4, with reference to key analytes in the context of available Groundwater Threshold Values (GTVs) and/or EPA Interim Guideline Values (IGVs). Reference is also made to the laboratory limit of detection (LOD) and where exceedances are reported for each monitoring period presented. A summary overview is provided in the following sub-sections.

19.4.10.1 AZ1 Northern Section

Baseline groundwater quality collected for AZ1 in 2018/2019, which included testing of samples at both historical monitoring wells and those boreholes recently drilled for contemporary hydraulic testing along the R132, generally indicated localised exceedances (i.e. within the area of the monitoring well sampled) which are indicative of 'urban or peri-urban setting' impacts on the underlying aquifer. In summary, there were no consistent exceedances or identifiable upward trends in any of the data collected here which would otherwise indicate possible extensive sources of contamination.

Few exceedances of the GTV, where available, are reported for this area. This overview is generally consistent with the current GWB status and WFD risk score for the area (refer Section 19.4.6).

Baseline groundwater quality collected for AZ1 over two rounds completed in early 2021 included sampling at both shallow and deep screened monitoring wells installed recently i.e. samples were collected at four no. representative monitoring wells. Appendix A19.3d discusses the reported laboratory test results which included exceedances above available thresholds/guideline values for analytes for example potassium, chloride, TPH and MTBE. In summary, and similar to the observations above, reported water quality results are consistent with an urban setting with no significant issues/variation in values recorded for either of the two sampling events completed in 2021.

Groundwater samples within AZ1 were collected from three boreholes (ABH08, ABH08ii, and ABH09) during three monitoring rounds between May and July 2021, located within the Fosterstown and DANP areas as part of Phase 5 water quality monitoring. The key exceedances of available IGVs were reported for chloride (all 3 no. boreholes) and for TPH (ABH08ii) principally. Further information can be found in Appendix A20.8 – Land Contamination Interpretive Report.

19.4.10.2 AZ2 Airport Section

There were no available historical wells within this geographical area for the initial 2018/2019 baseline sampling.

Baseline groundwater quality collected for AZ2 in 2019/2020 included testing of samples at boreholes drilled for contemporary hydraulic testing works at DASP. In general, the majority of the test results were reported at less than detection with rare exceedances of analytes reported above available GTVs, and no consistent exceedances or identifiable [upward] trends in any of the data collected.

The water quality overview for the DASP area within AZ2 is generally consistent with the current GWB status and WFD risk score for the area (refer Section 19.4.6).

Baseline groundwater quality collected for AZ2 in 2021 and as part of Phase 5 monitoring included sampling at both shallow and deep screened monitoring wells installed recently, and included wells installed for pumping test works. In total, representative samples were obtained from 6 no. locations at the Dublin Airport station location (NBH04, NBH60, NBH61, NBH62, ABH10, ABH12) and 4 no. at the DASP (MN/104/BH/003, NBH06, NBH06A, NBH06W).

Some minor exceedances of the respective GTV are noted however for Dublin Airport boreholes for example hydrocarbons at shallow wells NBH60 and NBH62, and deep well NBH04 (degraded kerosene); SVOCs at shallow wells NBH60 and NBH61, and deep well NBH04 (SVOC/VOC). Other key observations include the following: The PAH congeners Benzo(a)pyrene (0.042mg/l), benzo(ghi)perylene (0.023mg/l), fluoranthene (0.054mg/l) and indeno(123cd)pyrene (0.022mg/l) were encountered at NBH60 at concentrations of approximately 50 to 4000 times higher than IGV. IGV exceedances for Total TPH were recorded at NBH04 and NBH60, with concentrations of 1.86mg/l and 1.81mg/l respectively, about 180 times the IGV. It should be noted that the distribution of individual hydrocarbon fractions was different at both boreholes NBH04 and NBH60 suggestive of different contamination sources. Additionally, these hydrocarbons were detected at different depths; the well screen interval of NBH60 is between 0.8mBGL and 1.5 mBGL and the origin of encountered hydrocarbons is likely to be related to Made Ground as elevated soil concentration of TPH (420 mg/kg) was encountered at 0.5mBGL in Made Ground. NBH04 has a well screen interval between 16mBGL and 30mBGL within the bedrock.

The following metals exceeded the relevant IGV: barium, boron, cobalt, manganese, potassium and total iron. Chloride concentrations were above screening levels (IGV) at all locations, with elevated ammoniacal nitrogen also reported at both Dublin Airport and DASP. The EQS was slightly exceeded for Biological Oxygen Demand (BOD) at two locations (DASP area and Dublin Airport). Four selected locations from Dublin Airport and the historic quarry were subjected to PFAS Total Oxidisable Precursor (TOP) analysis; all the PFAS/PFOA/PFOS compounds within the analysis suite were below the limit of laboratory detection (0.00005mg/l).

Appendix A19.3d presents a summary of the analytical results for geographical area AZ2.

Note: Chapter 20 (Soils & Geology) discusses the potential for information gaps in terms of the presence of contaminants within the subsurface and this is also applicable to the Dublin Airport site.

19.4.10.3 AZ3 Dardistown to Northwood Section

There were no available historical wells within this geographical area for the initial 2018/2019 baseline sampling and no hydraulic testing completed within this area during 2019/2020.

Baseline groundwater quality collected for AZ3 over two rounds completed in early 2021 included sampling at both shallow and deep screened monitoring wells installed recently, i.e. samples were collected at four no. representative monitoring wells. Additional groundwater sampling was undertaken (again in early to mid-2021) within the AZ3 area as part of the Phase 5 monitoring works and included boreholes AWN01, AWN02, MN/104/BH/002A, MN/104/TP/006, NBH12, NBH73-S. Exceedances of available threshold/guideline values were reported for ammoniacal nitrogen and chloride (in the majority of the samples collected). Hydrocarbons were also recorded, though the concentrations were only marginally elevated. PAHs were recorded in one sample (MN/104/BH/002A).

Similar to the observations above, reported water quality results are consistent with an urban setting. This overview is generally consistent with the current GWB status and WFD risk score for the area (refer Section 19.4.6). Appendix A19.3d presents the analytical results for geographical area AZ3.

19.4.10.4 AZ4 Northwood to Charlemont Section

Baseline groundwater quality collected for AZ4 in 2018/2019 included testing of samples at both historical monitoring wells and those boreholes recently drilled for contemporary hydraulic testing within a predominantly urban environment. In general, laboratory test results indicated localised exceedances which are indicative of 'urban setting' impacts on the underlying aquifer, for example detections of organics ('lube oil') above LOD were reported for samples collected in the city centre where 'stagnant' water and 'unprotected' monitoring well head cover was recorded. No field visual or olfactory observations with regard to the presence of hydrocarbon type contamination was noted within AZ4. In summary, there were no consistent exceedances or identifiable [upward] trends in any of the data collected for this period which would otherwise indicate possible extensive sources of contamination.

For samples collected during pumping tests undertaken in 2019/2020 few exceedances of the GTV, where available, are reported however with minor exceedances for some metals at Tara Station as well as for some major anions possibly reflecting tidal influence on local groundwater here. This overview is generally consistent with the current GWB status and WFD risk score for the area (refer Section 19.4.6).

For the most recent groundwater quality monitoring, undertaken predominantly in 2021 at boreholes installed as part of the Phase 1 - 5 works, a summary is provided below on the basis of the linear extent of area AZ4 and the number of key Project work locations within this geographical area.

19.4.10.4.1 Ballymun

Groundwater samples were collected from 3 no. boreholes (NBH203A-S, NBH203A-D, ABH25) within the Ballymun Station area during monitoring rounds completed between January - July 2021. ABH25 (Phase 5 borehole) was sampled on 3 no. occasions, NBH203A-D on 2 no. occasions and NBH203A-S once. NBH203A-S is installed with a well screen between 18.4mBGL - 18.5mBGL within a band of slightly sandy slightly clayey Gravel. NBH203A-D well screen is installed between 22.0mBGL - 35.0mBGL within the Limestone bedrock.

TPH fractions Aliphatic TPH C_6-C_{21}, Aromatic TPH C_{12}-C_{16}, Aliphatic TPC C_8-C_{16}, C_{21}-C_{35} and Aromatic TPH C_{21}-C_{35} were detected in NBH203A-D and NBH203A-S respectively during the January 2021 sampling event. Groundwater samples collected from NBH203A-D in March 2021 were reported with TPH fractions below laboratory MDL. *(Note: The recorded TPH could be related to potential historical storage tanks associated with Ballymun Shopping Centre, or an historic tank noted on mapping between 1937 and 1975 (Chapter 20 Soils & Geology). However, as the detection was not repeated during subsequent monitoring cross contamination of the initial sample during sampling or transport cannot be ruled out at this stage).*

19.4.10.4.2 Collins Avenue

Groundwater samples were collected from two boreholes within the Collins Avenue Station area namely NBH207-D and NBH102-S. Detections of chloride, manganese, and boron were reported to exceed available IGV at both monitoring locations, along with an exceedance for iron concentrations at NBH102-S. Elevated Ammoniacal Nitrogen as N was recorded for both monitoring locations.

19.4.10.4.3 Albert College Park

Groundwater samples were collected from 1 no. borehole within the Albert College Park Intervention Shaft Works area at borehole ABH30i (Phase 5 borehole). Exceedances of assessment criteria are reported for metals (selenium, manganese, potassium, boron) and inorganic compounds (ammoniacal nitrogen, BOD, chloride and nitrite) during both monitoring rounds. Potential sources of contamination have not been identified in the proposed Works Area in this location.

19.4.10.4.4 Griffith Park

Groundwater samples were collected from 4 no. [NBH] boreholes within the Griffith Park Station area namely NBH17, NBH211, NBH223-D, NBH223-S. The nitrogen species - nitrate, nitrate and ammoniacal nitrogen – together with the analyte chloride were identified at most locations; these compounds often result from organic decay and could be a result of the presence of an historical burial ground at this location. In addition, some metals (manganese, potassium boron, manganese, iron barium) have been identified. A single detection of benzene was reported at the eastern extent of the proposed Works Area (NBH223-S), no obvious source for this has been identified.

19.4.10.4.5 Glasnevin

Groundwater samples were collected from 16 no. [NBH/GBH] boreholes located within the Glasnevin Station area during four monitoring rounds. The spatial coverage of the groundwater sampling boreholes used for quality monitoring cover the station box footprint, the proposed Works Area to the west of the station box and the area within approximately 250m of the proposed Works Area. On the whole, ammoniacal nitrogen and chloride appear to be widespread above assessment criteria both within the Works Area (station box and west of station box) and adjacent to the Works Area. These determinands could result from a variety of sources including cemeteries which are present in the wider area. In addition, metals are present including iron, manganese, potassium and boron as well as elevated hardness and BOD.

19.4.10.4.6 Mater

Groundwater samples were collected from 13 no. [NBH/ABH] boreholes within the Mater Station area. With the exception of five of these locations (referenced as historical Norwest Holst monitoring points B1, C-D, E1-D, E1-S, E2 drilled and sampled back in 2008) all other groundwater samples were collected during contemporary monitoring events undertaken between January - July 2021. In summary, petroleum hydrocarbons and PAHs were identified in several locations in the groundwater at the proposed Mater Station location which may be reflective of the hydrocarbon content associated with Made Ground present. Nitrogen species (ammoniacal nitrogen, nitrite) and some metals (manganese, iron, boron and arsenic) are also reported here.

19.4.10.4.7 O'Connell Street

Groundwater samples were collected from 5 no. [NBH] boreholes within the O'Connell Street Station area, namely NBH22-S, NBH23A, NBH23W, NBH24-S and NBH23. In summary, organic contaminants were identified in the groundwater towards the south of the proposed Works Area (TPH, tetrachoroethene in NBH24-S). Elsewhere, exceedances of criteria were mainly for inorganic (nitrite, chloride, phosphorous) and metals (manganese, potassium, boron and selenium).

19.4.10.4.8 Tara Street

Groundwater samples were collected from 4 no. [NBH] boreholes within the Tara Station area, namely NBH25-S, NBH26CA, NBH26CW and NBH64. In summary, exceedances of assessment criteria were primarily for inorganic (ammoniacal nitrogen, chloride, sulphate, TDS and phosphorous) and metallic (cobalt, magnesium, manganese, nickel, potassium, sodium barium, boron, calcium, iron) contaminants, likely to be associated with the urban nature of the area.

19.4.10.4.9 St Stephen's Green

Groundwater samples were collected from 3 no. [NBH/ABH] boreholes within the St Stephen's Green Station area namely NBH219B-S, NBH219B-D and ABH53 (Phase 5 borehole). Exceedances of assessment criteria were primarily for inorganic (chloride, ammoniacal nitrogen) and metallic (iron, manganese, potassium and boron) contaminants, likely to be associated with the urban setting of the area with one instance of hydrocarbons (TPH) recorded at NBH219B-D.

19.4.10.4.10 Charlemont

Groundwater samples were collected from three boreholes within the Charlemont Station area namely NBH30W, NBH31 and ABH59. Exceedances of assessment criteria were primarily for inorganic (chloride, ammoniacal nitrogen and chloride) and metallic (manganese, boron, and potassium) contaminants, likely to be associated with the urban nature of the area.

In summary, the baseline groundwater quality results for samples collected from monitoring boreholes within the AZ4 area, which includes locations within the Dublin City Centre, are consistent with an urban setting. Exceedances of the respective GTV/ IGVs are noted at/ in the vicinity of all proposed Works Areas with only occasional reported concentrations for hydrocarbons (Ballymun, Griffith Park, Mater, O'Connell Street, St Stephen's Green). Appendix A19.3d presents the analytical results for geographical area AZ4 for Phase 1-5 ground investigation boreholes selected for sampling and testing.

19.4.11 Groundwater Levels

Groundwater levels (static water level [SWL]) were collected by the contractor for the Phase 1-4 Ground Investigation works completed for the proposed Project during 2019-2020, and for Phase 5 boreholes for 2021. The collated data included groundwater level information from proposed Project specific monitoring wells collected during/ following the ground investigation works. SWLs are measured on site to the nearest centimetre below top of casing/standpipe. A separate groundwater monitoring programme included for continuous datalogging of water levels at approx. 48 no. monitoring wells spatially along the alignment, for approximately one year. Appendix A19.4 presents the available hydrographs for monitoring wells continuously logged within AZ1-AZ4.

The following subsections present an overview of observed groundwater levels at some of the key wells located within the geographical areas AZ1 to AZ4.

19.4.11.1 AZ1 Northern Section

In general, groundwater levels for Phase 1-4 boreholes ranged from 1.6mBGL to 7.6mBGL between chainage: 1+000 & 3+900 within area AZ1 (Appendix A19.10). Groundwater level fluctuations in individual boreholes ranged from 0.3m to 1.1m over the monitoring period. The shallowest recorded groundwater depth is located close to the Broadmeadow River where the ground level is +4.0mOD. Between chainage: 3+900 & 6+050 monitoring records show that the groundwater levels ranged from 1.8mBGL to 3.4mBGL with a maximum fluctuation of 0.22m recorded in groundwater levels in both available boreholes over the monitoring period.

Specifically, at the R132 north section test area (Figure 19.8), groundwater levels are measured at four newly drilled boreholes namely NBH401 (gravel/bedrock screen), NBH402 (bedrock), NBH403 (overburden), NBH403 (bedrock), NBH404 (overburden), and NBH404 (bedrock). SWL measurements for May 2020 indicated a range of 3.92mBGL to 4.28mBGL (+3.22mOD to +3.39mOD) for the shallow overburden wells. The recorded range for the deeper bedrock wells was measured at 3.82mBGL to 4.27mBGL (+3.85mOD to +3.27mOD) and is similar to the shallow well SWL observations. Continuous datalogging of water levels includes NBH401 (gravels), NBH402 (bedrock) and NBH403 (gravels) with water levels recorded at typically 15-minute intervals and converted to elevation Malin Head.

Diagram 19.7 below presents the hydrograph for continuously monitored borehole NBH401 with the well screened specifically within the gravels, and NBH402 screened within the bedrock. The hydrographs are shown alongside the geological long section for additional context.

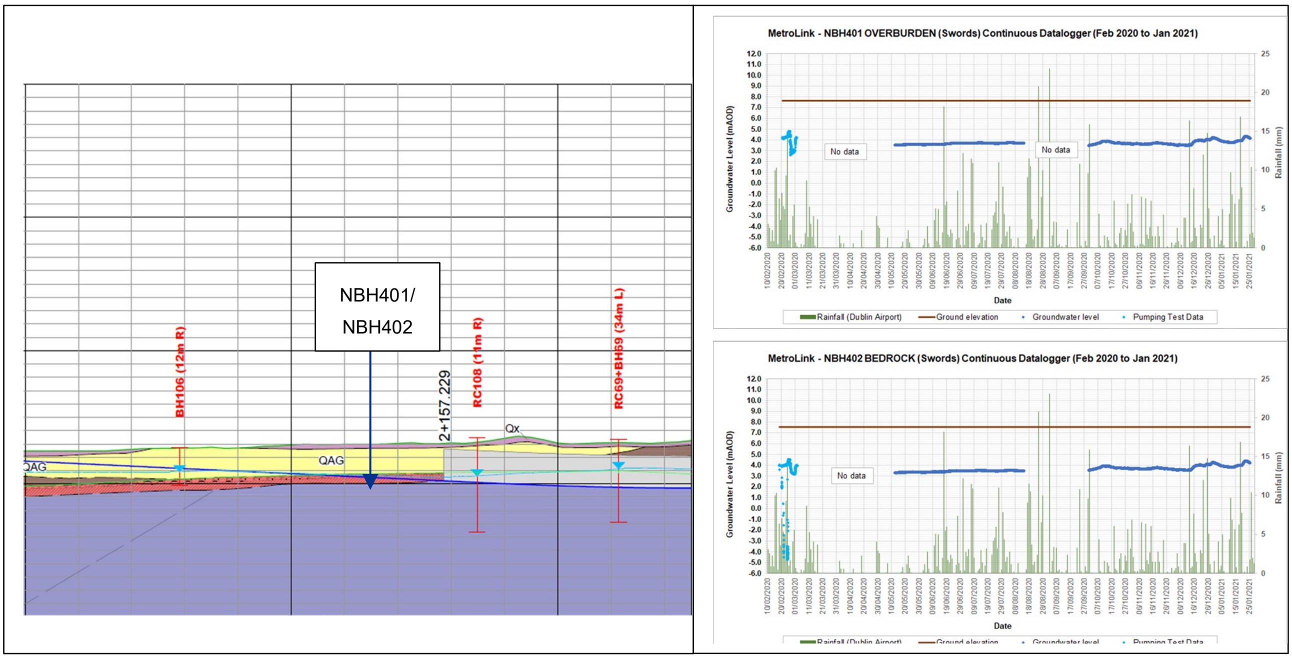

Diagram 19.7: Groundwater Hydrograph at R132 (North) -NBH401 (gravels) & NBH402 (bedrock)

At the R132 south test area (Figure 19.8), groundwater levels are measured at three newly drilled boreholes namely NBH406 (bedrock), NBH407 (bedrock), NBH408 (bedrock). SWL measurements for May 2020 indicated a range of 4.12mBGL to 5.13mBGL (+5.56mOD to +6.60mOD) for the three bedrock wells during the summer monitoring event. Continuous datalogging of water levels includes NBH401 (gravels) and NBH402 (bedrock) with water levels recorded at typically 15-minute intervals and converted to elevation Malin Head.

Diagram 19.8 presents the hydrograph for continuously monitored borehole NBH406 screened within the bedrock. The hydrograph is shown alongside the geological long section for additional context, with the well installed in the CMUP bedrock.

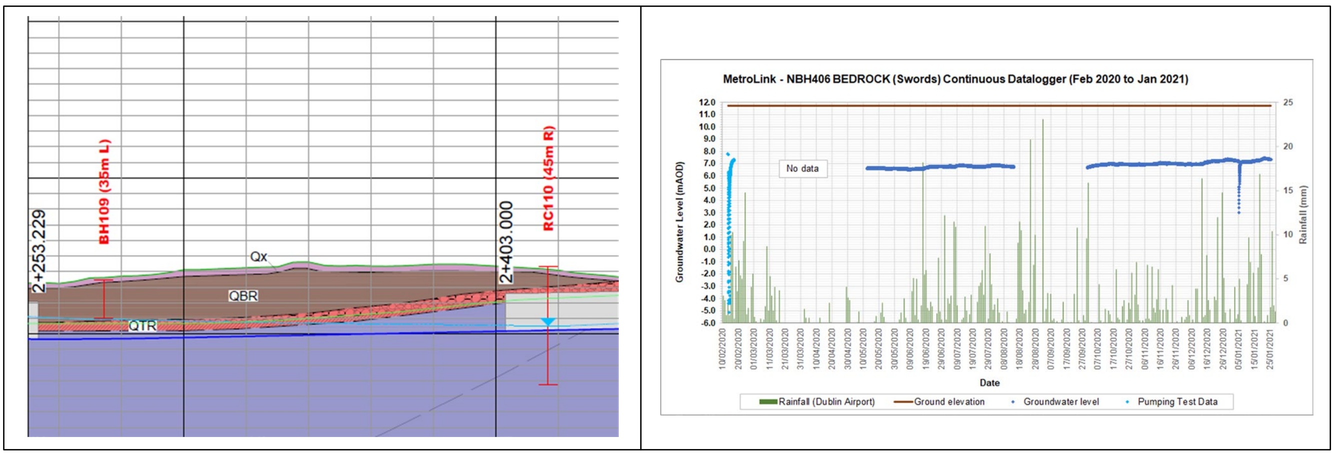

Diagram 19.8: Groundwater Hydrograph at R132 (South) - NBH406 (bedrock)

Manual measurements of water levels undertaken at selected monitoring boreholes within area AZ1 between February and July 2021 mainly and completed as part of the Phase 5 ground investigation included boreholes ABH08ii, Fosterstown (overburden; range of 1.32-1.49mBGL), ABH08, Fosterstown (overburden; range of 1.06-1.23mBGL) and ABH09, DANP (overburden; range of 5.64-8.34mBGL).

19.4.11.2 AZ2 Airport Section

Between chainages: 6+040 & 8+480, monitoring records generally show that the groundwater levels ranged from 3.1mBGL to 10.12mBGL (Appendix A19.10). The fluctuation in groundwater levels in individual installations ranged from 0.1m to 0.2m over the monitoring period. Specifically, within the AZ2, current SWL manual measurements are available for the DASP site, located to the south of Dublin Airport and the Old Airport Road; Table 19.16 summarises the field records.

Table 19.16: Groundwater Levels at DASP (Portal 2)

NBH No.	Installation Geology	Ground level (mAOD)	Monitoring Period	SWL (mBGL)	SWL (mAOD)
NBH05	Overburden	+59.80	03/12/2019-09/12/2020	5.44 to 6.01	+54.35 to +53.70
NBH05	Bedrock	+59.80	03/12/2019-09/12/2020	4.77 to 6.21	+55.03 to +53.59
NBH06A	Overburden	+60.18	03/12/2019-09/12/2020	5.01 to 6.43	+55.18 to +53.75
NBH06W	Bedrock	+60.18	03/12/2019-09/12/2020	4.70 to 6.28	+55.49 to +53.90

Continuous datalogging of water levels at DASP includes NBH05 (overburden and bedrock), NBH06A (overburden) and NBH06W (bedrock); water levels are recorded at typically 15-minute intervals and converted to elevation Malin Head. Diagram 19.9 below presents the hydrograph for continuously monitored borehole NBH06A with the well screened specifically within the gravels, and NBH06W screened within the bedrock. The hydrographs are shown alongside the geological long section for additional context. Both hydrographs indicate recorded levels which, although slightly reactionary to local meteoric recharge, do not vary significantly for the period monitored, i.e. <1m minimum variation in both gravels and bedrock wells. The boreholes are located within a predominantly agricultural tillage setting

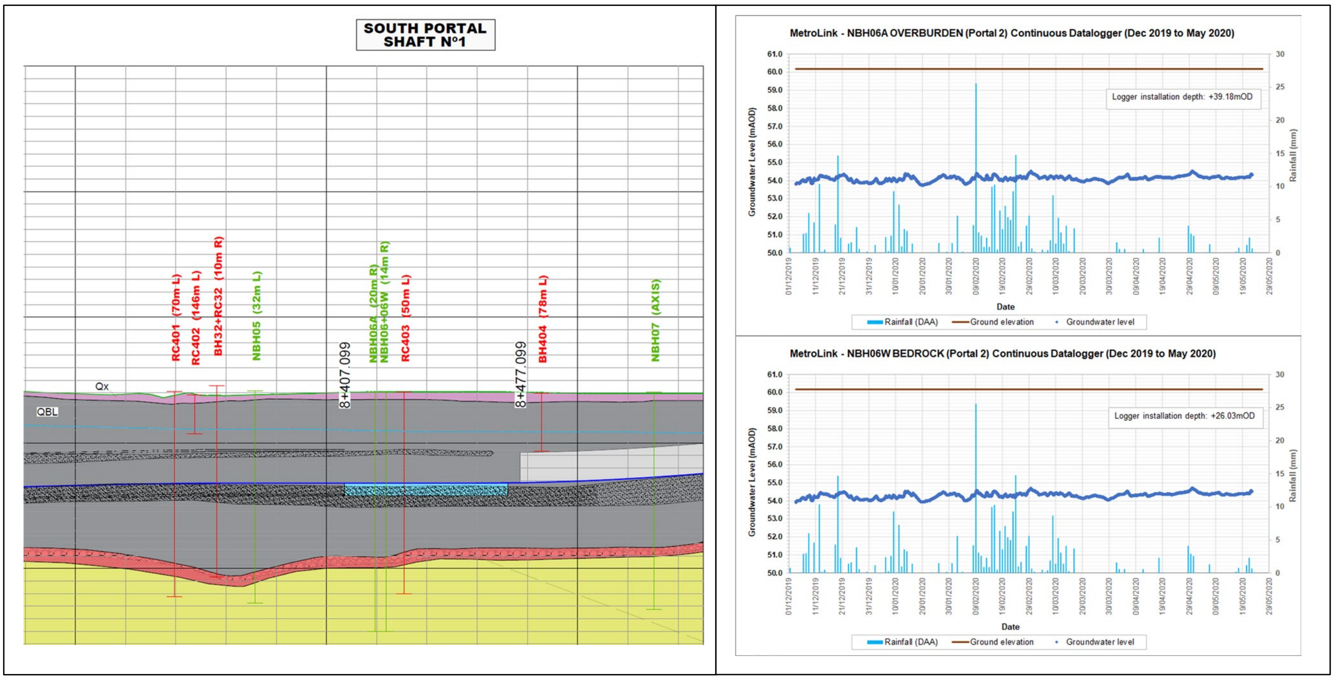

Diagram 19.9 Groundwater hydrograph at DASP - NBH06A (Gravels) & NBH06W (bedrock)

Manual measurements of water levels undertaken at selected monitoring boreholes within area AZ2 between February and July 2021 mainly and completed as part of the Phase 5 ground investigation included boreholes ABH10 (overburden/bedrock; range of 11.95-13.12mBGL), ABH12 (bedrock; range of 2.36-2.86mBGL), ABH15 (bedrock; range of 8.86-11.52mBGL) and ABH16 (overburden; range of 9.15-9.47mBGL).

19.4.11.3 AZ3 Dardistown to Northwood Section

In general, between chainages: 8+480 & 10+240 monitoring records show that groundwater levels ranged from 2.6mBGL to 11.2mBGL (Appendix A19.10). The fluctuation in groundwater levels in individual installations ranged from 0.2m to 3.7m over the monitoring period. The shallowest recorded groundwater depth was located close to the future Dardistown Station and where the ground level is approximately +61mOD. The deepest recorded groundwater depth was located close to the M50 motorway where the ground level is approximately +66mOD. Additional water level data is available for 2 no. new wells located to the west of the proposed Dardistown station with SWL details as follows:

- AWN01 (Sands/Gravels) 25/02/2021 5.74mBGL (+55.12mOD); 29/03/2021 6.04mBGL (+54.82mOD)
- AWN02 (deep, bedrock) 25/02/2021 5.92mBGL (+59.76mOD); 29/03/2021 10.25mBGL (+55.43mOD)

Specifically, monitoring wells NBH12 (deep), NBH73 (shallow and deep) and NBH202 (deep), are located within AZ3 and in close proximity to the proposed deep excavation at Northwood. Recorded SWLs are available for these monitoring wells and are presented in Table 19.17.

Table 19.17: Groundwater Level Measurements at Northwood Station

NBH No.	Installation geology	Ground level (mAOD)	Monitoring Period	SWL (mBGL)	SWL (mAOD)
NBH12	Bedrock	+59.91	10/05/2019-05/09/2019	13.10 to 14.33	+46.81 to +45.58
NBH73 (S)	Overburden	+61.89	15/07/2019-05/09/2019	8.92 to 9.90	+52.97 to +51.99
NBH73 (D)	Bedrock	+61.89	15/07/2019-05/09/2019	11.24 to 12.20	+50.65 to +49.69

NBH No.	Installation geology	Ground level (mAOD)	Monitoring Period	SWL (mBGL)	SWL (mAOD)
NBH202 (D)	Bedrock	+58.34	14/07/2020-22/10/2020	8.54 to 9.44	+49.80 to +48.90

Continuous datalogging of water levels at Northwood includes borehole NBH202 (D, bedrock); water levels are recorded at typically 15-minute intervals and converted to elevation Malin Head. Appendix A19.4 presents the hydrograph for NBH202(D).

Manual measurements of water levels undertaken at selected monitoring boreholes within area AZ3 between February and July 2021 mainly and completed as part of the Phase 5 ground investigation included borehole ABH21 (overburden/bedrock; range of 6.69-7.26mBGL) located at Northwood tunnel.

19.4.11.4 AZ4 Northwood to Charlemont Section

In general, between chainages: 10+240 & 12+300, monitoring records show that the depth to groundwater ranged from 9.7mBGL to 14.7mBGL (Appendix A19.10), with the fluctuation in groundwater levels in individual installations ranging from 0.1m to 0.2m over the monitoring period. The shallowest recorded groundwater depth was located close to the Ballymun Station where the ground level is approximately +62mOD. The deepest recorded groundwater depth was located close to the Glasnevin Station where the ground level is approximately +52mOD.

Between chainages: 12+300 & 15+700, monitoring records show that the depths to groundwater ranged from 1.3mBGL to 12.7mBGL (Appendix A19.10). The fluctuation in groundwater levels in individual installations ranged from 0m to 0.31m over the monitoring period. The deepest recorded groundwater depths were located close to the Mater Station where the ground level is approximately +17mOD.

Groundwater monitoring records for the proposed alignment between chainages: 15+700 and 20+100 show that the groundwater depths ranged from 3.4mbgl to 8.9mbgl (-0.1mOD to 8.8mOD) (Appendix A19.10). The fluctuation in monitored levels in individual installations ranged from 0m to 0.2m over the monitoring period. The shallowest groundwater depths were encountered in installations located close to the River Liffey. The deepest recorded groundwater depth was located close to the O'Connell Street Station where the ground level is approximately +5mOD. Specifically, within AZ4, SWL measurements are available for the majority of the proposed stations, and current indicative water levels are presented in Diagram 19.15 below which summarises the field records (from north to south).

Table 19.18: Groundwater Levels in Area AZ4

NBH No.	Reference Works Area	Installation geology	Ground level (mAOD)	Monitoring Period	SWL (mBGL)	SWL (mAOD)
NBH203	Ballymun	Bedrock	+62.00	23/06/2020-02-10-2020	10.06 to 10.32	+51.95 to +51.68
NBH204		Bedrock	+59.36	14/07/2020-26/10/2020	9.56 to 12.42	+48.54 to +46.94
NBH206	Collins Avenue	Bedrock	+51.95	23/06/2020-22-10-2020	8.85 to 9.38	+43.10 to 42.58
NBH207		Overburden	+50.96	23/06/2020-22-10-2020	10.98 to 11.97	+39.99 to 38.99
NBH207		Bedrock	+50.96	23/06/2020-22/10/2020	10.09 to 10.69	+40.87 to +40.27
NBH211	Griffith Park	Bedrock	+19.09	23/06/2020-22/10/2020	0.04 to 8.00	+19.05 to +11.09
NBH223		Overburden	+18.85	23/06/2020-22/10/2020	1.26 to 2.13	+17.59 to +16.72

NBH No.	Reference Works Area	Installation geology	Ground level (mAOD)	Monitoring Period	SWL (mBGL)	SWL (mAOD)
NBH223		Bedrock	+18.85	23/06/2020-22/10/2020	0.34 to 0.80	+18.51 to +18.05
NBH18	Glasnevin	Overburden	+24.25	03/12/2019-09/122020	7.09 to 8.81	+17.15 to +15.44
NBH18		Bedrock	+24.25	03/12/2019-18/08/2020	10.77 to 11.60	+13.48 to +12.65
NBH19W		Bedrock	+26.17	03/12/2019-16/12/2020	7.71 to 12.08	+18.46 to +14.09
NBH19A		Overburden	+26.10	03/12/2019-16/12/2020	8.42 to 10.58	+17.68 to +15.52
NBH215	Mater	Overburden	+22.81	23/06/2020 to 22/10/2020	15.30 to 16.23	+7.51 to +6.57
NBH215		Bedrock	+22.81	23/06/2020 to 22/10/2020	14.10 to 15.81	+8.71 to +7.00
NBH216A		Overburden	+21.99	23/06/2020	15.19	+6.80
NBH216A		Bedrock	+21.99	23/06/2020	18.30	+3.69
NBH23A	O'Connell Street	Overburden	+5.06	04/12/2019-16/12/2020	4.35 to 5.11	+0.71 to -0.04
NBH23W		Bedrock	+5.13	04/12/2019-09/12/2020	4.20 to 5.83	+0.51 to +0.33
NBH24		Overburden	+5.11	04/12/2019-16/12/2020	4.22 to 5.03	+0.82 to +0.08
NBH24		Bedrock	+5.11	04/12/2019-16/12/2020	4.43 to 5.24	+0.68 to -0.12
NBH25	Tara Street	Overburden	+3.51	04/12/2019-09/12/2020	3.14 to 3.90	+0.37 to -0.39
NBH25		Bedrock	+3.51	04/12/2019-09/12/2020	2.99 to 3.74	+0.52 to -0.23
NBH26CA		Overburden	+3.96	04/12/2019-17/12/2020	3.56 to 4.35	+0.39 to -0.39
NBH26CW		Bedrock	+4.02	04/12/2019-17/12/2020	3.47 to 4.29	0.55 to -0.27
NBH219B	St Stephen's Green	Overburden	+12.52	13/07/2020 to 22/10/2020	4.43 to 5.10	+8.09 to 7.42
NBH219B		Bedrock	+12.52	13/07/2020 to 22/10/2020	4.51 to 5.05	+8.01 to +7.47
NBH220		Overburden	+12.34	23/06/2020 to 22/10/2020	4.15 to 4.69	+8.19 to +7.65
NBH220		Bedrock	+12.34	23/06/2020 to 22/10/2020	4.15 to 6.58	+8.19 to +5.76
NBH29	Charlemont	Bedrock	+16.04	04/12/2019-03/02/2020	4.21 to 4.67	+11.83 to +11.37
NBH30		Bedrock	+15.81	04/12/2019-03/02/2020	3.09 to 4.95	+12.73 to +10.86

Continuous datalogging of water levels within the AZ4 includes approximately 38 no. locations from Ballymun to Charlemont. Monitoring includes a mix of both overburden and bedrock screened wells. Groundwater levels are recorded at typically 15-minute intervals and converted to elevation Malin Head.

Appendix A19.4 presents the available hydrographs for monitoring wells continuously logged within AZ4. However, a number of hydrographs for key deep excavation stations are included below and include Diagram 19-10 Collins Avenue Station (bedrock wells NBH206 and NBH207), Diagram 19.11 O'Connell Street Station (overburden NBH23A and bedrock NBH23W), and Diagram 19.12 Tara Station (overburden NBH26A and bedrock NBH26W). The hydrographs are shown alongside the geological long section for additional context. Potential tidal effects are also presented for Tara Station located to the south of the River Liffey.

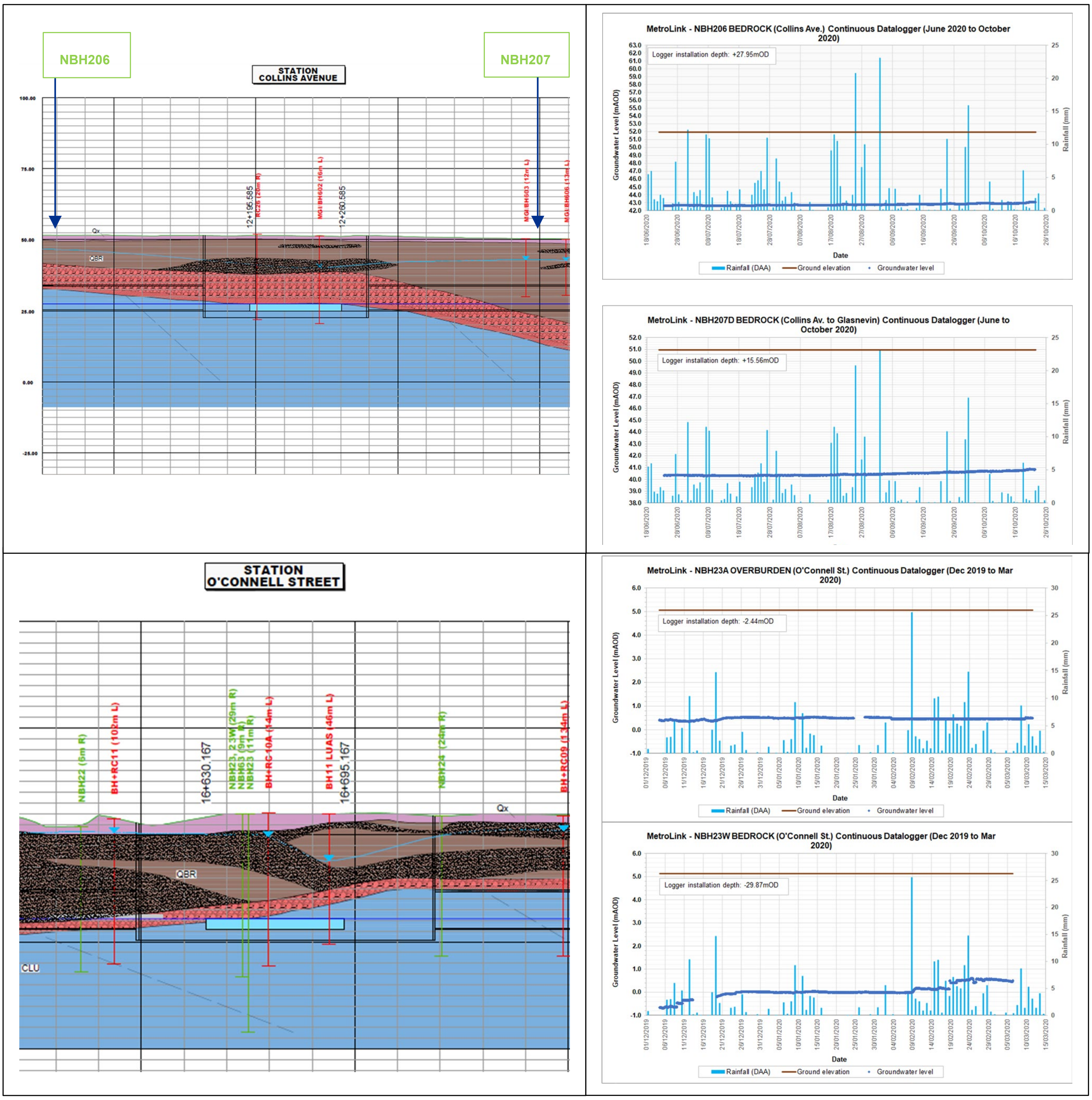

Diagram 19.11: Groundwater Hydrograph at O'Connell Street -NBH23A (overburden) & NBH23W (bedrock)

Diagram 19.11 above indicates minimal change in recorded groundwater levels for overburden well NBH23A screened within gravel strata (0.20m) for the period presented and possibly reflects the lack of localised recharge due to hardstanding ground cover in the Dublin City Centre setting. Levels are also generally above mean sea level (ordnance datum). In contrast, for the same period, recorded levels are shown to vary from -0.70mAOD to +0.60mAOD, a variation over the winter months of approx. 1.3m. Review of the data for both boreholes indicates no obvious tidal influence (i.e. very minimal change in levels - NBH23A, 55mm and NBH23W 70mm, over two days) and the more focused hydrographs do not follow the pattern observed for NBH26A and NBH26W at Tara Street to the south of the River Liffey (see below). Furthermore, the hydrographs do not indicate any effects from dewatering activities, where this occurs at nearby construction/other sites.

Diagram 19.12 below indicates a nominal change in recorded groundwater levels for overburden well NBH26A screened within gravel strata (0.65m) for the period presented, levels fluctuating near mean sea level (ordnance datum). A similar variation in levels is also recorded for NBH26W (bedrock screen) at

0.50m for the same period, with levels lying close to mean sea level (refer Diagram 19.13 below). Furthermore, the hydrographs do not indicate the effects of any dewatering activities where this occurs at nearby sites (for example near Townsend Street or Pearse Street).

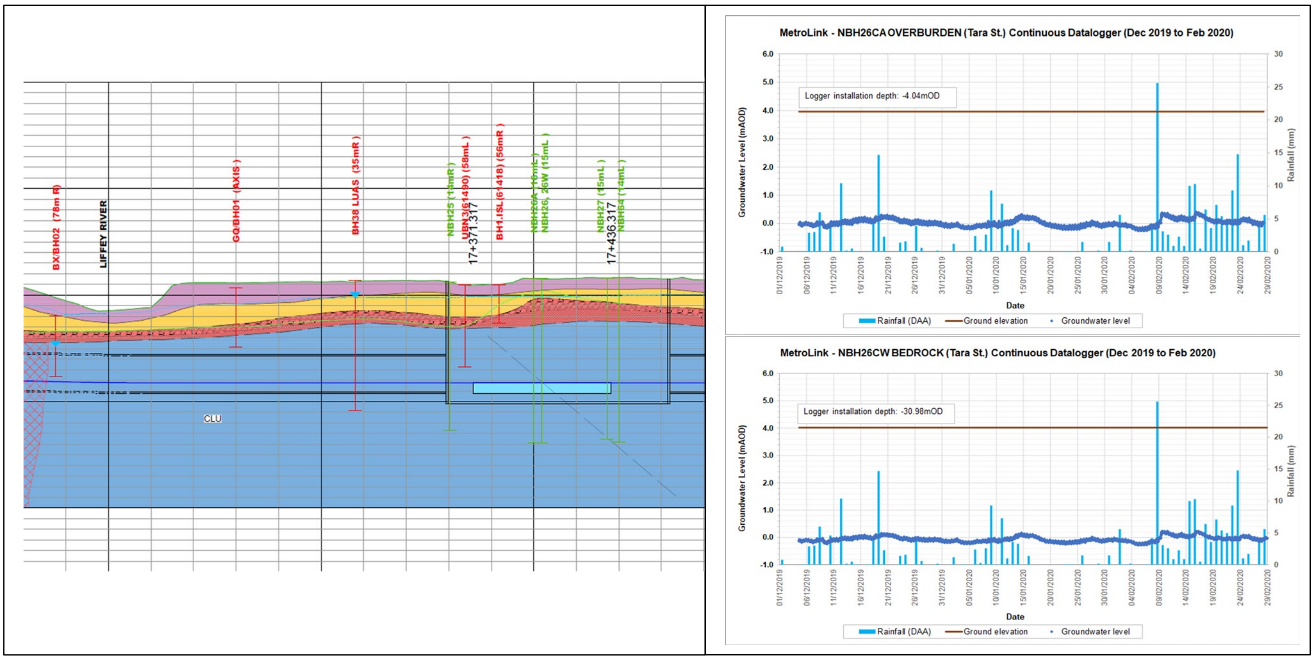

Diagram 19.12: Groundwater hydrograph at Tara Street -NBH26A (overburden) & NBH26W (bedrock)

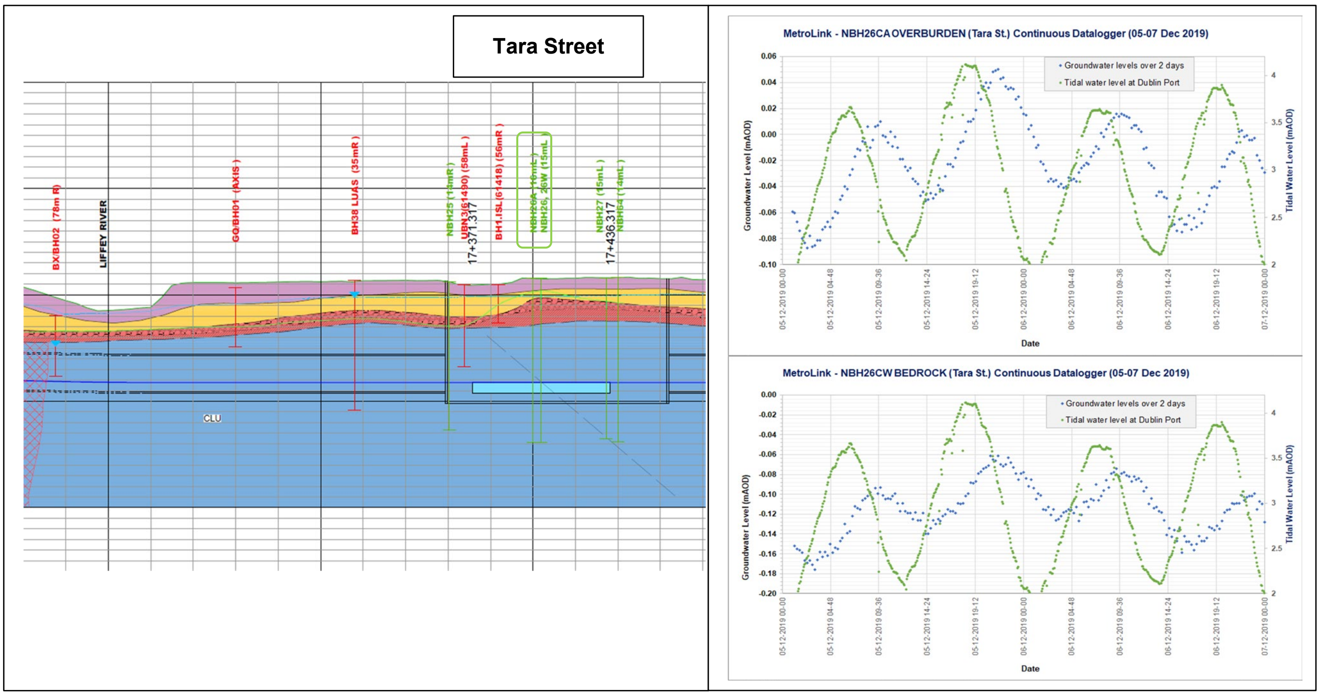

Diagram 19.13: Groundwater & Tidal Hydrograph at Tara Street -NBH26A (overburden) & NBH26W (bedrock)

Diagram 19.13 above clearly presents the effects of tidal influence at both shallow (gravels) and deep (bedrock) boreholes with a good correlation between the patterns for logged groundwater level (over two days) set against the tidal information at the nearby Dublin Port for the same period. The levels pattern for NBH26A does however indicate a better 'match' in terms of tidal effects when compared with the bedrock hydrograph which indicates a more 'delayed' response and reduced connection between the rock and the River Liffey watercourse.

Manual measurements of water levels undertaken at selected monitoring boreholes within area AZ4 between February and July 2021 mainly, and completed as part of the Phase 5 ground investigation included the following boreholes: ABH25, Ballymun (overburden/bedrock; range of 11.93-12.20mBGL), ABH26 Ballymun (bedrock; range of 8.11-8.46mBGL), ABH30i, Albert College (bedrock; single value of 6.29mBGL), ABH39, Mater (bedrock; range of 11.56-11.62mBGL), ABH40, Mater (overburden/bedrock; range of 14.10-15.07mBGL), ABH59, Charlemont (bedrock; values of 4.23mBGL, 4.33mBGL) and ABH53, St Stephen's Green (bedrock; range of 5.67-6.47mBGL).

19.4.12 Groundwater Flow Orientation Zones AZ1 to AZ4

Locally, groundwater flow orientation along the proposed Project alignment can be quite variable over relatively short distances owing to the compact nature of the geology and the influence of the Quaternary deposits. Hydraulic flow conditions in Dublin aquifers relate primarily to shallow groundwater associated with fluvio-glacial and alluvial sand and gravel deposits, and the deeper groundwater associated with the BoD as well as within the Carboniferous Limestone bedrock which is controlled by fissure permeability.

The bulk of the groundwater movement in Dublin strata occurs in the outcrop/sub-crop areas, at shallow depths, relatively rapidly along short flow paths and discharge is via springs or into stretches of the normally effluent streams/rivers where these cross the aquifers (Appendix A19.10). Groundwater elevations (mOD) confirm that groundwater flow follows the general topography and regional surface water drainage patterns. There may also be some influence on flow direction in Dublin City Centre or other urban settings for example from nearby basement construction, piling to variable depth and associated (typically short-term) dewatering effects. Regional groundwater flow towards the main rivers therefore contributes to the recharging of streams and surface watercourses in the wider area. The potentiometric surface inclination varies between 10% and 25%, with maximum slopes around the Tolka River (Appendix A19.10), with groundwater gradient ranging from 0.001 to 0.05.

Additional information on regional groundwater flow orientation is presented in the following subsections and includes reference to Hydrogeological Plans (Appendix A19.10) and detailed groundwater contour maps as presented in Appendix A19.5. The Hydrogeological Plans are presented under EIAR Figures and are based on interpretation of groundwater movement using groundwater level data for monitoring boreholes gather to date and in the context of the proposed alignment.

In summary, the detailed groundwater contour maps (where available) for each of the AZ1-AZ4 areas are consistent and cross-referenced with the interpreted groundwater flow orientation presented in the Hydrogeological Plans for the proposed Project.

19.4.12.1 AZ1 Northern Section

Within this extent of the proposed Project, in addition to glacial deposits acting as conduits for groundwater flow, the BoD/Top of Weathered Rock layer is defined as the main path for groundwater flows. There is also a fault (GSI, 2022) orientated north-west to south-east with approximate location at chainage: 3+000 and is expected to intersect the alignment to the north of Seatown Station. It is unknown whether this feature may naturally impact on regional flow patterns interpreted to be towards Malahide Estuary and the Irish Sea. Another (GSI, 2022) WSW-ENE fault runs parallel to the alignment between the Swords and Fosterstown Stations some 300m to the north of the alignment, orientated to the coast.

Detailed groundwater contour maps for the Seatown/Swords Central area including at the R132, using static water level data from 19/02/2021, indicate a general S-N orientation towards the Broadmeadow River and Malahide Estuary with the Ward River and Broadmeadow River also likely to influence the direction of groundwater flow in the vicinity of Swords.

19.4.12.2 AZ2 Airport Section

Within this extent of the proposed Project, groundwater seepage along the BoD is frequent within the coarse sandy gravel soils, and weathered rockhead. However, the Waulsortian Formation in this area is more prone to karstification than the other limestone formations encountered along the alignment which invariably will impact on flows within the underlying bedrock.

Detailed groundwater contour maps for the Dardistown (DASP) area south of Collinstown Lane (L2015), using SWL data from 19/02/2021, indicate a general north-south to south-east flow orientation for the gravels away from Dublin Airport and towards the lower lying coastal areas.

19.4.12.3 AZ3 Dardistown to Northwood Section

Similar to AZ2, groundwater seepage along the BoD is frequent within the coarse sandy gravel soils, and weathered rock along this extent of the proposed Project. Within the BoD, layers of sand and gravel were encountered locally and were observed with groundwater seepage and/or moderate inflows. No detailed flow maps were undertaken here due to the linear nature of the borehole locations.

19.4.12.4 AZ4 Northwood to Charlemont Section

The general orientation of interpreted groundwater flow in the area from Ballymun to Griffith Park is in a south to south-easterly direction towards the lower lying coastal areas. This flow orientation is likely facilitated by the presence of fluvio-glacial deposits (in addition to the BoD) that can potentially act as conduits for groundwater flow towards the Tolka River and Dublin Bay/the Irish Sea. Farther to the south, and north and south of the River Liffey, the interpreted regional groundwater flow orientation is generally towards the River Liffey and Dublin Bay.

Detailed groundwater contour maps for the proposed station at Griffith Park, Glasnevin, Mater, O'Connell Street, Tara Street and St Stephen's Green using SWL data from 19/02/2021, indicate a general flow orientation towards the River Liffey and Dublin Bay.

19.4.13 Hydraulic Testing

19.4.13.1 Existing Data on Inflows in Dublin City Centre Area

19.4.13.1.1 Historical Inflows

Data on historical inflows within the Dublin City Centre area was collated as part of the review for 'Metro North'. In general, this information is also very relevant in the context of the unchanging superficial and solid hydrogeological setting for the current proposed Project alignment. Table 19.19 provides a summary of this information with the historical details also referenced to the AZ1 to AZ4 and particular works areas associated with the proposed Project. Importantly, the details provided on pumping test data and observations made in the field provide an insight into conditions that may/may not be expected during similar excavations as part of the current proposed Project. The case studies also highlight the variability in groundwater levels and how mitigation of inflows can be achieved through effectively designed cut-off walls and pumping for example.

It is important to note, however that when consideration is given to current modelled inflows estimated for proposed station boxes and cuttings, then there will be differences in anticipated volumes of ingress water. This is primarily due to the fact that every construction site is different, and the incidence of water ingress is managed differently, and Dublin City itself has changed significantly with additional basement structures, piled foundations, increased hardstanding reducing local recharge and so on. The sites shown in Table 19.19 also refer to historical projects and construction methodologies have improved dramatically in the intervening period. Furthermore, the case studies presented below are not specifically within the Project boundary. In summary, for the MetroLink project, a significant amount of effort has been made to fully characterise the water-bearing strata through which the proposed development will advance in terms of station boxes, cuttings and tunnel alignment. The modelled Plaxis2D inflows (refer Section 19.5.3.4) are based on contemporary data from geotechnical and hydrogeological investigations with mitigation of inflows factored into all respective design features. The modelling is based on a series of field hydraulic testing phases (refer Figure 19.8) completed using monitoring wells installed as part of the Phase 1-4 GI mainly (based on the specific reference test areas). Data was collated from those tests including level data gathered from wells installed in shallow and deep horizons with nearby groundwater level observation undertaken at similar [geology] screened wells. Hydraulic testing included Step and Constant rate stages with a variety of outflows (m3/hr) applied, and over two test periods, in order to provide sufficient data to feed in to the Plaxis2D modelling exercise. In addition to the hydraulic testing, the available GI records (and Geological Long Sections) were used to define the test area strata through which groundwater flows and which fed into the objectives of the modelling works (refer also Section 19.3.6.4.1 above).

Table 19.19: Summary of Groundwater Observations from Underground Construction Case Histories in Dublin

Ref. Area	Project ID	Project details	Ground profile /depth to base of stratum (mBGL)	Pumping test information	Observations
AZ4	Custom House Docks, 1988	-Excavation depth of 7.50mbgl. -Anchored sheet pile wall seated in glacial till.	▪ Made Ground /6.0 ▪ Gravels /10.0 ▪ Glacial Till /12.0 ▪ Bedrock ▪ Groundwater /2.0-4.0	-Two well pumping tests carried out from separate wells for 24 hours with further 24-hour recovery period. -Drawdown of 4m achieved in one well (predominantly in gravel), with predicted radius of influence of 700m and calculated k = 1x 10^{-5} to 1x10^{-7}m/s.	Maximum recorded tidal variation of site area was 0.5m, compared with 4.5m in adjacent docks, suggesting reasonably water-tight river and dock walls and low permeability silt or clay in the bed of the docks and river. -Required drawdown achieved by a combination of wells and local sumps. Maximum tolerable groundwater drawdown of 1.5m at the Custom House agreed with OPW and breached only once.
AZ4	Jervis Street Shopping Centre, 1995	-Site area 0.9ha. -Excavation depth of 5.5m to 7.3mbgl. -Bored secant piled wall. Male piles toed in 0.75m to 1.5m into rock, female piles toed in 0.5m. -Excavation of centre of site commenced during installation of secant piled wall with restriction that groundwater in gravels did not drop by more than 1m.	▪ Made Ground /3.2 ▪ Alluvium /3.3 ▪ Gravels /5.5 ▪ Glacial Till /6.3 ▪ Weathered rock /6.8 ▪ Intact rock ▪ Groundwater /3.2 (i.e. 0mOD)	-One pumping well in rock and two observation wells in gravel. -Groundwater lowered by 4.4m by pumping at 68 litres/min. -Minimal effect on water level in gravels due to presence of glacial till below gravels.	Groundwater lowering achieved by pumping locally from sumps near formation level. No attempt to reduce water table across the site. -Pumping (typically from 4-6 no. pumps) was intermittent due to the nature of the weathered rock. Groundwater level maintained successfully to allow all construction in the dry. Water level drawdown in the rock was between 1m and 4m shortly after pumping began. As all adjacent structures on piled foundations to rock, no implications for building damage. Water levels in gravels generally remained relatively steady with 0.5m to 1.0m drawdown.
AZ4	Jervis Street Shopping Centre, 1995	-As above plus: significant groundwater inflow noted during sheet	-As above	-As above	Generally, groundwater level in gravels noted to be in hydraulic continuity with bedrock with the exception of 3 no.

Ref. Area	Project ID	Project details	Ground profile /depth to base of stratum (mBGL)	Pumping test information	Observations
		pile wall and excavation trial, led to decision to adopt secant piled wall with cut-off in rock; contingency plan to recharge gravels included but not required in practice.			piezometers which showed drops of up to 4m.
AZ4	Marks and Spencer, Grafton Street, 1995-1996	-Excavation depth of 7.2m. Sheet pile wall driven to top of bedrock.	▪ Made Ground /3.3 ▪ Glacial Till /5.4 ▪ Glacial Gravel /8.8 ▪ Bedrock ▪ Groundwater /4.5	-	Problems caused by the seepage of water into the site from the weathered top of the bedrock, which were solved by pumping from shallow wells and sumps. *
AZ4	Clarendon Street, 1996	-Excavation depth of 6.0m. King post wall with toe at 7mbgl and lean mix concrete onto excavated vertical faces between king posts. Water seepage a concern.	▪ Made Ground /1.0 ▪ Glacial Till /8.0 ▪ Bedrock ▪ Groundwater /4.5	-	2 out of 4 no. inclinometers recorded no movement. 1 no. inclinometer recorded 5mm of movement where the glacial till had been replaced locally by a water bearing gravel. It was found that except where the gravel was encountered, the water seepage was very small. *
AZ4	Schoolhouse Lane, 1995/1996	-Excavation depth of 5.5m. Contiguous bored pile retaining wall seated on bedrock. Significant water seepage was a concern.	▪ Glacial Till /5.6 ▪ Glacial Gravel /8.0 ▪ Bedrock ▪ Groundwater /4.2	-	No measurable movement recorded. Observed seepage was insignificant, probably due to the low permeability of the glacial till. *
AZ4	Site bounded by Westmoreland St., Fleet St. and College St., 1999	-Excavation depth of 6.3m. Bored secant piled wall. Pile toes at -4mOD (1m into intact rock).	▪ Made Ground /4 ▪ Glacial Till /6 ▪ Weathered rock /7 ▪ Intact rock ▪ Groundwater /3 (i.e. +1mOD)	-	Groundwater was pumped from sumps within the excavation. -Standpipes around the site recorded no significant change in groundwater level.
AZ4	Westin Hotel, College Street, 1999	-Excavation depth of 6.3m. Bored secant	▪ Made Ground /4 ▪ Glacial Till /6	-	Groundwater level falls by 0.7m from south to north towards River

Ref. Area	Project ID	Project details	Ground profile /depth to base of stratum (mBGL)	Pumping test information	Observations
		piled wall. -Male pile toed in at -4mOD (1m into intact rock) -Female piles toed in at -2.3mOD (0.3m into weathered rock). -Site lies 100m south of River Liffey, tidal influence on groundwater levels small (approx. 0.2m to 0.3m).	▪ Weathered rock /7 ▪ Intact rock ▪ Groundwater /3 (1mOD)		Liffey. Small decrease in groundwater level during basement works between 0m and 0.9m. Significant pumping was carried out both from sump pumps and from a submersible pump in a borehole near the centre of the site. -The secant piled wall formed an effective cut-off. Rainfall affected groundwater levels. -No tidal effect over a 24-hour monitoring period.
AZ4	Dublin Port Tunnel, 2001/2002	56.6m diameter shaft, 28m deep, formed by 1.5m thick diaphragm walls, approx. 32.5m deep.	▪ Made Ground/2 ▪ Glacial Till/25 ▪ Bedrock ▪ Groundwater/2	-	High groundwater levels controlled by dewatering from wells around the shaft during excavation.
AZ4	Dublin Port Tunnel, 2001/2002	-Construction of groundwater model for Dublin region using information gained during ground investigations for, and construction of, the tunnel.	▪ Made Ground ▪ Estuarine deposits ▪ Glaciomarine sand and gravel ▪ Glacial Till ▪ Bedrock ▪ (Depth varies)	4 No. pumping tests targeting the bedrock/glacial till interface, limestone bedrock and estuarine gravels (2 No.).	Overlying glacial tills act as a confining unit to the limestone which produces almost artesian heads within that unit. The uppermost gravels, sands and silts are transmissive sediments draining the system towards the Irish Sea. Topography is the primary driving force behind the flow system in the study domain. Recharge is linked to the depth to which flow occurs in the limestone and is limited, ultimately, by rainfall into the system. Drawdown of 2mm to 6mm was predicted in the saturated limestone above the unlined tunnel during 8-hour nightly cessations of work. **
AZ4	Smithfield, 2003	-Site area 1.2ha. Excavation depth of 10m. Anchored diaphragm wall	▪ Made Ground/3 ▪ Dense Gravels/14.8 ▪ Bedrock	-	Groundwater levels measured outside the diaphragm wall showed very little variation during the works,

Ref. Area	Project ID	Project details	Ground profile /depth to base of stratum (mBGL)	Pumping test information	Observations
		(800mm thick) founded on bedrock. -Site lies 200m north of River Liffey. -Pumping from well in centre of site to dewater the gravels and sump pumping at base of excavation as necessary.	▪ Groundwater/4		suggesting an effective cut-off was provided by the wall. -Prior to start of construction groundwater levels were typically +0.8mOD. During subsequent dewatering the level dropped to about +0.2mOD and subsequently showed a small increase towards +0.3mOD.

Notes to table:

**: Author concludes that: "Retaining walls in Dublin have often been designed with significant toe embedment in order to minimise water seepage. It has been found in practice that the seepage through the glacial clays is very small. However, significant seepage can occur through the top, weathered portion, of the bedrock".*

***: No published observations of groundwater drawdown measured during construction. However, it has been indicated that rapid reductions in head within bedrock occurred in response to relatively small initial inflow to openings during pumping tests and excavation of the tunnels. Recovery of head was rapid once the tunnel lining was constructed.*

Appendix A19.6 presents the original data in its entirety for reference.

19.4.13.1.2 Other Contemporary Sourced Data on Inflows within Dublin

As part of the data collection on groundwater inflow potential within the Dublin City Centre setting in particular, an independent hydrogeological review was completed for the area near the proposed Tara Station (chainage: 17+360 to chainage: 17+460) (Appendix A19.11). The key comments in this report scenario with respect to inflow assessment in the area to the east and west of Tara Station include the following:

- Groundwater elevation at reference Site A located ~40m west of Tara Street is +0.60mOD. Bedrock was encountered, on average, at approximately -3.1mOD. Natural ground primarily comprised (silty and sandy) gravels with areas of (clayey, gravelly, silty, fine to coarse) sand. The required excavation level was -3.7mOD and the site was surrounded by a continuous secant piled wall.
- Groundwater elevation measured at Site B located ~80m east of Tara Street was approx. +0.5mOD and was consistent with measurements from Site A. The targeted dewatering depth was approx. -3mOD and the site [B] was not surrounded by a secant pile wall.
- Site A -Dewatering works lasted for a 32-week period. The average pumping rate over this period was 0.67l/sec with weekly average pumping rates ranging from 0.3l/sec to 1l/sec. The excavation was excavated to below the bedrock surface.
- Site A -As dewatering at a rate of less than 1l/sec was sufficient to keep the site dry, this could be inferred as a conservative measure of vertical (base up) groundwater ingress.
- Site A -Several leaks and seepages through the secant pile wall were noted at the reported groundwater level. In general, failures in the secant wall will result in significantly higher inflows.
- Site B -The absence of a secant pile wall necessitated high pumping rates in order to dewater the site to the requisite level. For the duration of the dewatering phase (approx. 6 months), the average discharge flow rate was 9 l/sec, however a maximum flow rate of 22l/sec was required for periods.
- Site B -The extent and highly productive nature of the gravels and cobble bed encountered above rock is noted. Significant ingress was encountered in the SW corner of the excavation. It must be noted that the main excavation was approximately 500m^2 in area and only partially penetrated the gravel. Hence, greater flows would be expected from a deeper excavation at this location.

- Site B -Dewatering excavations such as these requires telemetric monitoring and an automated alarm system to ensure continuous pumping is maintained and to ensure that all discharged water is compliant with the pertinent discharge licence limits.
- Groundwater flow direction at both sites is anticipated to flow northwards towards the River Liffey with tidal influences likely.
- Over a five-month period on a construction site at Sir John Rogerson's Quay (located further east) the highest range of tidal variance was recorded between 0.79m to 1.3m. Tidal influences would be expected to be more pronounced in the gravel overburden if hydraulically connected to the River Liffey or historical riverine deposits such as those associated with the Stein River and Gallows River which are presumably culverted nearby; their location, course and depth should be ascertained.
- Groundwater ingress is fundamentally controlled by the completeness and integrity of the secant pile wall and position with respect to bedrock.
- Vertical ingress from the Limestone bedrock adjacent to the proposed site was <1.0l/s. This is consistent with the authors' experience in Dublin City Centre. Greater levels of ingress have however, been observed on construction sites where bedrock faults are encountered.

Specifically comparing the historical pumping rates found in Hydrogeological Review for Tara Street and Swords Central (Appendix A19.11) above with the modelled inflow rates derived from Plaxis2D modelling then some similarities are observed for the Tara Station area. For example, Site A, with a secant pile wall, a [manageable] inflow of up to 1l/sec is presented whereas for Tara Station (Plaxis2D), also with secant piled wall, an inflow of 2.91l/sec is modelled reducing to 0.42l/sec where a bottom grout plug is applied. This latter modelled inflow rate approximates the higher (non-secant pile wall) scenario, Site B located to the east of the proposed Tara Station and which may have intercepted buried tributaries associated with the historical Gallows water course (refer also Section 19.4.3).

Specific reference is made by Appendix A19.11 to dewatering in more cohesive boulder clays and reference is made to Swords Central for comparison in terms of different hydrogeological settings. The authors cite a scenario typical of the geology found towards the north of the alignment, where the excavation was completed to a depth of approx. -5mOD (9m below ground level) with a piled secant wall surrounding the site. For the duration of the dewatering works (approx. 15 months) the average weekly dewatering pumping rate was approx. 320m^3 per week (or approximately 0.5l/sec). A comparison with the [Plaxis2D] modelled scenario for Swords Central (with a secant piled wall) indicates approx. 0.69 l/sec modelled reducing to 0.09l/sec where a bottom grout plug is applied.

Appendix A19.11 states that due to the reported aquitard nature of the boulder clay the overburden inflows are likely to be low. It is envisaged that less water will be encountered during the excavation of the station at Swords Central compared to the deep excavation of the station box at Tara Street.

19.4.13.2 Pumping Tests Undertaken for the proposed Project

Hydraulic testing was completed for cut sections and specific underground station locations along the alignment as summarised in Table 19.20. A number of observation boreholes were installed in addition to the pumping borehole which was tested on two separate occasions with the aim of studying groundwater inflow potential during cut/station box construction within representative hydrogeological settings along the alignment. The hydraulic testing programme, completed on newly drilled Phase 1 & Phase 3 boreholes, allowed confirmation of local aquifer characteristics, identification of the likely impact on the natural groundwater regime within the local area and provided an assessment for determining likely modelled discharge rates during the Construction Phase of the proposed Project. It is critical to understand the likely behaviour of the aquifer in advance of any construction excavations in order to estimate potential for lateral seepages, upwelling, barrier effects and other water-related issues which could originate during and after construction.

The testing programme consisted of different seasonal periods (where possible) and comprised 24 no. pumping tests (Test Areas 1-5 and R132 - North and South areas) with Step Tests and follow-on constant rate test (CRT) of three-day duration typically (reduced only where significant outflow was recorded as consistently high). Each CRT was followed by a nominal 24-hour Recovery period to assess natural non-pumped rebound effects. In order to validate the Plaxis2D modelling for inflows at station boxes, the pumping test data was used for the purpose of calibration in addition to the stratigraphy defined for the geological profiles at the modelled stations.

Data from pumping tests also inform dewatering modelling with more specific reference to the incidence of Glacial granular (Sand/Gravel) deposits rather than solid (Limestone) geological ground conditions. As such, dewatering modelling (refer also Section 19.5.3.4) must be considered alongside ground settlement modelling, as the removal of groundwater from porous material will invariably lead to spatial settlement issues. Data collected from pumping tests have facilitated this additional interpretation for the proposed Project.

Note: While ground settlement is directly related to reduced groundwater levels, pore water pressure release, loss of fines through dewatering and so on, it is a geotechnical matter primarily and is discussed separately in greater detail as part of a Settlement Study which is also discussed in EIAR Chapter 20 (Soils & Geology). Notwithstanding this, as settlement is intrinsically linked to hydrogeological and geological interpretation and the conceptual site understanding for the proposed Project, reference is duly made to settlement throughout this Chapter.

Table 19.20: Summary of Pumping Tests Completed along the Proposed Alignment

Ref. Area/Chainage (Approx.)	Date	Pumping Test No.	Test Type (Rock/Soil)	Pumping Well ID	Observation BH ID	Max Flow Applied (m^3/s)	Max Drawdown (mBGL)	Max COD before construction = pumping test (m)	Max cone during construction dewatering prior to toe-grouting (m), Plaxis2D	Max cone of depression post grouting (m) and prior to final sealed structure, PLAXIS2D	Permeability (m/s)	Recovery Characteristics	Risk Level Applied
AZ1 Seatown R132 North/2+130	25/02/2020	**1**	S	NBH401	NBH403, NBH404, NBH405	3.69E-04	5.3	49.71	56.80	45.33	*(1.08E-06)*	Regional aquifer has high water level recovery characteristics, typically with a rate of 1metre per min observed for wells screened in rock. (Recovery in subsoils - N/A as limited drawdown in water table prior to rebound).	H
	20/02/2020		R	NBH402	NBH403, NBH404, NBH405	7.5E-04	12.19	35.19	56.80	45.33	3.80E-08		H
AZ1 Seatown R132 South/2+390	13/02/2020	**1**	R	NBH406	NBH407, NBH408	8.0E-04	16.14	30.99	56.80	45.33	3.80E-08		H
AZ1 Seatown R132 North/2+130	23/09/2020	**2**	S	NBH401	NBH403, NBH404, NBH405	1.44E-03	5.42	40.72	56.80	45.33	*(1.08E-06)*		H
	21/09/2020		R	NBH402	NBH403, NBH404, NBH405	1.10E-03	12.82	35.14	56.80	45.33	3.80E-08		H
AZ1 Seatown R132 South/2+390	16/09/2020	**2**	R	NBH406	NBH407, NBH408	1.00E-04	16.93	30.68	66.79	46.35	-		H

Ref. Area/Chainage (Approx.)	Date	Pumping Test No.	Test Type (Rock/Soil)	Pumping Well ID	Observation BH ID	Max Flow Applied (m^3/s)	Max Drawdown (mBGL)	Max COD before construction = pumping test (m)	Max cone during construction dewatering prior to toe-grouting (m), Plaxis2D	Max cone of depression post grouting (m) and prior to final sealed structure, PLAXIS2D	Permeability (m/s)	Recovery Characteristics	Risk Level Applied
AZ2 PORTAL 2/ 8+420	06/05/2019	**1**	R	NBH06W	NBH6A, NBH5S, NBH5D, NBH7S, NBH7D	2.44E-03	43.66	10.92	-	-	7.37E-07	In the bedrock layers the aquifer recovers to initial SWL very quickly; in 3 (three) hours the drawdown went from 41m to 7m. Similar recovery is observed in granular subsoils	H
	19/06/2019		S	NBH06A	NBH6, NBH5S, NBH5D, NBH7S, NBH7D	8.33E-03	19.12	9.98	-	-	9.86E-07		
	25/06/2019		S	NBH06A	NBH6, NBH5S, NBH5D, NBH7S, NBH7D	8.33E-03	19.19	9.98	-	-	9.86E-07		
AZ2 PORTAL 2/ 8+420	08/09/2020	**2**	S	NBH06A	NBH05, NBH07	5.30E-04	21.01	44.69	-	-	-	-	H
	02/09/2020		R	NBH06W	NBH05, NBH07	1.39E-03	43.92	12.62	-	-	-		H

Ref. Area/Chainage (Approx.)	Date	Pumping Test No.	Test Type (Rock/Soil)	Pumping Well ID	Observation BH ID	Max Flow Applied (m³/s)	Max Drawdown (mBGL)	Max COD before construction = pumping test (m)	Max cone during construction dewatering prior to toe-grouting (m), Plaxis2D	Max cone of depression post grouting (m) and prior to final sealed structure, PLAXIS2D	Permeability (m/s)	Recovery Characteristics	Risk Level Applied
AZ4 Glasnevin/14+850	07/09/2019	1	S	NBH19A	NBH 19 NBH 18S NBH 18D NBH 20S NBH 20D	3.89E-04	17.30	183.63	180.88	107.35	1.48E-06	Recovery occurs at an order of 7.2 meters per day, so it is considered fast and consistent with strata for Charlemont	M
	15/07/2019		R	NBH19W	NBH 19A NBH 18S NBH 18D NBH 20S NBH 20D	3.89E-04	35.10	103.18	180.88	107.35	1.22E-06		
AZ4 Glasnevin/14+850	19/06/2020	2	R	NBH19W	NBH19A	5.60E-04	37.20	180.03	180.88	107.35	1.22E-06		H
	18/06/2020		S	NBH19A	NBH19W, GBH04 S, GBH04 D, NBH20 S, NBH20 D, GBH01 S, GBH01 D	3.30E-04	16.81	382.53	180.88	107.35	1.48E-06		
AZ4 O'Connell Street/16+650	28/07/2019	1	R	NBH23W	NBH 23A NBH 22S NBH 22D NBH 24S NBH 24D	3.78E-03	32.94	30.42	175.20	124.49	3.15E-06	Recovery is similar to the Portal 2 aquifer, very fast and at an order of	H

Ref. Area/Chainage (Approx.)	Date	Pumping Test No.	Test Type (Rock/Soil)	Pumping Well ID	Observation BH ID	Max Flow Applied (m³/s)	Max Drawdown (mBGL)	Max COD before construction = pumping test (m)	Max cone during construction dewatering prior to toe-grouting (m), Plaxis2D	Max cone of depression post grouting (m) and prior to final sealed structure, PLAXIS2D	Permeability (m/s)	Recovery Characteristics	Risk Level Applied
AZ4 O'Connell Street/16+650	12/03/2020	**2**	S	NBH23A	NBH23W	1.33E-02	10.50	18.21	175.20	124.49	1.23E-05	3.5 metres per minute	H
	18/03/2020		R	NBH23W	NBH23A	5.28E-02	30.58	18.85	175.20	124.49	3.15E-06		
AZ4 Tara Street/ 17+410	18/09/2019	**1**	R	NBH26W	NBH26A	2.50E-04	31.73	4.79	176.45	134.27	1.13E-07	Recovery cannot be measured properly due to minimal reductions in WL measured during pumping	H
AZ4 Tara Street/ 17+410	03/03/2020	**2**		R		NBH26W		NBH26A		*Data range reported as similar to initial test 1 (18/09/2019)*			H
AZ4 Charlemont /19+330	14/05/2019	**1**	R	NBH30W	NBH29 NBH30 RC01 RC02	4.00E-03	34.30	73.71	134.95	104.67	8.34E-07	The bedrock aquifer recovers quickly, at an order of 8 metres /day	M
AZ4 Charlemont /19+330	05/02/2020	**2**	R	NBH30W	NBH29 NBH30 RC01 RC02	5.27E-03	32.25	66.66	134.95	104.67	8.34E-07		M

Notes: R = Test undertaken in bedrock; S = Test undertaken in granular subsoils (Gravels). COD = Interpreted cone of depression (or ZOI) at the maximum drawdown indicated. Plaxis2D = hydro-geotechnical modelling software used. Risk Level = the interpreted risk scale applied to each test area shown (see Section 19.5.3.5 below). In the majority of cases, the maximum outflow applied during the pumping test phase was observed to decrease over the full test duration during both test stages.

The radius/cone of depression, COD (also referred to as the ZOI in terms of impact potential) depends on the parameters of the aquifer, T (Transmissivity) and S (Storage coefficient) in addition to the pumping outflow rates applied during testing, and duration of that test. The COD can therefore increase with prolonged pumping times with higher values observed especially in highly transmissive aquifers. In Table 19.20, the results of pumping tests have been extrapolated to the different station areas where hydraulic testing was not undertaken but which have similar geological setting in order to estimate the likely COD radius before construction works.

With regard to initial assessment of potential risk arising from pumping within the immediate periphery of the test areas listed, Table 19.20 also presents a risk level (Key: L=Low, M=Medium, H=High). The risk scale is based on qualitative assessment at this stage (further assessment is provided in Section 19.5.3.5 below) with consideration of following criteria:

- The potential seepage rates and which is directly related to water-bearing granular lenses present.
- The relative thickness of the subsoil/rock layer at the test area from contemporary exploratory boreholes.
- The possibility of a 'barrier effect' caused by the construction site presented.
- The spatial/environmental setting in which the construction site is located, for example residential setting/countryside area.

Specifically, with regard to all proposed stations located within Dublin City Centre, due to the presence of historic buildings/monuments for example, the risk level is considered to be high.

19.4.13.2.1 AZ1 Northern Section

A series of pumping tests was undertaken at locations near Seatown and adjacent to the proposed cut sections at the R132, with test wells screened within both the overburden and bedrock. Table 19.20 highlights the key data for two no. separate pumping tests undertaken at Seatown R132 North (chainage: 2+130) and Seatown R132 South (chainage: 2+390) in February 2020 and again in September 2020. Overall, the maximum drawdown (mBGL) achieved at Seatown R132 North for the Gravels borehole was ~5.4m and ~12.8m for the well screened in the bedrock, with both target drawdown depths achieved at a generally reducing outflow rate over the full duration of each test. The maximum drawdown (mBGL) achieved at Seatown R132 South for the bedrock borehole (no gravels well) was ~16.9m with the target drawdown depth achieved at a generally reducing outflow rate over the full duration of each test.

Based on the results of the pumping tests and interpreted regional flow direction, a qualitative Risk Level 'H' is applied here. The two test areas at the R132 are located within an area where the possibility of a 'barrier effect' exists (refer Section 19.5.3.6).

19.4.13.2.2 AZ2 Airport Section

A series of pumping tests was undertaken at DASP with test wells screened within both the overburden and bedrock. Table 19.20 highlights the key data for two no. separate pumping tests undertaken at DASP (chainage: 8+420) in June 2019 and again in September 2020. Overall, the maximum drawdown (mBGL) achieved at DASP for the [significant water-bearing] Gravels borehole was ~21m (using a 35m3/hr pump size capacity) and ~44m for the well screened in the underlying bedrock, with the target drawdown depth achieved at the bedrock well only, and at a generally reducing outflow rate over the full duration of the test.

Based on the results of the pumping tests, water-bearing granular lenses and interpreted regional flow direction, a qualitative Risk Level 'H' is applied here. The test area is located within an area where the possibility of a 'barrier effect' exists (refer Section 19.5.3.6).

19.4.13.2.3 AZ3 Dardistown to Northwood Section

There were no pumping tests undertaken within this section of the proposed Project. The section of the proposed alignment in AZ3 is predominantly at grade/elevated with the exception of the DASP and to the immediate north of Northwood Station. The future station at Dardistown will be founded within the

QBL subsoils. Notwithstanding this, the Dardistown site is also in close proximity to AZ2 for which hydraulic testing has been completed.

19.4.13.2.4 AZ4 Northwood to Charlemont Section

Glasnevin

A series of pumping tests was undertaken at Glasnevin with test wells screened within both the overburden and bedrock. Table 19.20 highlights the key data for two no. separate pumping tests undertaken at Glasnevin (chainage: 14+850) in July/September 2019 and again in June 2020. Overall, the maximum drawdown (mBGL) achieved at Glasnevin for the Gravels borehole was ~17.3m and ~37.2m for the well screened in the underlying bedrock, with both target drawdown depths achieved at steady state but followed by a generally reducing outflow rate over the full duration of each test.

Based on the results of the pumping tests and spatial/environmental setting for Glasnevin, a qualitative Risk Level 'M' is applied here.

O'Connell Street

A series of pumping tests was undertaken at O'Connell Street with test wells screened within both the overburden and bedrock. Table 19.20 highlights the key data for two no. separate pumping tests undertaken at O'Connell Street (chainage: 16+650) in July 2019 and again in March 2020. Overall, the maximum drawdown (mBGL) achieved at O'Connell Street for the [significant water-bearing] Gravels borehole was ~10.5m (using a 50m3/hr pump size capacity, and 24-hour test only) and ~32.9m for the well screened in the underlying bedrock. The target drawdown depths were generally achieved at both wells, with a reducing outflow rate observed at the bedrock borehole only, over the full duration of each test.

Based on the results of the pumping tests, water-bearing granular lenses, spatial/environmental setting and interpreted regional flow direction, a qualitative Risk Level 'H' is applied here. The test area is located within an area where the possibility of a 'barrier effect' exists (refer Section 19.5.3.6).

Tara Street

A series of pumping tests was undertaken at Tara Street with test wells screened within both the overburden and bedrock. Table 19.20 highlights the key data for two no. separate pumping tests (bedrock here as very low flows in the overburden borehole) undertaken at Tara Street (chainage: 17+410) in September 2019 and again in March 2020. Overall, the maximum drawdown (mBGL) achieved at Tara Street for the bedrock borehole was ~31.7m. The target drawdown depth was generally achieved at the bedrock well (and at the gravel well) however with a reducing outflow rate observed over the full duration of each test.

Based on the results of the pumping tests, spatial/environmental setting and interpreted regional flow direction, a qualitative Risk Level 'H' is applied here. The test area is located within an area where the possibility of a 'barrier effect' exists (refer Section 19.5.3.6).

Charlemont

A series of pumping tests was undertaken at Charlemont with a single test well screened within the bedrock (overlying geology comprises QBR >10m). Table 19.20 highlights the key data for two no. separate pumping tests undertaken at Charlemont (chainage: 19+330) in May 2019 and again in February 2020. Overall, the maximum drawdown (mBGL) achieved at Charlemont for the bedrock borehole was ~32m. The target drawdown depth was achieved at the bedrock well on both occasions however with a reducing outflow rate observed over the full duration of each 72-hour test.

Based on the results of the pumping tests and spatial/environmental setting, a qualitative Risk Level 'M' is applied here.

19.4.14 Surface Water Courses and Groundwater Interaction

Groundwater may potentially contribute to baseflow at surface water courses identified along the proposed alignment during the baseline assessment, but where baseflow is possible, the degree of contribution from groundwater is not fully determined and will be contingent on the local hydrogeological setting. In general, PL (poor aquifers) provide little groundwater for water supply or for baseflow to surface water bodies. Furthermore, baseflow contribution to watercourses is typically a function of a high-water table in the area of that surface water flow. Table 19.21 summarises the key hydrological attributes along the proposed alignment and includes a brief description of the setting of that respective watercourse in terms of local hydrogeology and potential for connectivity with the underlying water-bearing overburden strata and/or bedrock. Data also follows information available at the EPA (2021) and GSI (2022).

Table 19.21: Summary Description of Hydrology Attributes along the Proposed Project

Ref.	Waterbody Name	Location with regard to Proposed Alignment	Approx. Chainage	Geology at/near Feature Crossing Point	Summary Description/Comments
AZ1	Staffordstown Stream (south of Turvey River)	North of Estuary P&R	NE of chainage: 1+000	QBR over Top of Weathered Rock/CMUP bedrock	Often incorrectly referred to as the Turvey River which flows farther north of the Staffordstown Stream. This stream is located to the north/north-east of the alignment with proposed [Operational Phase] treated and attenuated surface water discharged to it via a connection with the Lissenhall Great tributary at design catchment A1. Watercourse likely set in (undifferentiated) alluvium/low permeable limestone tills, poorly drained. Hydraulic connectivity with bedrock unknown; M groundwater vulnerability.
AZ1	Lissenhall Great Stream	North/north-east of Estuary P&R	NE of chainage: 1+000	QBR over Top of Weathered Rock/CMUP bedrock	Tributary of the Staffordstown Stream east of Project boundary, >250m NE of [above ground] tracks. Watercourse likely set in [relatively thin] low permeable limestone tills, poorly drained subsoils. Hydraulic connectivity with bedrock unknown; M groundwater vulnerability.
	Broadmeadow River	Between Estuary and Seatown Stations	1+540	QBR over Top of Weathered Rock/CMUP bedrock	Proposed alignment crosses directly over both the Broadmeadow River and Ward River to the west of the existing Lissenhall Bridge and Balheary Bridge; crossing is at surface i.e. a [FRA-modelled] spanning viaduct. Watercourse likely set in/connected to (undifferentiated) alluvium over boulder clay (1.00-6.00mBGL). H groundwater vulnerability, potential hydraulic connectivity with bedrock but not proven.
	Ward River	Between Estuary and Seatown Stations	1+640	QBR over Top of Weathered Rock/CMUP bedrock	See above comment on proposed Ward River crossing. Watercourse shown as set in (Made Ground -undefined) (GSI, 2022) however the feature is underlain by/connected to alluvium and gravels near the confluence with the Broadmeadow River. Potential for hydraulic connectivity with bedrock unknown and thicker sequence of boulder clay (compared with Broadmeadow) with M groundwater vulnerability. Outcrop noted in Swords Village.

Ref.	Waterbody Name	Location with regard to Proposed Alignment	Approx. Chainage	Geology at/near Feature Crossing Point	Summary Description/Comments
	Seapoint stream	North-east of Seatown	2+540	Qx over QBR/CMUP bedrock	Minor watercourse is not crossed directly by proposed alignment. Watercourse is likely fully culverted from Mantua to Malahide Estuary discharge point. Geological setting indicated by GSI as predominantly made ground overlying Irish Sea Till derived from Limestones
	Greenfields Stream	East of Seatown Station	3+040	Qx over QBR/CMUP bedrock	Watercourse is not crossed directly by proposed alignment; headwaters likely culverted. This stream flows directly to Malahide Estuary. Geological setting indicated by GSI as predominantly made ground overlying low permeable till derived from Limestones
	Swords Glebe	West of Swords Central Station	3+840	Qx over QBL/CMLO bedrock	Tributary of the Ward River and is not crossed directly by the proposed alignment. Geological setting is predominantly low permeable tills with occasional superficial lacustrine deposits.
	Gaybrook River	East of Fosterstown and Swords Central Stations	4+780	Qx over QBL/CMLO bedrock	The Gaybrook River is not crossed directly by the proposed alignment, however the smaller Gaybrook Stream located farther to the north is intersected by the retained cut section of the alignment just north of Fosterstown. Geological setting at watercourse near Station is predominantly low permeable till (black boulder clay) derived from Limestones
	Sluice River/Forrest Little Stream	Between Fosterstown and Dublin Airport Stations	5+960; 5+770	Qx over QBL/CMUP bedrock	The Sluice River and its tributary Forrest Little Stream (to the north of the Sluice) are both crossed directly by the proposed alignment, north of the Naul Road. Geological setting (with connectivity) at both watercourses is alluvium and gravels underlain by predominantly [regional] low permeable Till (black boulder clay) derived from Limestones; H groundwater vulnerability however thick (~16m) sequences of black boulder clay prevail here which will likely negate any connectivity with the bedrock.

Ref.	Waterbody Name	Location with regard to Proposed Alignment	Approx. Chainage	Geology at/near Feature Crossing Point	Summary Description/Comments
AZ2	Marshallstown Stream/Commons East	Between Fosterstown and Dublin Airport Stations	5+740	Qx over QBL/CMUP bedrock	Tributaries of the Sluice River; both are not crossed directly by the proposed alignment.
	Cuckoo Stream	South-east of Dublin Airport	7+770	Qx over QBL/CTO bedrock	The open section is not crossed directly by the proposed alignment however the tunnel alignment may cross beneath culverted sections of this watercourse within the airport grounds. Geological setting is low permeable Tills.
AZ3	Mayne River	Between Dublin Airport and Dardistown Stations	8+960	Qx over QBL/CTO bedrock	Headwaters of the Mayne River are directly crossed by proposed depot footprint and surface track alignment. Geological setting is low permeable Tills. L groundwater vulnerability with thick (~13m) sequences of black boulder clay.
	Santry River	Between Dardistown and Northwood Stations	9+980	Qx over QBR & QBL/CLU bedrock	Proposed alignment crosses directly over the Santry River to the immediate east of the M50 interchange with the Naul Road/Ballymun Road at incline alignment. Geological setting is low permeable Tills. L groundwater vulnerability with thick (~13m) sequence of brown boulder clay.
AZ4	Bachelors Stream	West/south-west of Collins Avenue Junction (DCU)	13+160	Qx over QBR/CLU bedrock	Tributary of the Tolka River and is not crossed directly by the proposed alignment. Geological setting is alluvium over low permeable Tills.
	Tolka River	Between Griffith Park and Glasnevin Stations	13+920	QBR/CLU bedrock	The proposed alignment crosses beneath the Tolka River at Saint Mobhi Road at tunnel alignment. Geological setting is alluvium (connectivity) underlain by [possibly thin sequence] low permeable Tills. H groundwater vulnerability (GSI, 2022) with potential for hydraulic connectivity with bedrock but unknown (drilling indicates stiff boulder clay locally).
	Royal Canal	Between Glasnevin and Mater Hospital Stations	14+950	Qx over QBR/CLU bedrock	The proposed alignment crosses beneath the Royal Canal at tunnel alignment. Geological setting is low

Ref.	Waterbody Name	Location with regard to Proposed Alignment	Approx. Chainage	Geology at/near Feature Crossing Point	Summary Description/Comments
					permeable tills (thick sequence). L groundwater vulnerability: canal feature is a historically 'sealed' entity.
	River Liffey	Between O'Connell Street Station and Tara Station	17+200	Qx over QAG/CLU bedrock	The proposed alignment crosses beneath the River Liffey at tunnel alignment. Geological setting is predominantly alluvium with variable permeability (connectivity) i.e. approx. 10m of alluvial sands and gravels indicating greater potential for hydraulic connectivity with the Calp bedrock below despite regional L-M groundwater vulnerability.
	Grand Canal	Between St Stephen's Green and Charlemont Stations	19+250	Qx over QBR/CLU bedrock	The proposed alignment crosses beneath the Grand Canal at tunnel alignment. Geological setting is low permeable Tills. M groundwater vulnerability: canal feature is a historically 'sealed' entity.
	River Dodder	East of Charlemont Station	19+340	Qx over QBR/CLU bedrock	The Dodder is not crossed directly by the proposed alignment. Geological setting is alluvium and low permeable Tills.
	River Poddle	West of Charlemont Station	19+720	Qx over QBR/CLU bedrock	The Poddle is not crossed directly by the proposed alignment. Geological setting is low permeable tills; significantly culverted.

In summary, based on a review of the local hydrogeological setting for each of the features identified, the main watercourses crossed by the proposed Project where there is potential hydraulic connectivity as baseflow with water-bearing strata and/or the underlying bedrock include the Broadmeadow River, Ward River, Sluice River, Forrest Little Stream and River Liffey, with potential for connectivity also at the Tolka River.

19.4.15 Groundwater Dependent Terrestrial Ecosystems (GWDTE) & Natura 2000 Sites

There is only one European site located within the same GWB as the proposed underground section of the proposed Project. This is the Rye Water Valley/Carton SAC which is designated for a groundwater dependent QI Annex I habitat and is located >15km farther to the west. This European site also contains other groundwater dependent habitats which support the two QI Annex II species for which it is also designated.

The proposed Project alignment/boundary does not directly overlap with any European site. The nearest European sites include the following:

- Malahide Estuary SAC/SPA and Baldoyle Bay SAC/SPA, which are located downstream of the proposed Project; and
- North Dublin Bay SAC, South Dublin Bay SAC, North Bull Island SPA and South Dublin Bay and River Tolka SPA.

19.5 Predicted Impacts

19.5.1 Introduction

A detailed description of the proposed Project (construction and operation) is provided in Chapter 5 (MetroLink Construction Phase) and Chapter 6 (MetroLink Operations & Maintenance). This section outlines the characteristics of the proposed Project in relation to the hydrogeological environment and assesses the predicted impacts.

Each aspect has been assessed in terms of a 'Do Nothing' scenario (i.e. Project does not proceed, and no development occurs), the Construction Phase and the Operational Phase. A summary of the design with regard to hydrogeology is provided below and a detailed assessment of the predicted impacts (both quantitative and qualitative) is provided in more detail in the subsequent sections.

Dewatering and unmitigated releases to ground during the Construction Phase could have permanent water quality and quantity impacts on the hydrogeological (and hydrological/ecological) environment if not effectively mitigated. However, for the proposed Project, Construction Phase management includes mitigation measures presented in the EIAR and outlined in the outline Construction and Environmental Management Plan (CEMP) (Appendix A5.1) for the proposed Project to protect receiving waters (groundwater and surface water) and ensure continued conveyance of natural groundwater flow patterns, as well as of surface water courses.

During the Operational Phase, the proposed Project has a low potential for groundwater quality impact as there is limited potential for accidental releases: the vehicles are electric and there is minimal bulk chemical storage. Chemicals will be required for maintenance works only and where required are stored within bunds. Operational stormwater drainage is designed in accordance with SuDS and is collected and discharged to stormwater sewer or open river sections following appropriate attenuation and treatment. Interceptors are included in maintenance yards and carparking areas. There is only a limited potential for collection of drainage water from within the tunnel (which will be an enclosed, watertight system) for example at the interface with stations, and this will be discharged to public wastewater sewer. There will be no Operational Phase dewatering.

This section ranks the magnitude and significance of any potential hydrogeological impacts in line with TII (NRA, 2009) guidelines. Where hydrogeological impacts are predicted then these are also assessed for interaction with other related aspects of the environment, most notably Biodiversity, Soils & Geology, Hydrology and Material Assets.

The elements of the proposed Project that will interact with the hydrogeological environment fundamentally are those activities that have the capacity to change the groundwater regime in terms of recharge of groundwater levels, regional/local flow patterns and water quality. As such, the principal potential hydrogeological impacts on the character of the receiving aquifers include the following:

- Impact to underlying aquifer as a result of removal during tunnelling and deep excavations;
- Changes in groundwater recharge characteristics;
- Changes in groundwater quality due to accidental spillages of potentially polluting substances;
- Impact on groundwater as a result of substances injected into the ground during the TBM tunnelling works (Appendix A5.14). Specifically, TBM consumables include *inter alia* the following:
  - Annulus grouting (water and ordinary Portland cement, mixed together to produce a flowable grout material with additional additives to stabilise the grout and prolong the working time).
  - Spoil conditioning additives generally consisting of a liquid foam agent that is mixed with water in foam generators on the backup gantries to produce a thick shaving-like foam that can be injected into the chamber in front of the bulkhead. These can include polymers which can be added to reduce the clogging (stickiness) of clay.
  - Main bearing grease - Two different types of grease are continually pumped into the bearing from drums positioned on the backup gantries in order to prevent spoil from getting into the roller bearings for example.
  - Tail seal grease – This prevents water and the annulus grout from getting into the tail can and is applied using a powerful pump and injector tool.
  - Bentonite - A bentonite slurry will be used to launch the machine before any ground is mined and is used as a transport medium to remove spoil from the TBM but is not always needed.
- Impact to groundwater levels and flow patterns along the full alignment due to the proposed Project (potential 'barrier' effect) as a result of cut sections or underground structures intercepting groundwater flow paths;
- Impact potential on groundwater contributions to identified surface watercourses; and
- Impact on sites of ecological importance (e.g. Malahide Estuary, SAC) within water courses crossed by or downstream of the proposed development and which may receive baseflow from groundwater. Refer to the Nature Impact Statement (NIS) for further details.

The key aspects of the cut sections and deep excavations along the alignment of the proposed Project are summarised in Table 19.22 and are relevant to the assessment of impacts on the hydrogeological environment. Details on the ZOI provided in Table 19.22 are discussed in more detail under Section 19.5.3.5.

Table 19.22: Summary of Geometric Features of Proposed Project Stations

Ref. Area	Station Name	Structure Type	Approx. Chainage	Length (approx. m)	TOR Depth (mBGL)	Excavation volume estimated (m^3)	Max ZOI radius (m) from feature
AZ1	Estuary	At Grade	1+238 to 1+300	65	0.0	-	-
	Seatown	Retained cut	2+824 to 2+889	82	6.5	10,700	66.79
	Swords Central	Retained cut	3+792 to 3+857	82	6.5	10,700	56.80
	Fosterstown	Retained cut	4+758 to 4+823	82	6.5	10,700	33.57
AZ2	Dublin Airport	Underground	7+016 to 7+081	120	26.0	78,000	83.20
AZ3	Dardistown	Retained cut	9+021 to 9+086	82	6.5	10,700	24.61
	Northwood	Underground	10+296 to 10+361	150	20.0	75,000	104.97

Ref. Area	Station Name	Structure Type	Approx. Chainage	Length (approx. m)	TOR Depth (mBGL)	Excavation volume estimated (m³)	Max ZOI radius (m) from feature
AZ1	Estuary	At Grade	1+238 to 1+300	65	0.0	-	-
	Seatown	Retained cut	2+824 to 2+889	82	6.5	10,700	66.79
	Swords Central	Retained cut	3+792 to 3+857	82	6.5	10,700	56.80
	Fosterstown	Retained cut	4+758 to 4+823	82	6.5	10,700	33.57
AZ4	Ballymun	Underground	11+237 to 11+302	110	26.0	71,500	151.13
	Collins Avenue	Underground	12+195 to 12+260	120	27.0	84,000	213.22
	Griffith Park	Underground (U)	13+778 to 13+843	120	28.0	118,000	165.71
	Glasnevin	Underground (U)	14+835 to 14+900	120	28.0	118,000	180.88
	Mater	Underground (U)	15+615 to 15+680	112	29.0	84,500	201.50
	O'Connell Street	Underground	16+630 to 16+695	140	29.0	105,500	175.20
	Tara	Underground	17+371 to 17+436	105	28.0	79,400	176.45
	St Stephen's Green	Underground	18+452 to 18+571	115	28.0	80,500	149.22
	Charlemont	Underground	19+339 to 19+404	120	27.0	81,000	134.95

Note: TOR indicates top of rail and is indicative of the minimal drawdown depth (mBGL) required during the Construction Phase to achieve relatively dry working conditions; ZOI – Zone of Influence of drawdown as a result of [modelled, Plaxis2D] Construction Phase dewatering activities prior to [base of excavation] toe-grouting as a mitigation measure.

19.5.2 Do Nothing Impact Assessment

In the event of the proposed Project not being constructed, there would be no resulting impacts on the existing hydrogeological environment along the alignment of the proposed development. The baseline hydrogeological environment presented in Section 19.4 would remain the same.

19.5.3 Construction Phase Impact Assessment

Activities associated with the Construction Phase can interact with hydrogeological receptors by changing the groundwater regime that a receptor is dependent upon. Potential impacts outlined in this section are pre-mitigation and include the principal impacts listed in Section 19.5.1 above. Mitigation measures are described in Section 19.6 and residual impacts, i.e. post mitigation measures, are outlined in Section 19.7.

19.5.3.1 Groundwater Resources

The proposed Project will involve localised removal of the bedrock aquifer through tunnelling and in deep excavations associated with proposed stations, as well as in cut sections, and especially where saturated rock is removed. The deep excavation for station boxes and alignment cuttings that intercept groundwater will typically lead to a reduction in localised groundwater level, the aquifer saturated thickness and the aquifer unsaturated thickness for the cut sections and station box footprint. Consequently, where the groundwater potentiometric surface is not intercepted, then there will only be a reduction in the unsaturated thickness. During construction, where overburden/hardstanding is removed then there is also potential for an increase in the quantity of effective rainfall available to recharge to ground or run off as surface water.

Section 19.4.9 above presents the recharge characteristics for each of the AZ1 to AZ4 areas. For AZ1, the quantity of recharge that can infiltrate to ground is limited due to low permeable ground conditions. At Dublin Airport, AZ2 area, hardstanding and low permeable subsoils will also limit recharge effects despite a potentially higher recharge co-efficient at Dublin Airport Station itself. Generally, the recharge co-efficient for areas AZ3 and AZ4 is estimated at 20% or less and reflects the degree of hardstanding in what is essentially an urban setting.

In terms of water as a resource and usage during the Construction Phase, this will vary from site to site and as the construction programme evolves. At peak, the most significant use of water will be at sites where on-site batching of concrete is proposed; currently at Estuary, the DASP, Dardistown Depot, Northwood Station and Portal, Ballymun and Griffith Park stations and at tunnel drive sites. Pre-application enquiries for water supply and foul discharge connection have been submitted to Irish Water for each station and consultation is on-going to date. Water usage for the Construction Phase is discussed in Chapter 5 (Appendix A5.11); mitigation measures to limit the use of water consumption during the Construction Phase are presented under Section 19.2.6.7 below.

19.5.3.1.1 Summary of Impact Assessment:

A quantity of limestone rock will be excavated for the construction of the proposed Project. This volume represents a very small percentage of the overall bedrock aquifer volume and for this reason, in line with TII rating, the magnitude of the impact on the underlying [Ll and Pl] bedrock aquifer is *Negligible* and the significance of the effect is *Imperceptible.*

The bedrock aquifers along the alignment are not regionally important aquifers. Notwithstanding this, they do represent a groundwater resource potential. However, the characteristics of the proposed Project at Construction Phase will not significantly change the recharge characteristics along the alignment and therefore will not cause any significant impact on the natural groundwater regime within the underlying aquifers. In line with TII (2009) rating, the magnitude of the impact on the Ll, Pl aquifers from changing recharge is *Negligible* and the duration and significance of the effect is *Permanent, Imperceptible*.

The water quality of the bedrock aquifers will not deteriorate due to the proposed Project and as such the proposed Project meets the requirements of the European WFD. Furthermore, there is no likely impact on Natura 2000 sites from construction dewatering or potential pathway for a construction leak through the groundwater aquifer.

19.5.3.2 Groundwater Supplies

The proposed Project will pass through an area with potable water supply which is mostly provided by public supply mains, typical of the urban/ peri-urban setting through which the alignment will pass.

Section 19.4.7 above presents a number of groundwater abstractions which may be impacted by the proposed Project however these are based on a varying degree of location accuracy (GSI, 2022). Lowering of groundwater levels during construction related dewatering activities refers directly to drawdown of the water table or potentiometric surface. Where groundwater levels at potential supply wells are lowered due to construction related dewatering of the bedrock aquifer, or the groundwater quality at these wells is impacted, the abstraction points could be rendered unusable for the period of dewatering which applies to that site.

The potential impact of Construction Phase dewatering of the bedrock aquifer on identified wells can be assessed by comparing the abstraction locations to the anticipated drawdown ZOI, where data is available to allow same. If the wells are located within the ZOI, then by adopting the 'precautionary principle' it can be assumed that they will be impacted by dewatering of the bedrock aquifer mainly. A similar assessment can be applied to dewatering within granular overburden in the case of shallow water supplies/domestic wells that wholly intercept shallow granular supply and/or buried non-culverted watercourses.

In terms of construction activities and potential impact (i.e. levels and water quality) on identified water supply wells, it is important to assess whether the supply point lies up or down-gradient of the alignment and the type of construction activity that relates to that particular chainage, for example is the alignment in tunnel, cut or deep excavation. If a groundwater supply is assessed as lying up-gradient of the proposed Project, it therefore cannot be impacted by any potentially polluting materials however locally groundwater levels may be impacted by the respective works in the area of this supply (i.e. the supply may lie within the ZoI of dewatering; see also Section 19.5.3.5).

If a well is assessed as down-gradient, then there is potential for local groundwater supply quality deterioration and a replacement of supply will be provided for the interim period of construction dewatering. With regard to 'unknown' wells which could be intercepted by the tunnel excavation, this presents an additional impact.

It is noted that in many cases groundwater wells were situated close to streams and as such may not have been authentic 'spring' wells, but rather direct abstraction points (take-offs) from watercourses. These may have become redundant over time for example where watercourses were subsequently culverted thereby cutting off the supply. In addition to this, historical wells (for example the ancient well at rear of 8 Harcourt Terrace, >100m north of the proposed Charlemont Station: Chapter 26 (Architectural Heritage) may have been sunk deeper to tap into lower water-bearing strata and this is evident in Dublin City Centre. The presence of any well along the tunnel alignment, but in particular deeper boreholes, can be an important geotechnical risk in tunnel excavation. Tunnel boring with a closed-face system operating with a positive face pressure can lead to water/mud release at ground level if the pressurized tunnel cutterhead intercepts an unknown well. The proposed tunnel system is to be designed to cater for fluctuations in both ground and water pressures.

19.5.3.2.1 Summary of Impact Assessment:

As stated in Section 19.5.3.1, the [Ll, Pl] bedrock aquifers along the alignment do represent a groundwater resource. As such, groundwater supplies may be impacted by groundwater lowering during cuts/station/shaft construction, this also refers to short-term lowering of water levels which will re-stabilise post construction. Apart from where a degree of short-term dewatering activity will be required during the Construction Phase, the tunnelling process itself is not likely to have any impact on groundwater flow to either identified or unidentified well supplies (tunnel will be sealed from underground flow) unless a particular source is directly intercepted by the TBM path which is considered unlikely based on review of wells in the area of the proposed Project tunnel alignment. In this case, the impact will be permanent, the well will be decommissioned following best practice guidelines and a replacement well supply will need to be provided.

Without adequate design and mitigation measures to control off-site groundwater lowering effects as discussed in Section 19.6.2.3 below, the potential for impact on any existing groundwater supplies is considered *Moderate adverse* in terms of magnitude (TII, 2009) and *Short-term* in duration of effect.

19.5.3.3 Groundwater Quality and Discharge of Water

The proposed Project will consist of 16 no. stations, including 11 no. underground stations as well as two separate single bore, twin-track tunnel sections and surface running sections. Additional significant works include the construction of the Dardistown Depot, the P&R Facility, viaduct and bridge structures. These proposed Project features all have the potential to impact on groundwater (and surface water) quality during the Construction Phase. Sources of water for discharge off site include primarily groundwater from dewatering of the R132 cuts, TBM Portal sites, station boxes, intervention shafts and discharge from the TBM process itself, but also localised surface water run-off.

A number of surface water features will be crossed by the proposed Project, as discussed in Section 19.4.14 above. These include the Broadmeadow River, Ward River, Gaybrook Stream, Sluice River (and Forrest Little Stream), and the Mayne River, Santry River, Tolka River, Royal Canal, River Liffey and the Grand Canal. Some construction sites are located within close proximity of identified watercourses and hence there is some potential for contamination of same as a result of construction related activities. Furthermore, as indicated in Section 19.5.3.5 below, identified watercourses (which will include a number of features receiving Operational Phase treated/attenuated surface water run-off volumes) will generally converge with downstream European sites of ecological interest (refer to the Natura Impact Statement for further details).

Combined surface water and groundwater water discharges from construction site areas are initially likely to be high in sediment, with potentially elevated alkalinity where cement works is on-going and will require adequate attenuation and treatment prior to approved discharge to the respective, defined sewer. In the event that these options are not available, tanker disposal is an alternative that will be used.

Within the construction site footprint, there is potential for 'drainage to ground' related pollution (i.e. accidental release during construction) which could include hydrocarbons and alkaline water from cement works, grouting and wheel wash water entering local groundwater. Run-off from temporarily stockpiled (sterile and/or contaminated) material on-site, including subsoil stockpiling, could also impact on both groundwater and surface water (where nearby), for example at Northwood Station located south-west of the Santry River.

The potential impacts from interception of [incipient] epikarst within the Waulsortian rock at Dublin Airport is highlighted during the Construction Phase as having a potential impact on the hydrogeological regime by either modifying pathways (reactivating sediment filled epikarst or blocking active epikarst) as well as from point input recharge for contaminants. Furthermore, there is some potential for 'draw-in' of historically contaminated groundwater within the subsoil/bedrock at Dublin Airport (Section 19.4.6 - Industrial Facility GWB (ref. P0480-02)). Chapter 20 (Soils & Geology) also discusses subsoil assessment in the area of Dublin Airport in the context of water pollution arising out of the disturbance of made ground material in particular. This would indicate the potential for 'information gaps' in terms of the presence of contaminants within subsurface materials including within areas that were specifically investigated through site investigation works (i.e. trial pits, boreholes). Also, with regard to Dublin Airport, water pollution could occur from run-off of any stockpiled subsoils that are recorded as contaminated during Construction Phase works. Surface water run-off and infiltration through stockpiles can lead to mobilising of contaminants and potentially causing pollution of surrounding hydrogeological environment. Notwithstanding this, Chapter 20 (Soils & Geology) assesses the baseline for contaminated land within the AZ2 Airport Section and summarises that the majority of the identified potential sources are outside the proposed Works Area and/or have a minor or mild assessed severity with no specific linked instances of made ground or contamination identified.

Construction related pollutants that do infiltrate to ground will have limited mobility and will be limited to the footprint of that construction site. On this basis, the risk to the groundwater quality in the Ll aquifer of the Swords GWB and Dublin GWB is limited to the construction footprint and not beyond it - the use of secant piles and D-walls at proposed stations will further reduce lateral mobility of pollutants where accidently discharged. In the unlikely event of significant flow paths (fault or fracture zones) being encountered, for example near Dublin Airport within the Waulsortian limestone, during construction, then these shall be mitigated against using the methodology proposed for Karst as described under Section 19.6.2.2.

All contaminated water and/or construction process water resulting from Construction Phase works has the potential to contaminate subsoils and the underlying aquifer (including surface water) if not mitigated. This water will be contained within the site and tankered off-site to a licenced facility for disposal or treatment.

Run-off associated with on-site dampening activities where diaphragm walls are installed (for example at Griffith Park (Tolka River) and within the city centre at Tara Street (River Liffey)) poses a potential impact on local water quality. Ineffective management of material at batching/bentonite plants also represent potential impact on water quality through run-off effects.

Faecal contamination of subsoils and groundwater arising from inadequate treatment of on-site toilets and washing facilities (grey water) is also a potential impact on the water environment if not properly managed.

Where poorly treated water is approved for localised re-injection to ground through designed boreholes located up-gradient and/or down-gradient of the site, and which are used for the purposes of preventing off-site settlement issues for example (i.e. not as a water management option through wider area recharge to ground wells), then this could potentially impact on local/regional groundwater quality. Note: No localised re-injection to ground -outside the excavation footprint - of dewatered water from Dublin Airport deep excavations will be permitted but rather this water will be tankered off site for appropriate disposal.

Table 19.23 presents a summary of the construction excavation and compound sites along the alignment together with the estimated daily rate of discharge to that receiving feature. Water discharge/management will ensure that the final estimated discharge volume matches greenfield run-off rates for the receiving sewer feature. The estimated outflows (m^3/day) are based on calculated volumes of water as anticipated from each of the work areas listed and are further discussed under Section 19.5.3.4 below with regard to inflow assessment and dewatering requirements.

Table 19.23: Summary of Construction Excavation Discharge from Stations and Associated Work Areas

Ref. Area	Site Reference	Approx. Chainage	Construction Site Type	Estimated Discharge (m^3/day)	Comments
AZ1	Estuary Station	1+250	Station Excavation (Station at grade)	N/A	Station at grade with no significant excavation works.
	Balheary Park to Malahide Roundabout	2+253 to 3+460	Excavation of long section of retained cut and cut & cover	3,017	The section analysed results in a value of 2.5 m^3/day/m (for 1,207m)
	Seatown Station	2+800 to 2+890	Station Excavation	98.5	Secant piling to below TOR level
	Malahide Roundabout to Pinnock Hill Roundabout	3+520 to 4+400	Excavation of long section of predominantly retained open cut track	2,200	The section analysed results in a value of 2.5 m^3/day/m (for 880m)
	Pinnock Hill to DANP	4+400 to 6+040	Excavation of long section of predominantly retained open cut track	508	The section analysed at chainage 5+000 results in a value of 0.31 m^3/day/m (for 1,640m) Cut and cover at DANP
	Swords Central Station	3+830	Station Excavation	59.6	Secant piling to significantly below TOR level Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
	Fosterstown Station	4+780	Station Excavation	22.0	Secant piling to significantly below TOR level Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available

Ref. Area	Site Reference	Approx. Chainage	Construction Site Type	Estimated Discharge (m^3/day)	Comments
AZ2	DANP	6+040	Deep Excavation/TBM tunnel	0.31 m3/day/m	The section analysed at chainage: 5+000 results in a value of 0.31 m3/day/m
AZ2	Dublin Airport Station	7+050	Station -Deep Excavation, D-walls	32.8	Calculated Q^{out} t is from Plaxis-2D modelling; on-site attenuation and storage available
AZ2	DASP	8+440	Deep Excavation/TBM tunnel	2.51 m3/day/m	The section analysed at chainage: 8+420 results in a value of 2.51 m^3/day/m
AZ3	Dardistown (Future Station)	8+840	Station Excavation - retained cut, piling	34.3	Calculated Q^{out} t is from Plaxis-2D modelling; on-site attenuation and storage available
AZ3	Dardistown Depot	9+040	Excavation (various cut/fill)	2.51 m3/day/m	Assumes the values analysed for section at chainage: 8+420 which results in value of 2.51 m^3/day/m
AZ3	M50 Viaduct	9+700	Viaduct	N/A	-
AZ3	Northwood Portal	10+040	Deep Excavation/TBM tunnel	228.6	Since it is closer to Northwood Station, the estimated discharge of 228.6 m^3/day is assumed here
AZ3	Northwood Station	10+340	Station -Deep Excavation, D-walls	228.6	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
AZ4	Ballymun Station	11+260	Station -Deep Excavation, D-walls	300.7	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
AZ4	DCU Collins Avenue Station	12+220	Station -Deep Excavation, D-walls	200.5	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
AZ4	Albert College Park Intervention & Ventilation Shaft	12+800	Deep Excavation	200.5	Since it is between DCU Collins Avenue Station and Griffith Park Station, the estimated discharge of 200.5 m^3/day is assumed here
AZ4	Griffith Park Station	13+800	Station -Deep Excavation, D-walls	262.8	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
AZ4	Glasnevin Station	14+850	Station -Deep Excavation, D-walls	600.7	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
AZ4	Mater Station	15+640	Station -Deep Excavation, D-walls	299.9	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
AZ4	O'Connell Street Station	16+660	Station -Deep Excavation, D-walls	212.9	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
AZ4	Tara Station	17+400	Station -Deep Excavation, D-walls	251.6	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available

Ref. Area	Site Reference	Approx. Chainage	Construction Site Type	Estimated Discharge (m^3/day)	Comments
	St Stephens Green Station	18+480	Station -Deep Excavation, D-walls	259.6	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available
	Charlemont Station	19+360	Station -Deep Excavation, D-walls	202.2	Calculated Q^{out} is from Plaxis-2D modelling; on-site attenuation and storage available

In addition to the deep excavation stations, significant works areas are also associated with the tunnel bore launch locations where the underlying hydrogeology will be exposed during construction; these are namely:

- DANP is the northern TBM receiving point for the Airport tunnel which will run below the Airport between chainage: 6+000 & chainage: 8+400, approximately;
- The TBM launch site immediately south of Collinstown Lane (Old Airport Road) and Dublin Airport is referred to as DASP and allows the tunnel launch and drive northwards towards the proposed deep station at Dublin Airport; and
- Adjacent to the proposed Northwood Station to the west of the R108 and south of St Margaret's Road. This TBM launch site allows the tunnel launch and drive southwards towards Ballymun Station and onwards to the proposed Charlemont Station in the suburb of Ranelagh where it will remain.

Other significant excavation works where the underlying hydrogeology will also be exposed (temporary to short-term) include intervention and escape shafts, i.e. access shaft located at Albert College Park. Construction is similar to the underground stations with the shafts scheduled to terminate at similar depths in similar geology but with secant piles rather than D-walls. Two approximately 23m long connection tunnels driven from the shaft at Albert College Park to connect to the running tunnel, smaller evacuation and ventilation tunnels will be constructed using Sprayed Concrete Lining technique (SCL). SCL is also proposed for the tunnel south of Charlemont as well as for SCL tunnels from DASP. As such, generally similar construction principles for the underground stations will apply to these shafts/tunnels with the protection of the local hydrogeological environment and its related attributes a key requirement of the outline CEMP (Appendix A5.1). The SCL tunnelling will utilise advance probing and grouting as necessary.

With regard to the Southern section TBM (City drive), after passing through Charlemont Station and continuing south to construct the over-run, cross-over and turnback tunnel, this machine unit will be driven off-line south of Charlemont Station, buried and encased in concrete. However, the quantity of TBM left is relatively small i.e. the vast majority of the TBM will be dismantled and removed from the tunnel. Notwithstanding this, and with the objective of negating any impacts on the hydrogeological (and hydrological) environment, those parts that are left, will require thorough cleaning to prevent any water/soil quality impacts and are then encased in concrete.

19.5.3.3.1 Summary of Impact Assessment:

In the 'absence' of adequate design and mitigation measures for the effective management of water discharges from cut sections, deep excavations and from the tunnelling process, which are discussed in Section 19.6 below, the potential impact (TII, 2009) on the underlying aquifer is considered *Small adverse* in terms of magnitude and *Short-term* in duration effect. However, with the design measures put in place for MetroLink the resulting significance of the impact is considered *Imperceptible.*

For Construction Phase discharge to defined sewers, then 'fit for purpose' design measures (refer also Section 19.6) will include adequate attenuation of outflows in order to 'mimic' the current flow regime/flow capacity of the receiving sewer feature (i.e. allow discharge at Local Authority defined/permitted rates). The absence of any direct construction related discharge to nearby watercourses will avoid water transfer outside of any sub-catchment boundary. For discharges to sewer, water quality compliance as required will apply.

The construction of the alignment and station for the proposed Project will entail short-term dewatering which will require collection, effective treatment and attenuation of water prior to off-site discharge to defined sewer.

Typically, the estimated rate of discharge based on modelling of outflows undertaken for each of the work areas will decrease once sealing/containment at the excavation areas (through deep-set walls/piles with application of bottom (toe)-grouting) has been completed below the phreatic water table. Containment is a gradual process at all sites.

Design measures, as part of constructability planning, include the use of adequate containment measures for chemicals temporarily stored within construction compounds and maintenance yards, use of petrol/oil interceptors in maintenance yards and car parking areas, and the proper management and use of environmentally friendly herbicides where applied. There are downstream salmonid fishery habitats in the sub-catchments traversed by the proposed Project. Operation of a Construction Phase sediment and pollution prevention plan (as is outlined in the outline CEMP Appendix A5.1) and a programme of daily monitoring (pH, suspended solids and conductivity) prior to discharge off site will minimise the potential for accidental discharge to approved discharge points. In any event of approved discharges to ground these will be sufficiently treated, effectively attenuated and monitored to ensure water quality is not compromised and kept within the [agreed] permitted discharge quality limits as approved by the relevant Local Authority or asset owner which is the key requirement on top of specific mitigation measures included in the design.

The southern section TBM drive will be buried south of Charlemont Station and, following dismantling to the minimum requirements and thorough cleaning of the remaining components, will be encased in concrete (refer also Section 19.6.2.6 below for further details on mitigating impact potential).

Without adequate design and mitigation measures, which are discussed in detail under Section 19.6, the potential for impact (TII, 2009) on groundwater and surface water quality (and potentially surface water flow regimes) is generally considered *Moderate adverse* in terms of magnitude and *Short-term* in duration effect.

19.5.3.4 Groundwater Inflow Assessment

19.5.3.4.1 Metro North – Inflows

Section 19.5.3.5 includes reference to Metro North and historical reporting of groundwater inflows for the same general alignment. Table 19.19 presents historical records on the potential for groundwater lowering and observed spatial impacts of same, with low impact potential reflective of low permeable subsoils/bedrock, and medium to high impact assessed as a result of higher permeable subsoils and fracture discontinuities in bedrock.

19.5.3.4.2 Proposed Project – Inflows

According to a review of the data available and associated with groundwater inflows in particular, potential hydrogeological risks have been identified for the proposed Project and include the following:

- Groundwater inflow into the tunnel section,
- Groundwater inflow into cut sections and within deep station excavations, and
- Substantial water inflows under pressure both during deep excavation and during TBM advance works, as well as SCL tunnelling works.

Note: The assessment of groundwater inflow potential for the proposed Project is intrinsically linked to the interpreted ZOI that will occur as a direct result of dewatering activities within variable geological strata as defined by both historical and contemporary [Phase 1 to 5] ground investigations. Wider area recharge to ground implications, as discussed under Section 19.4.9, is also an important factor here.

Groundwater inflow as a hydrogeological risk and impact is further discussed below.

19.5.3.4.3 Groundwater Inflow into the Tunnel Section

In the fluvio-glacial sequence along the alignment, there is a multi-layer aquifer system controlled by granular sediments (sand, gravel and cobbles/boulders). There is also the important water-bearing interface between soil/rock layers (i.e. BoD/UWR) essentially the 'discordant contact' between the Boulder Clay/BoD and the Carboniferous bedrock sequence below, and this represents a major saturated groundwater flow zone within the Dublin area. This poses a difficulty in terms of determining precisely where this contact lies and therefore represents an inherent hydrogeological constraint in addition to geological/geotechnical difficulties. The variability in defining this 'contact' level is estimated to be around +/- 2m when exploratory boreholes are <100m apart; this can change to +/- 5m when the distance between boreholes is between 100m and 300m. The uncertainty in the determination of the position of this soil/rock interface or contact is related to the variability in the pre-glacial topography and will have a bearing on potential inflow to the tunnel section during excavation.

Additionally, there is a fractured aquifer within the Carboniferous sequence which is controlled by discontinuities, fractures and fault zones, with incipient epikarst porosity also identified (i.e. Waulsortian limestone, CWA).

All these water-bearing strata, as defined and described in the baseline assessment under Section 19.4.3 above, represent a likely source of groundwater encountered within the tunnelled alignment during the excavation process.

The excavation of the proposed Project tunnels using a closed-face pressurised TBM will reduce groundwater inflow risks. During tunnelling the face pressures are monitored and adjusted to suit the prevailing conditions and the tunnel lined continuously with excavation so there is no exposed ground.

19.5.3.4.4 Substantial Water Inflows under Pressure both during Deep Excavation and during TBM Advance Works

In the Boulder Clay there is a multi-layer water-bearing strata present in the different granular layers comprising sand, gravel and/or boulders. Each layer can form confining conditions with artesian water under pressure. The unique texture of the fluvio-glacial deposits, with limestone boulders embedded in a gravel-sand-clay matrix, can lead to the development of underground water channels with potential significant groundwater flow/pressure characteristics.

Excavations below the phreatic level can produce substantial water inflow into deep excavations and a consequent depression of the potentiometric surface. This can be a challenge in underground workings beneath a city/urban setting because it can result in a loss of material through washing out and compaction of soil through pore water loss. These processes can therefore result in significant settlement of the existing ground surface, with subsequent damage to surrounding buildings. It is for these reasons that the deep station are planned to be excavated only after the walls (d-walls) have been constructed and any potential water paths controlled.

The relationship between surface settlements and tunnel excavation depth is neither simple nor linear. Ground movements depend on several factors including (1) geological, hydrogeological and geotechnical conditions, (2) tunnel geometry and depth, (3) excavation methods, and (4) the quality of workmanship and management. It is however clear that a shallow tunnel will tend to have a greater effect on surface structures than a deep one.

For the proposed Project, tunnel excavation in both the Boulder Clay and the underlying rock present technical challenges that the TBM is to be designed for. In terms of solid geology, the Calp Limestone has fault/ fissure/ fracture zones, adverse dipping and large weathered shale beds and bedrock fracturing can also potentially represent pressurized water discharge points. These features can lead to TBM face instability and potentially increased settlement especially where the tunnel alignment is constantly changing from south to north in variable geological settings. The features generally occur infrequently, and the use of forward probing or other ground radar detection radar means can be used to identify their presence. The proposed variable density TBM can operate in both a slurry mode and in EPB mode ensuring that the TBM is capable of coping with the changing conditions.

The tunnel excavation must be sealed from underground water to avoid a decrease in the phreatic level to minimise any settlement impacts. The problem of subsidence (including 'sink hole' generation by tunnel collapse) increases with the settlement caused by the loss of subsoil removed during excavation of the tunnel. The system will be designed to monitor excavation quantities and reconcile against theoretical quantities to ensure over- excavation is eliminated.

With regard to SCL tunnelling there is also a risk of encountering such charged geological units. It is planned to undertake forward probing (to identify in advance) and grouting as required to stem any such flows.

19.5.3.4.5 Groundwater Inflow into Cut Sections and Within Deep Station Excavations

Historically, based on inflows during the construction of the 50m diameter TBM launch shaft constructed for the Dublin Port Tunnel, the predicted flow at Tara Station would be c. 6l/s when adjusted for shape factors. An assessment of the expected water quantities for the construction of the Mater Station in 2009 for an earlier design of Metro North resulted in an anticipated rate of between 6l/s to 9l/s.

Excavation below the groundwater level can therefore result in significant water flow into the excavation and a lowering of the water table/potentiometric surface if not carefully managed. Excavation construction work will affect:

- The multi-layer water-bearing strata within the Boulder Clay (fluvio-glacial sediments).
- The BoD and UWR units (comprising the basal zone of the Boulder Clay sequence and the upper and weathered zone of the Carboniferous sequence, a major saturated zone within the Dublin area).
- The fractured aquifer of the Carboniferous sequence, including the potential for epikarst within the Waulsortian Formation (CWA), which is more prone to karstification and is likely to be more permeable and porous than the other limestone formations along the alignment. This risk is located at Dublin Airport Station.

The analytical calculations for groundwater ingress into the station excavation were designed by IDOM and Oviedo University for deep dewatering at the Riyadh Metro Line Three (Saudi Arabia) where modelling showed relatively good correlation with the actual water flow values obtained in that station excavation. In general, for the Riyadh Metro Line Three case study the modelled water flow data was between 10% to 30% higher than the actual [field] water flow data. This precision obtained by the analytical method was superior to other conventional hydrogeological software and is applied to the proposed Project but using local hydrogeological and geometric data as key, viable input. In brief, Plaxis2D was used to carry out finite element modelling of the representative cross sections for each station (using the hydrogeological profiles as listed above) and the groundwater flow analyses were carried out using PlaxFlow, an add-on module to Plaxis2D that may be used for the analysis of both steady state and time-dependant conditions (refer also Section 19.3.5 above). The Plaxis2D groundwater inflow modelling report is presented as Appendix A19.8.

The excavation of the deep stations within Dublin City Centre urban setting must be carried out with the minimum effect on the phreatic water table in order to avoid the potentially significant impact of ground settlement occurring. Possible methods of groundwater extraction from within deep excavations include localised sump pumping, deep well dewatering (groundwater lowering) with submersible pumps, and/or a system of well points around the excavation footprint to effectively lower/draw down the water table level within the excavation in advance of excavation so dry workings can follow. The actual technique used during the Construction Phase will be refined based on the results of further ground investigation and assessments. However, design for the RO will entail the use of a deep well dewatering system including periphery wells for groundwater level monitoring and for use in stabilizing of levels as required i.e. where approved [geotechnical based] recharge to ground is employed.

A summary of the hydrogeological data available and interpreted for each of the stations is presented below for areas AZ1 to AZ4. The key modelled results with regard to the likely dewatering requirements for all excavations are included as well as highlighting the interpreted ZOI from groundwater lowering activities. The inputs to the modelling exercise considered contemporary data collated from hydraulic testing in 2020/2021 as well as data captured from other [existing/historical] construction sites with deep excavations in the Dublin City/Fingal areas where construction-related dewatering information was available; this allowed validation of modelled outputs. As stated in Section 19.4.13.2, in the majority of cases, the maximum outflow applied during the pumping test phase (to achieve the requisite drawdown) was observed to 'decrease' over the full test duration during all test stages. The initial pumping rate applied to the CRT stage based on the results of the respective Step Tests was continually reduced and notably within the bedrock screened wells. This observation is very relevant when modelling/assessing groundwater inflow at cut sections or deep excavations.

With regard to retained cut and cut & cover sections, along the alignment different structural solutions (comprising piled walls and U-sections) are proposed depending on the TOR depths, geotechnical conditions (including groundwater pressure resistance in addition to loading) and the possibility of open excavation and include reference to the management of groundwater ingress potential (refer Chapter 4 for further details on retained cut and cut & cover locations). The proposed retained cut and cut & cover sections are predominantly located within non-urban or peri-urban settings. For the retained cuts, waterproofing with piled wall solutions is an acceptable design measure as are piled walls for cut & cover sections where the structures are not as extremely deep as would apply to a station box scenario. It is considered that with the secant pile walls and the bottom slab the cut sections will be fully sealed with groundwater paths flowing to design drainage wells. The U section solution is proposed for those sections of the alignment where open excavation is possible.

Note: It is worthwhile emphasizing that diaphragm walls (D-walls) and secant piles incorporated as part of the Project design (for example at station boxes and cuttings) are proposed with the objective of ensuring that the full lateral extents of all excavations are 'water-tight'. This is a key component of the overall design and, together with proposed effective toe grouting, will ensure that groundwater ingress to all [sequenced] deep excavations is mitigated/reduced during the Construction Phase. This underlying construction methodology is part of the discussion presented within the following subsections.

19.5.3.4.6 AZ1 Northern Section

Estuary Park & Ride

The key hydrogeological data available and interpreted for the Estuary Park & Ride station is presented below.

Table 19.24: Estuary P&R Facility - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx.) m Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD/general thickness, m)	Confined/Unconfined Groundwater/general SWL (mBGL)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Estuary At grade, 62 x 15 (d) 1+238 & 1+300	N/A, at grade	QBL<10 m (5) BoD (3) CMUP	Confined groundwater/1.60m to 5.00m	No test	-	-	-	-	Station at grade, no modelling; SWL fluctuation 0.3m to 1.10m

There is no existing data on permeability at Estuary Station to characterise potential water ingress behaviour within the subsoil and rock at this location. However, this proposed station does not involve deep excavation works.

Seatown

The key hydrogeological data available and interpreted for the Seatown station is presented below.

Table 19.25: Seatown -Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2)	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2)	Post-Grouting inflows (l/s) Plaxis2)	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2)	Comments
Seatown 142.775 x 20 x 6.5 (d) 2+850	-1.00	QBR <10m (6) BoD (2) CMUP	Confined groundwater/10.50-8.0	No test; similar to Swords Central	66.79	Max lateral Q^{in}: 0.5-0.8 Max vertical Q^{in}: 1.14 (upwelling) :	Note: No grouting proposed	46.35	Retained cut Station; actual Station length is 82m

Application of the data collated for Swords Central to this site, and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Seatown Station will be in the order of 5.23l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates inflow from the bottom of the station footprint of approx. 1.14l/sec (~98.5m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 100m^2, the estimated seepage would be in the range of 0.5l/sec and 0.8l/sec.

Swords Central

The key hydrogeological data available and interpreted for the Swords Central Station is presented below.

Table 19.26: Swords Central - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used *	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and prior to final sealed structure Plaxis2D	Comments
Swords Central	+7.50	QBL <10m & Fluvio-	Confined groundwa	Max s = 12.82 (mOD)	56.80	Max lateral	Note: No groutin	45.33	Retained cut Station;

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used *	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and prior to final sealed structure Plaxis2D	Comments
98.362 x 20 x 6.5 (d) 3+830		glacial Sands (15.5) QBL >10m (8.5) BoD (5.5) CMLO	ter/24.0-22.80	Steady State (SS) (m3/s): 1.44·10-3 Max radial COD (m) interpreted from SS test conditions: ~40.72		Qin: 0.7-1.1 Max vertical Q^{in}: 0.69 (upwelling):	g proposed		actual Station length is 82m

*Note: * As a result of the TOR and base of Station not set in bedrock, the pumping test data for subsoils is applied in the calculations above.*

Assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Swords Central Station will be in the order of 8.0l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates inflow from the bottom of the station footprint (including through the underlying QBL - Black Boulder Clay) of approx. 0.69l/sec (~59.6m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 100m^2, the estimated seepage would be in the range of 0.7l/sec and 1.1l/sec.

Fosterstown

The key hydrogeological data available and interpreted for the Fosterstown Station is presented below.

Table 19.27: Fosterstown - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Fosterstown 135.875 x 20 x 6.5 (d) 4+790	+25.8	QBL < 10m & Fluvio-glacial Sands (34.55) QBL >10m & Fluvio-glacial Sands (16.80) BoD (11.80) CMLO	Unconfined groundwater/38.05-35.80	No test; similar to Glasnevin	33.57	Max lateral Q^{in}: 0.7-1.1 Max vertical Q^{in}: 0.26 (upwelling):	Note: No grouting proposed	29.91	Retained cut Station; actual Station length is 82m

Application of the data collated for Glasnevin Station to this site, and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Fosterstown Station will be in the order of 8.18l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates inflow from the bottom of the station footprint (including through the underlying QBL -Black Boulder Clay) of approx. 0.26l/sec (~22.0m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 100m^2, the estimated seepage would be in the range of 0.7l/sec and 1.1l/sec. Fosterstown Station will be entirely constructed within the QBL subsoil, with k values in the range of 4.37E-^{05} m/s.

19.5.3.4.7 AZ2 Airport Section

The key hydrogeological data available and interpreted for the Dublin Airport station is presented below.

Table 19.28: Dublin Airport - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Dublin Airport 314.412 x 25 x 26 (d) 7+050	+35.05	Qx (64.68) QBR <10m (61.68) BoD (59.68) CWA	Unconfined groundwater/62.68-56.68	N/A	83.20	Max lateral Q^{in}: 2.7-4.5 Max vertical Q^{in}: 0.38 (upwelling):	Note: No grouting proposed	79.91	This 120m long U/G Station cannot be compared with results from other pumping tests completed.

(Note: Hydraulic tests completed on discontinuities from similar rock coring at tunnels in North Spain resulted in water inflows of ~ 10.0 l/s).

Assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Dublin Airport Station will be in the order of 41.1l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates inflow from the bottom of the station footprint (predominantly through the WA bedrock) of approx. 0.38l/sec (~32.75m3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 117m², the calculated seepage would be in the range of 2.7l/sec and 4.5l/sec. This is also dependent on the characteristics of the rock there, i.e. shallow sub-crop, outcrop, unaltered limestone or karstic 'tube'. Dublin Airport Station will be entirely constructed within the CWA bedrock, with equivalent permeability values in the range of KI = 2.35x10-6 (m/s) for [shallow] subsoils and KI = 6.27x10-7 (m/s) and KII = 5.40x10-7 (m/s) for rock.

Note: There is potential for development of groundwater flow in Waulsortian limestone. The relative purity of Waulsortian limestone makes it amenable, under the right conditions, to dissolution and karst development. Recent borehole drilling within the Waulsortian limestone for the proposed Dublin Airport Station indicated incipient karstification development in subvertical joints. This infers potential for enhanced porosity and permeability, locally.

19.5.3.4.8 AZ3 Dardistown to Northwood

Dardistown (Future Station)

The key hydrogeological data available and interpreted for Dardistown (future station) is presented below.

Table 19.29: Dardistown - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Dardistown 82 x 20 x 6.5 (d) 9+050	N/A	Qx (58.4) QBL <10m (50.4) QBL >10m (48.4) BoD (45.4) CTO	Unconfined groundwater/50.40-49.0	No test; similar to O'Connell Street - Tara Street	24.61	Max lateral Q^{in}: 0.9-1.5 Max vertical Q^{in}: 0.4 (upwelling):	Note: No grouting proposed	23.94	Future retained cut Station, TOR +55.10 mOD

Application of the data collated for O'Connell Street Station/Tara Station to this site and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Dardistown Station will be in the order of 10.54l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates inflow from the bottom of the station footprint (including through the underlying QBL - Black Boulder Clay) of approx. 0.40l/sec (~34.3m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 100m^2, the estimated seepage would be in the range of 0.9l/sec and 1.5l/sec. Dardistown Station will be entirely constructed within the QBL subsoil, with equivalent permeability values in the range of KI = 1.08x10^{-6} (m/s) for soils, and KI = 3.80x10^{-8} (m/s) and KII = 3.80x10^{-8} (m/s) for rock.

Northwood

The key hydrogeological data available and interpreted for the Northwood station is presented below.

Table 19.30: Northwood - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Northwood 150 x 25 x 20 (d) 10+340	+33.61m OD	Qx (58.3) QBR <10m (50.3) QBR >10m (48.3) BoD (45.3) CLU	Unconfined groundwater/53.3 -52.0	No test; similar to Charlemont	104.97	Max lateral Q^{in}: 0.7-1.1 Max vertical Q^{in}: 2.65 (upwelling):	0.38 Note: This is important for water management **during** construction and before final sealing works	62.53 Relates to the modelled extent of 'radial supply of water' during dewatering **post** toe-grouting and before final sealing.	As the different strata are similar to Charlemont, this pumping test area has been assigned. D-Wall installed, assume 1.5m toe grouting completed

Application of the data collated for Charlemont Station to this site, and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Northwood Station will be in the order of 10.3l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 2.65l/sec (~228.6m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 147m^2, the estimated seepage would be in the range of 0.7l/sec and 1.1l/sec. Northwood Station will be constructed within the QBR subsoil and CLU rock, with equivalent permeability values in the range of KI = 1.50x10^{-6} (m/s) & KII = 2.67x10^{-7} (m/s) for subsoils, and KI = 7.19x10^{-6} (m/s) & KII = 7.19x10^{-6} (m/s) for rock.

19.5.3.4.9 AZ4 Northwood to Charlemont

Ballymun

The key hydrogeological data available and interpreted for the Ballymun Station is presented below.

Table 19.31: Ballymun - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure (Plaxis2D)	Comments
Ballymun 110 x 25 x 26 (d) 11+270	+28.95	Qx (59.52) QBR <10m (51.12) QBR > 10m + Fluvio-glacial Sands (42.12) BoD (39.12) CLU	Unconfined groundwater/53.12-51.12	No test; similar to Glasnevin	151.13	Max lateral Q^{in}: 0.8-1.3 Max vertical Q^{in}: 3.48 (upwelling):	0.34 Note: This is important for water management **during** construction and before final sealing works	106.13 Relates to the modelled extent of 'radial supply of water' during dewatering **post** toe-grouting and before final sealing.	D-Wall installed, assume 1.5m toe grouting completed

Application of the data collated for Glasnevin Station to this site, and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Ballymun Station will be in the order of 12.2l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 3.48l/sec (~300.7m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 116m^2, the estimated seepage would be in the range of 0.8l/sec and 1.3l/sec. Ballymun Station will be constructed within the QBR subsoil and CLU rock with permeability values recorded in the range of 1.94E-04m/s (QBR <10m) & 5.90E-06m/s (QBR >10m) for subsoils, 2.90E-04m/s for BoD unit, and 2.00E-06m/s (CLU) for rock.

Collins Avenue

The key hydrogeological data available and interpreted for the Collins Avenue station is presented below.

Table 19.32: Collins Avenue - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) (Plaxis2D)	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Collins Avenue 120 x 26 x 27 (d) 12+220	+18.51	Qx (49.42) QBR <10m & Fluvio-glacial Sands (41.10) QBR >10m & Fluvio-glacial Sands (39.42) BoD (29.42) CLU	Unconfined groundwater/43.42-41.10	No test; similar to O'Connell Street & Tara Street	213.22	Max lateral Q^{in}: 1.1-1.8 Max vertical Q^{in}: 2.32 (upwelling):	0.32 Note: This is important for water management **during** construction and before final sealing works	147.46 Relates to the modelled extent of 'radial supply of water' during dewatering **post** toe-grouting and before final sealing.	D-Wall installed, assume 1.5m toe grouting completed

Application of the data collated for O'Connell Street Station/Tara Station to this site, and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Collins Avenue Station will be in the order of 16.3l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 2.32l/sec (~200.5m^3/day equivalent). If during the Construction Phase a breach occurs in the retained walls equivalent to a panel of 116m^2, the estimated seepage would be in the range of 1.1l/sec and 1.8l/sec. Collins Avenue Station will be constructed within the QBR subsoil and CLU rock with permeability values recorded in the range of 1.94E-04m/s (QBR <10m) & 5.90E-06m/s (QBR >10m) for subsoils, 2.90E-04m/s for BoD unit, and 2.00E-06m/s (CLU) for rock.

Griffith Park

The key hydrogeological data available and interpreted for the Griffith Park station is presented below.

Table 19.33: Griffith Park - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Griffith Park 120 x 35 x 28 (d) 13+820	-14.36	Qx (16.8) QBR < 10m (10.8) BoD (7.8) CLU	Unconfined groundwater/13.8 -12.8	No test; similar to Tara Street	165.71	Max lateral Q^{in}: 0.5-0.9 Max vertical Q^{in}: 3.04 (upwelling):	0.38 Note: This is important for water management **during** construction and before final sealing works	124.55 Relates to the modelled extent of 'radial supply of water' during dewatering **post** toe-grouting and before final sealing.	Although the soil is more permeable at Tara Station, the equivalent pumping test has been assigned based on subsoil thickness. D-Wall installed, assume 1.5m toe grouting completed

Application of the data collated for Tara Station, and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Griffith Park Station will be in the order of 8.22l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 3.04l/sec (~262.7m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 117m^2, the estimated seepage would be in the range of 0.5l/sec and 0.9l/sec. Griffith Park Station will be constructed within the QBR subsoil and CLU rock with permeability values recorded in the range of 1.94E-04m/s (QBR <10m) for subsoils, 2.90E-04m/s for BoD unit, and 2.90E-06m/s (CLU) for rock.

Glasnevin

The key hydrogeological data available and interpreted for the Glasnevin station is presented below.

Table 19.34: Glasnevin - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Glasnevin 120 x 35 x UNDEF (d) 14+850	-14.5	Qx (21.38) QBR <10m (15.63) QBR >10m & Fluvio-glacial Sands (-1.38) BoD (-5.38) CLU	Unconfined groundwater /19.63-17.63	Max drawdown: 35.1 mOD Steady State (SS) (m^3/s): $3.89 \cdot 10^{-3}$ Max radial COD (m) estimated from SS test conditions~180	180.88	Max lateral Q_{in}: 0.7-1.1 Max vertical Q_{in}: 6.95 (upwelling):	0.33 Note: This is important for water management **during** construction and before final sealing works	107.35 Relates to the modelled extent of 'radial supply of water' during dewatering **post** toe-grouting and before final sealing.	The bottom of the excavation is projected in gravels belonging to the BoD. D-Wall installed, assume 1.5m toe grouting completed

Assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Glasnevin Station will be in the order of 10.12l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 6.95 l/sec (~600.7 m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 96m^2, the estimated seepage would be in the range of 0.7l/sec and 1.1l/sec. Glasnevin Station will be constructed within the QBR subsoil and CLU rock with permeability values recorded in the range of 1.94E-04m/s (QBR <10m) & 5.90E-06m/s (QBR >10m) for subsoils, 2.90E-04m/s for BoD unit, and 2.90E-06m/s (CLU) for rock.

Mater

The key hydrogeological data available and interpreted for the Mater Station is presented below.

Table 19.35: Mater - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Mater 112 x 26 x 29 (d) 15+640	-11.0	Qx (20.14) QBR <10m & Fluvio-glacial Sands (12.75) QBR >10m & Fluvio-glacial Sands (2.75) BoD (-2.25) CLU	Unconfined groundwater/14.75-10.75	No test; similar to Glasnevin	201.50	Max lateral Q^{in}: 1.0-1.7 Max vertical Q^{in}: 3.47 (upwelling):	0.42 Note: This is important for water management **during** construction and before final sealing works	140.47 Relates to the modelled extent of 'radial supply of water' during dewatering **post** toe-grouting and before final sealing.	D-Wall installed, assume 1.5m toe grouting completed

Application of the data collated for Glasnevin Station, and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Mater Station will be in the order of 15.74l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 3.47l/sec (~300m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 112m^2, the estimated seepage would be in the range of 1.0l/sec and 1.7l/sec. Mater Station will be constructed principally within the QBR subsoil and upper CLU rock with permeability values recorded in the range of 7.30E-07m/s (QBR <10m) & 2.90E-06m/s (QBR >10m) for subsoils, 2.90E-04m/s for BoD unit and 2.90E-06m/s (CLU) for rock.

O'Connell Street

The key hydrogeological data available and interpreted for the O'Connell Street Station is presented below.

Table 19.36: O'Connell Street - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) (Plaxis2D)	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
O'Connell Street 140 x 26 x 29 (d) 16+660	-30.70	Qx (3.29) QBR <10m & Fluvio-glacial Sands (-4.71) QBR >10m & Fluvio-glacial Sands (-19.71) BoD (-21.71) CLU	Unconfined groundwater/1.29 to -0.71	Max drawdown: 32.94 (mOD) Steady State (SS) (m3/s): $3.78 \cdot 10^{-3}$ Max radial COD (m) estimated from SS test conditions: ~30.42	175.20	Max lateral Q^{in}: 1.0-1.7 Max vertical Q^{in}: 2.46 (upwelling):	0.37 Note: This is important for water management during construction and before final sealing works	124.49 Relates to the modelled extent of 'radial supply of water' during dewatering post toe-grouting and before final sealing.	D-Wall installed, assume 1.5m toe grouting completed

Assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the O'Connell Street Station will be in the order of 15.74l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 2.46l/sec (~212.9m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 112m^2, the estimated seepage would be in the range of 1.0l/sec and 1.7l/sec. O'Connell Street Station will be constructed principally within the QBR subsoil and upper CLU rock with permeability values recorded in the range of 7.30E-07m/s (QBR <10m) & 2.90E-06m/s (QBR >10m) for subsoils, 2.90E-04m/s for BoD unit and 5.64E-06m/s (CLU) for rock.

Tara Street

The key hydrogeological data available and interpreted for the Tara station is presented below.

Table 19.37: Tara - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Tara Street 105 x 27 x 28 (d) 17+400	-29.53	Qx (+0.39) QAG - Alluvial Sands (-4.61) BoD (-6.61) CLU	Unconfined groundwater/0.39 to -0.61	Max drawdown: 31.73m OD Steady State (SS) (m^3/s): $2.5 \cdot 10^{-4}$ Max radial COD (m) estimated from SS test conditions: ~4.79	176.45	Max lateral Q^{in}: 1.0-1.7 Max vertical Q^{in}: 2.91 (upwelling):	0.42 Note: This is important for water management **during** construction and before final sealing works	134.27 Relates to the modelled extent of 'radial supply of water' during dewatering **post** toe-grouting and before final sealing.	D-Wall installed, assume 1.5m toe grouting completed

Assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Tara Station will be in the order of 17.8l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 2.91l/sec (~251.6m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 112m^2, the estimated seepage would be in the range of 1.0l/sec and 1.7l/sec. Tara Station will be constructed principally within the QAG subsoil and CLU rock with permeability values recorded in the range of 7.30E-07m/s (QAG) for subsoils, 2.90E-04m/s for BoD unit and 5.64E-06m/s (CLU) for rock.

Note: The proximity of the proposed Tara Station box to the Stein River and Gallows River which are presumably culverted near this station location should be noted and full orientation/depth of the culverted watercourses duly identified and recorded. It is possible that buried tributaries [terraced gravels] of these features still remain in the area.

St Stephen's Green

The key hydrogeological data available and interpreted for the St Stephen's Green Station is presented below.

Table 19.38: St Stephen's Green - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
St. Stephens Green 115 x 25 x 28 (d) 18+480	-22.16	Qx (9.90) QBR <10m (4.90) BoD (0.90) CLU	Unconfined groundwater/6.9 - 5.9	No test; Similar to Charlemont	149.22	Max lateral Q^{in}: 0.5-0.8 Max vertical Q^{in}: 3.00 (upwelling):	0.38 Note: This is important for water management **during** construction and before final sealing works	114.95 Relates to the modelled extent of 'radial supply of water' during dewatering **post** toe-grouting and before final sealing.	D-Wall installed, assume 1.5m toe grouting completed

Application of the data collated for Charlemont Station, and assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the St Stephen's Green Station will be in the order of 7.82l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 3.0l/sec (~295.6m^3/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 111m^2, the estimated seepage would be in the range of 0.5l/sec and 0.8l/sec. St Stephen's Green Station will be constructed principally within the QBR subsoil and CLU rock with permeability values recorded in the range of 1.94E-04m/s (QBR <10m) for subsoils, 2.90E-04m/s for BoD unit and 5.64E-06m/s (CLU) for rock.

Charlemont

The key hydrogeological data available and interpreted for the Charlemont station is presented below.

Table 19.39: Charlemont - Summary of Key Hydrogeological Data

Location Ref. Dimensions (Approx. m) Chainage (Approx.)	Secant Pile/ D-Wall (mOD)	Geological profile (mOD)	Confined/Unconfined Groundwater/general SWL (mOD)	Pumping Test data used	Max COD during construction dewatering prior to toe-grouting (m) Plaxis2D	Assessed Inflows to Station at completion of excavation (l/s) Plaxis2D	Post-Grouting inflows (l/s) Plaxis2D	Max cone of depression post grouting (m) and/or prior to final sealed structure Plaxis2D	Comments
Charlemont 120 x 25 x 27 (d) 19+360	-18.18	Qx (13.85) QBR <10m (5.85) QBR >10m (3.85) BoD (-0.15) CLU	Unconfined groundwater/12.85 - 10.85	Max draw down: 34.3 Steady State (SS) (m^3/s): $4 \cdot 10^{-3}$ Max radial COD (m) estimated from SS test conditions: ~73.71	134.95	Max lateral Q^{in}: 1.6-2.2 Max vertical Q^{in}: 2.34 (upwelling):	0.32 Note: This is important for water management during construction and before final sealing works	104.67 Relates to the modelled extent of 'radial supply of water' during dewatering post toe-grouting and before final sealing.	D-Wall installed, assume 1.5m toe grouting completed

Assuming a laminar water flow and a continuous recharge of the aquifer, the dewatering process during the construction of the Charlemont Station will be in the order of 20.56l/sec as a maximum value. This is the maximum potential calculated underground water flow coming into the station in an excavation with free water flow.

Plaxis2D modelling indicates a potential significant inflow from the bottom of the station footprint (i.e. discharge from the underlying CLU limestone) of approx. 2.34l/sec (~202.2m³/day equivalent). If during the Construction Phase, a breach occurs in the retained walls equivalent to a panel of 117m², the estimated seepage would be in the range of 1.3l/sec and 2.2l/sec. Charlemont Station will be constructed principally within the QBR subsoil and CLU rock with permeability values recorded in the range of 1.94E-04m/s (QBR <10m) & 5.90E-06m/s (QBR >10m) for subsoils, 2.90E-04m/s for BoD unit and 5.64E-06m/s (CLU) for rock.

Note: It is unusual that the modelled groundwater inflows for the proposed station at Charlemont are higher than the maximum inflows calculated for the proposed Tara Station for example. As per results of analysis undertaken the permeability value for the majority of the station locations is driven by the permeability assessed within the BoD layer. In the case where BoD was not considered for Charlemont, then the permeability should be in the order of 10^{-8}m/s.

In summary, in terms of hydrogeological risk associated with groundwater ingress, the hydrogeological modelling indicates, conservatively, that there may be significant water flows including at the contact zone between soil and rock (BoD and UWR units) and in a lesser way in sand/gravel lenses within Boulder Clays. As part of data validation, the pumping tests carried out during recent phased ground investigations provided new and reliable data for assessment for the proposed Project. In effect, all Plaxis2D inputs were validated by pumping test data from 24 no. tests carried out in 2020/2021 and therefore positively influenced the calibration and subsequent outputs of the modelling exercises for ingress potential. The risk subsequently appears to be lower than that estimated with the data collected and assessed as part of Metro North (Appendix A19.10).

19.5.3.5 Groundwater Zone of Influence (ZOI)

19.5.3.5.1 Metro North

An assessment of the potential for groundwater lowering associated with underground construction for the Metro North project was undertaken for the Railway Procurement Agency (RPA) (RPA, 2009). The key objective of this historical review was to identify areas where groundwater would be lowered temporarily/permanently and how the groundwater level would be recharged, and by which means. This review is therefore very relevant to the current EIAR assessment of dewatering potential along the alignment including possible ZOI and where potential exists for the proposed Project to lower groundwater levels in areas where it was equally assessed for Metro North. The section effectively presents a comparative discussion on what was expected in the past in terms of groundwater management as part of the Metro North and what is proposed for the current proposed Project which is equally if not more effectively tackled in terms of the current design with contemporary mitigation methodologies.

The historical assessment for the RPA included a summary of the 'envisaged' construction methods and dewatering requirements, the ground profile, the approximate depth to groundwater and likely mitigation measures. Table 19.40 provides an overview of some of the pertinent information in this report with reference to the current proposed Project and potential impacts of dewatering requirements and groundwater lowering along the alignment using the geographical split reference AZ1-AZ4 to place the historical data in context.

Table 19.40: Assessment of Potential for Groundwater Lowering Associated with Underground Construction - Metro North

Ref. Area	Structure	Envisaged Dewatering	Assessment of Potential for Groundwater Lowering
AZ1	Retained cut, and cut and cover tunnel at Malahide Roundabout	Temporary sump pumping from within excavation during construction. No long-term dewatering.	**Low** due to low permeability of predominantly cohesive glacial till and relatively shallow cut.
AZ1	Fosterstown Underpass (retained cut, and cut and cover)	Temporary sump pumping from within open cut excavation during construction. No long-term dewatering.	**Low** due to low permeability of predominantly cohesive glacial till, groundwater cut-off provided by piled wall and relatively shallow cut.
AZ1	Cutting south of Fosterstown	Localised long-term reduction in groundwater table in vicinity of cutting.	**High** due to open cutting; however, localised and limited impact due to low permeability of predominantly cohesive glacial till and relatively shallow cut resulting in small magnitude of settlement that will not have a significant impact on the surrounding environment.
AZ2	Airport Tunnel DANP	Localised long-term reduction in groundwater table in vicinity of cut slopes.	**Low** due to low permeability of predominantly cohesive glacial till and cut-off provided by piled retaining wall. **High** due to open cutting; however, localised and limited impact due to low permeability of predominantly cohesive glacial till and relatively shallow cut resulting in small magnitude of settlement that will not have a significant impact on the surrounding environment.

Ref. Area	Structure	Envisaged Dewatering	Assessment of Potential for Groundwater Lowering
AZ2	Airport Stop	Temporary sump pumping from within excavation during excavation in soil and rock. No long-term dewatering.	**Low to medium** due to low permeability of predominantly cohesive glacial till and rock. Groundwater cut-off provided by retaining walls, including toe grouting of retaining walls and fissure grouting in rock where required to reduce potential for groundwater lowering to **low**.
AZ2	Airport Tunnel DASP	Localised long-term reduction in groundwater table in vicinity of cut slopes.	**Low** due to low permeability of predominantly cohesive glacial till and cut-off provided by piled retaining wall. **High** due to open cutting; however, localised and limited impact due to low permeability of predominantly cohesive glacial till and relatively shallow cut resulting in small magnitude of settlement that will not have a significant impact on the surrounding environment.
AZ4	Ballymun Stop	Temporary sump pumping from within excavation during excavation in soil. No long-term dewatering.	**Low** due to low permeability of glacial till and groundwater cut-off provided by retaining wall.
	DCU Stop		
	Griffith Avenue Stop		**Low** due to low permeability of rock and glacial till and groundwater cut-off provided by retaining wall.
	St. Patrick's Access Shaft	Temporary dewatering of glacial sands and gravels may be required within shaft in advance of shaft excavation.	**Low** due to low permeability of rock and glacial till and groundwater cut-off provided by retaining wall.
	Drumcondra Stop	Temporary sump pumping from within excavation during excavation in soil. No long-term dewatering.	
	Mater Stop	Temporary dewatering from wells within excavation of extensive glacial sand and gravel deposits required in advance of basement excavation. No long-term dewatering.	**Low to medium** due to relatively high permeability of sand and gravel deposits and need for dewatering. Groundwater cut-off provided by retaining wall toed into rock (cohesive glacial till/bedrock interface) including toe grouting of retaining walls where required to reduce potential for groundwater lowering to **low**.
	Parnell Square Stop	Temporary dewatering of glacial sands and gravels from wells within excavation required in advance of basement excavation. No long -term dewatering.	**Medium** due to relatively high permeability of sand and gravel deposits and need for dewatering. Groundwater cut-off provided by retaining wall toed into rock (glacial sand and gravel /bedrock interface) including toe grouting of retaining walls where required to reduce potential for groundwater lowering to **low**.
AZ4	O'Connell Bridge Stop	Temporary dewatering from wells in alluvium /glacial sands and gravels required from within excavation in advance of basement excavation. No long-term dewatering.	**Medium** due to presence of water bearing granular materials and River Liffey recharge source. Groundwater cut-off provided by retaining wall toed into rock (glacial sand and gravel /bedrock interface) including toe grouting of retaining walls where required to reduce potential for ground water lowering to **low**. It is anticipated that historical groundwater levels in the vicinity of the River Liffey are likely to have been as low as the base of the alluvial/estuarine deposits and, therefore, the likelihood of significant settlement caused by future groundwater lowering in these deposits is low.
		Temporary sump pumping from base of mined	**Medium to high** due to presence of water bearing granular materials and River Liffey recharge source above

Ref. Area	Structure	Envisaged Dewatering	Assessment of Potential for Groundwater Lowering
		tunnels. Possible temporary reduction in groundwater levels during construction of tunnels. No long-term dewatering.	bedrock. Inflow quantities dependent on presence of throughgoing joints and possible fault disturbed rock. It is anticipated that historical groundwater levels in the vicinity of the River Liffey are likely to have been as low as the base of the alluvial/estuarine deposits and, therefore, the likelihood of significant settlement caused by future groundwater lowering in these deposits is low. This risk is further reduced through the application of systematic ground treatment as required to further reduce the potential for groundwater inflows.
	St Stephen's Green Stop	Temporary dewatering of glacial sands and gravels from wells within excavation required in advance of basement excavation. No long-term dewatering.	**Low to medium** due to low permeability of rock, relatively high permeability of sand and gravel deposits and need for dewatering. Groundwater cut-off provided by retaining wall toed into rock (glacial sand and gravel /bedrock interface) including toe grouting of retaining walls where required to reduce potential for groundwater lowering to **low**.

The key conclusions drawn from the historical review on groundwater lowering and design proposals at the time, and with reference to the current proposed Project in terms of impact assessment, include the following points:

- In terms of temporary groundwater lowering, this would only be permitted 'by a certain amount' if the main contractor could demonstrate that, in addition to no detrimental impact to buildings, infrastructure or the environment, there would be no adverse impacts: therefore, groundwater recharge was not a prerequisite of groundwater lowering. *MetroLink: Specific site-based modelled groundwater lowering has been undertaken for all station boxes and cut sections with dewatering activities generally of temporary duration. The use of D-walls and secant piles will significantly mitigate against any lateral inflows; toe-grouting methodology will limit vertical up water ingress thereby helping to maintain some equilibrium of local water levels.*
- The reference design and associated construction planning satisfied the requirements of the [2008] EIS and construction requirements in the following way:
  - Groundwater cut-off to station boxes was achieved by diaphragm walls or bored piles supported by ground treatment as required. MetroLink: D-wall sealed structures with toe-grouting to 1.50m below base of D-wall forms a key component of the proposed design mitigation of groundwater ingress and off-site impacts on groundwater levels.
  - Ground treatment of the base of excavations as required. MetroLink: Sealed base of excavation at shallower elevation than base of D-wall (mOD) as part of proposed design. It is also proposed to extend the length of the D-walls and provide ground treatment in the form of permeation/fissure grouting to the toe of the D-walls in order to cut off or lengthen groundwater flow paths. Dewatering will also allow excavation of the base in dry conditions (refer also Section 19.5.3.4.4 above). It is therefore planned that full base grouting is not required, i.e. the aim will be to seal the base in place, although the risk remains that it may be required.
  - Fissure grouting of the limestone bedrock as required - both for station and tunnel excavation. MetroLink: Ground stability methodologies will apply in areas where hot spots are anticipated in terms of potential ground settlement as a result of both dewatering activities and subsoil removal during the tunnelling process for example.
  - Construction of the [tunnel] using TBM to install a watertight segmental tunnel lining with the ability to pressurise the tunnel face above the natural hydrostatic pressure of the ground, where required, to prevent significant groundwater inflows that could potentially result in groundwater lowering. MetroLink: EPB and Slurry TBM methodology will apply here to counteract similar potential impacts during the Construction Phase. More advanced and proven technologies since 2008 will be applied to MetroLink.
- With regard to permanent groundwater lowering, the Metro North project required that all permanent underground structures were designed as 'undrained, watertight structures' (with

'onerous watertightness criteria), therefore, underground structures would have no significant long-term impact on groundwater levels. The only long-term changes in groundwater level would be associated with cuttings below the water table or piezometric surface, which would tend to draw groundwater towards them resulting in a lowering of the water table in their close vicinity. *MetroLink: All below ground structures (deep excavations and cut sections) will be designed as water-tight/fully sealed structures with effective drainage designed to mitigate against groundwater mounding on the upgradient side of the feature. Local/regional groundwater flow will return to pre-construction patterns.*

- 'Tunnel boring methods and the expected ground conditions are such that general groundwater levels will remain substantially unaffected during construction. The glacial till has a very low permeability while the limestone in most cases will be predominantly dry'. *MetroLink: Groundwater flow patterns around tunnelled sections will generally remain unaffected during TBM advancement based on pressurized head where required and continuous lining of the bore including significant advances in TBM methodology since 2008. Any variation in groundwater levels will quickly return to pre-construction conditions. Extensive ground investigations, field tests and modelling works have significantly helped to characterise the hydrogeological setting through which the proposed Project will pass and this represents a contemporary assessment rather than reliance solely on historical data.*

- The construction of the O'Connell Bridge Station mined platform tunnels beneath the River Liffey was considered to represent a 'significant challenge, particularly with respect to the control of groundwater inflow'. The relatively high permeability of the superficial soils overlying rockhead at this location would provide little attenuation of flow from the River Liffey, and therefore steady state conditions could be assumed as credible 'worst case conditions' for flow calculations. If this scenario were valid, although groundwater drawdown may occur in the roof rock [UWR] as a result of the relatively small storage capacity, it is unlikely that significant groundwater drawdown will occur in the overlying superficial soils. *MetroLink: Plaxis2D modelling of station boxes north and south of the River Liffey (using contemporary data from a number of hydraulic field tests conducted in overburden and bedrock pumping wells) has been used to calculate [conservative] water inflows to the excavations before and after installation of water-tight D-walls at each. The modelling has also provided detail on calculated ZOI of [temporary] dewatering activities beyond the excavation footprint and deep set, grouted foundation walls.*
- 'Short-term lowering of the groundwater table within the supported excavation may sometimes be required in connection with the construction of the cut and cover tunnels and [station] boxes in open excavations from the surface (or top-down). However, published experience with this type of construction in Dublin (Table 19.40) demonstrates that residual inflows through the base of the excavation can usually be dealt with by means of a reasonably localised pumping system'. *MetroLink: As above, modelled ingress and ZOI calculations have been completed for all deep excavations with inflows reducing as the fully sealed structure is completed. Residual inflows will be managed by sump pumping or external periphery wells with groundwater discharged to sewer as treated water (Note: Additional re-use of water is also proposed at sites where dewatering will not be an on-going activity).*
- With regard to groundwater recharge this would either be to 'prevent excessive drawdown outside the zone of immediate excavation; or as a means of disposing of the abstracted groundwater'. The review stated that 'no requirement for the first of these ZOI was envisaged because the effect of excavation dewatering outside the excavation was expected in general to be 'negligible'. The review further commented that 'groundwater recharge is a potentially difficult … way of disposing of abstracted groundwater compared with discharge to a sewer or watercourse and is again not anticipated to be a requirement'. *MetroLink: It is unlikely that recharge will be used within city centre settings owing to the nature of the ground, existing basements and so on. Discharge of treated water for the proposed Project will be to available [defined] sewers under consent; management of water will also include [proactive] re-use of water on other MetroLink sites to reduce reliance of external source supply.*

19.5.3.5.2 The Proposed Project

For the current proposed Project, the ZOI has been modelled (refer Appendix A19.8) and details on the interpreted results are presented for each of the stations discussed under Section 19.5.3.4 above.

Lowering of the phreatic level, prior to excavating (or because of tunnelling works), may also cause immediate settlement to occur in layers or lenses of compressible soils, as well as in weathered rocky materials. The impact of such lowering of the groundwater table varies in proportion to its magnitude and radius of influence (i.e. ZOI).

The ZOI for the cut sections or deep excavation locations is typically referred to as the area within which groundwater levels are affected by dewatering of the saturated overburden and/or bedrock aquifer, i.e. drawdown effects with distance from the pumping location. During Construction Phase dewatering, the quantities of water intercepted by pumping will initially be higher as the groundwater storage in the bedrock is tapped into. When the storage component has been drained then the quantities that are intercepted will relate to recharge within the wider ZOI. Modelling for each excavation where pumping will be necessary indicates that groundwater levels will remain at/near their natural [pre-construction] level at specific distances outside of the footprint for the works area. As such, groundwater intercepted during the Construction Phase will remain within the surface water catchment that they would naturally have been received by.

The ZOI (also referred to as the cone of depression) is generally presented as a radius on either side of the subject works area (footprint) which is calculated using the upper range of local [Ll, Pl] aquifer properties and the hydraulic gradient of the potentiometric surface in the area of interest. The calculated maximum drawdown and ZOI for each of the cut sections/deep excavations is summarised in Table 19.22. The assessment of groundwater level drawdown, using Plaxis-2D modelling software, is considered 'conservative' as it assumes that drainage of the excavation area extends across the full footprint of the subject works area. The pumping test radius (cone of depression radius during the test) is estimated using the following formula:

$$s_1 - s_2 = \frac{Q}{2\pi T} ln\left(\frac{r_2}{r_1}\right)$$

And depicted in Diagram 19.14, where:

- Si: Distance from the original groundwater surface to the cone of depression
- Q: Water flow extracted
- T: Aquifer transmissivity
- Ri: Horizontal distance to/from the pumping test point

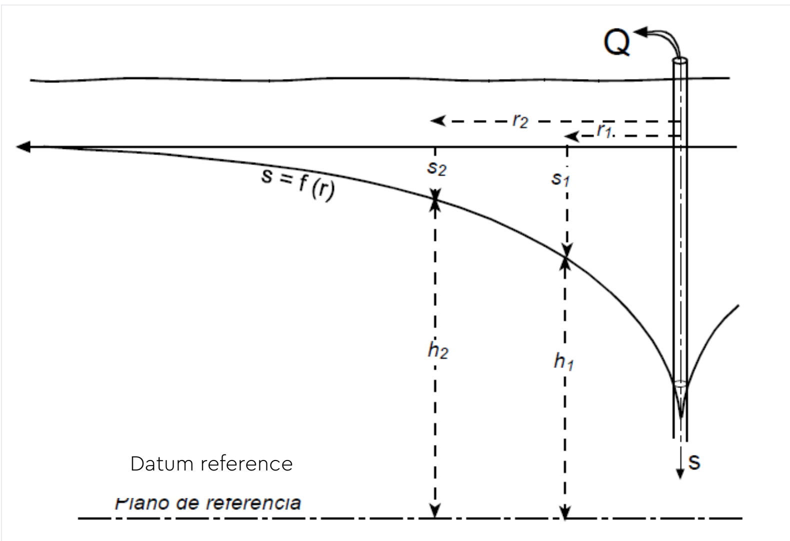

Diagram 19.14: Depiction of Pumping Test Radius

Where s_2=0, then r_2 is the cone of depression radius; rewriting the formula this is transformed to:

$$R = r_1 e^{\frac{s_1 2\pi T}{Q}}$$

Some considerations taken into account in calculations include the following:

- For the estimation of T, the equivalent permeability has been used (both soil and rock);
- For Q the break-even point (steady state condition) during the test has been considered; and
- S1 and r1 can be measured with the monitoring well associated with each test.

The modelling software used here is the Plaxis2D model which also uses equivalent permeability in the calculated outputs of R (estimated radius beyond point of pumping, as a result of drawdown effects and which is the maximum derived value between soil and bedrock at the same pumping test well point). A summary of the modelled R (zone of influence) for each of the proposed stations is provided in Table 19.41, which also considers the additional sealing effects of the bottom grout plug in the respective excavation.

Table 19.41: Summary of Modelled ZOI for Proposed Stations

Location Ref.	PUMPING WELL ID	OBSERVATION WELL ID	K_{eq} SOIL (m/s)	K_{eq} ROCK (m/s)	Q SOIL (m3/s)	Q ROCK (m^3/s)	R before construction (m)	R after construction (m)	R after grouting (m) (where applicable)	MAX DRAWDOWN (m)
Geographical Area Ref: AZ1										
SEATOWN R132 North	-	-	-	-	-	-	-	66.79	**46.35**	-
SWORDS CENTRAL (Seatown) R132 South	NBH406	NBH407	1.08E-06	3.80E-08	2.63E-04	7.14E-04	80.12	56.80	**45.33**	12.2
FOSTERSTOWN	-	-	-	-	-	-	-	33.57	**29.91**	-
Geographical Area Ref: AZ2										
DUBLIN AIRPORT	-	-	2.35E-06	6.29E-07	-	-	-	83.20	**79.91**	-
DARDISTOWN	-	-	1.08E-06	3.80E-08	-	-	-	24.61	**23.94**	-
Geographical Area Ref: AZ3										
NORTHWOOD	-	-	1.50E-06	7.19E-06	-	-	-	104.97	**62.53**	-
Geographical Area Ref: AZ4										
BALLYMUN	-	-	-	-	-	-	-	151.33	**106.13**	-
COLLINS AVENUE	-	-	2.64E-06	-	-	-	-	213.22	**147.46**	-
GRIFFITH PARK	-	-	1.42E-06	1.09E-06	-	-	-	165.71	**124.55**	-
GLASNEVIN	NBH19(A)	NBH19(W)	1.48E-06	1.22E-06	4.08E-04	3.55E-04	150.97	180.88	**107.35**	35.1
MATER	-	-	1.16E-06	1.75E-06	-	-	-	201.50	**140.47**	-
O'CONNELL STREET	NBH23(A)	NBH23(W)	1.20E-05	3.15E-06	-	3.83E-03	30.20	175.20	**124.49**	33.0

Location Ref.	PUMPING WELL ID	OBSERVATION WELL ID	K_{eq} SOIL (m/s)	K_{eq} ROCK (m/s)	Q SOIL (m3/s)	Q ROCK (m^3/s)	R before construction (m)	R after construction (m)	R after grouting (m) (where applicable)	MAX DRAWDOWN (m)
TARA	NBH26(W)	NBH26A	6.06E-06	1.13E-07	-	2.50E-04	4.79 *	176.45	**134.27**	32.0
ST STPHENS GREEN	-	-	2.09E-06	7.32E-05	-	-	-	149.22	**114.95**	-
CHARLEMONT	NBH30(W)	NBH29	1.74E-06	8.34E-07	-	4.00E-03	73.71	134.95	**104.67**	32.2

*Note: * The cone of depression results for Tara Street were quite low so test performed on the bedrock.*

Lowering of the groundwater table, prior to deep excavating or because of tunnelling, may cause immediate settlement to occur in layers or lenses of compressible soils, as well as in weathered, rocky materials. Settlement is therefore directly related to reduced groundwater levels over distance, pore water pressure release, loss of fines through dewatering and similar. The impact of such lowering of the groundwater table varies in proportion to its magnitude and radius/ZOI. Another mechanism responsible for settlement is the dewatering of coarse, fluvio-glacial sediments, embedded or lying beneath the Boulder Clay, and of large bodies of highly fractured bedrock located within the BoD and UWR units, respectively. The dewatering activities cause a compaction of the soil above and around the tunnel for example with associated superficial settlement (Appendix A19.10).

The excavation of the underground stations for the proposed Project will be below the phreatic level. For this reason, excavation methods must progress in dry working conditions with only controlled water inflow into the excavation using suitably designed retaining pile walls such as D-walls or secant pile walls with possible groundwater lowering in the general area outside the footprint. Where the construction methodology is correct and applied effectively, all excavations will be undertaken in relatively dry conditions and without significantly affecting the phreatic level. In the case where during the Construction Phase a diaphragm wall begins to leak then groundwater can flow into the open excavation. This can potentially result in some depression of the phreatic level leading to settlement issues at any existing buildings near the station excavation site. Differential ground settlement at such buildings, induced by a lowering of the phreatic level, can cause damage to the structure and/or aesthetic appearances.

The installation of D-walls or secant piles at specific cuts/station points will also impact favourably on the interpreted ZOI for that location, i.e. reducing significantly the radial (R) extent of dewatering and subsequently the impacts on local groundwater levels beyond the footprint of that works area. This also infers reduced impacts of off-site settlement issues.

The terrain (ground) models that were established in Plaxis2D have considered the stratigraphy of the geotechnical profiles for all proposed stations, in addition to the information provided by nearby boreholes and validation of aquifer characteristics using the results of hydraulic testing completed between 2020-2021. Diagram 19.15 presents a schematic of the Plaxis-2D model for O'Connell Street Station (deep excavation) in order to indicate the approach taken to interpret potential drawdown and ZOI effects at/beyond the construction footprint.

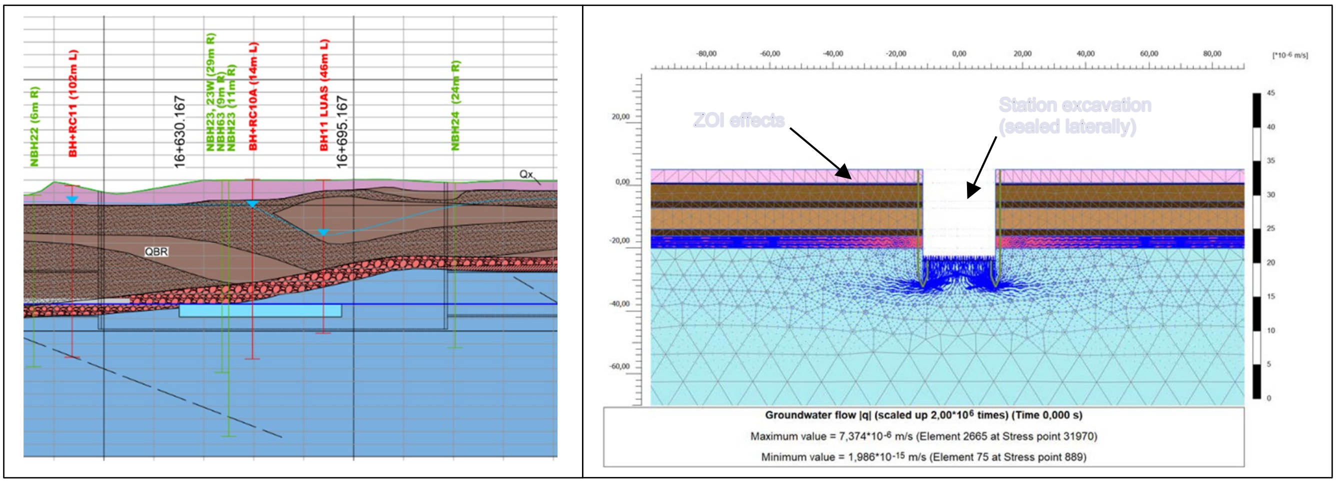

Diagram 19.15: O'Connell Street (Deep Excavation) - Modelled drawdown and ZOI effects

Based on information presented in Section 19.5.3.4 above and from tables shown for the proposed Project the ZOI is anticipated from dewatering effects. The ZOI also considers the point of station construction at Secant Pile or D-wall installation as well as Post Secant Pile or D-wall installation, i.e. base up ingress only prior to final sealing of the structure.

The following subsections further discuss the modelled ZOI from dewatering activities where undertaken as part of the construction excavation works for the proposed stations.

19.5.3.5.3 AZ1 Northern Section

Estuary

The proposed station at Estuary does not involve deep excavation works. As such, the potential for groundwater ingress behaviour within the subsoil and rock at this location has not been modelled. Furthermore, it is unlikely that significant dewatering will occur and therefore Imperceptible effects on off-site ecological receptors are predicted.

Seatown R132 North

The modelled ZOI for this proposed retained cut station is R = 66.8m from the centre of the excavation footprint. This is based on a [conservative] modelled outflow value of approximately 98.5m^3/day of groundwater discharge from the base of the station footprint (Plaxis2D). Seatown Station perimeter will be sealed (secant piles) within the CMUP rock and the modelled R at the completion of the excavation and prior to the final sealed structure is ~46.4m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Ward River - located >560m to the west, riverbed set in QBR/CMUP
- Malahide Estuary - located >840m to north-east
- Greenfields Stream - open (non-culverted) section located >640m to the east
- Seapoint Stream - open (non-culverted) section located >660m to northeast
- Dublin GWB (LI bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat Malahide Estuary SAC/SPA nor does the modelled ZOI intercept any watercourses that potentially receive baseflow (e.g. Ward River) and which ultimately discharge to this protected site. Dewatering at the Seatown station during works will be temporary only with the anticipated radius effect of dewatering (and corresponding inflows) reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions). Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Swords Central (Seatown) R132 South

The modelled ZOI for this proposed station is R = 56.80m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 59.6m^3/day of groundwater discharge. Swords Central Station perimeter will be sealed (secant piles) within the QBL (extending to BoD) and the modelled R at the completion of the excavation and prior to the final sealed structure is ~45.3m (similar to Seatown).

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Ward River - located >560m to the northwest, riverbed set in QBR/CMUP
- Malahide Estuary - located >1.5Km to north-east
- Greenfields Stream - open (non-culverted) section located >1.4Km to the northeast
- Swords Glebe Stream - open (non-culverted) section located >480m to northwest
- Gaybrook Stream North - open channel located >310m to the southeast, and ponds [with potential for wildlife] located >500m to the east of the alignment from Pinnock Hill Roundabout.
- Tributary to the Gaybrook - open channel located >590m to the south
- Swords GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

Similar to Seatown, the predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat Malahide Estuary SAC/SPA nor does the modelled ZOI intercept any watercourses that potentially receive baseflow (e.g. Ward River) and which ultimately discharge to this habitat feature. Dewatering at the Swords Central Station during works will be temporary only with the anticipated radius effect of dewatering (and corresponding inflows) reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions). Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Fosterstown

The modelled ZOI for this proposed station is R = 33.57m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 22m^3/day of groundwater discharge. Fosterstown Station perimeter will be sealed (secant piles) solely within the QBL subsoils with water-bearing Fluvio-glacial sands (also recorded in the wider area). The modelled R at the completion of the excavation and prior to the final sealed structure is ~29.9m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Swords Glebe Stream - open (non-culverted) section located >620m to north
- Gaybrook Stream North - open channel located >240m to the northwest, riverbed set in QBL
- Gaybrook - open (non-culverted) section located >530m to the east
- Tributary to the Gaybrook - open channel located >400m to the southeast
- Sluice River - located >850m to the south, riverbed set in QBL
- Forest Little Stream (Sluice) - located >950m to the south, riverbed set in QBL
- Swords GWB (Ll bedrock aquifer); GSI boundary with Dublin GWB ~70m from proposed station
- Groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat Malahide Estuary (SAC/SPA) or Baldoyle Bay (SAC/SPA) nor does the modelled ZOI intercept any watercourses that potentially receive baseflow and which ultimately discharge to these habitat features. Dewatering at the Fosterstown Station during works will be temporary only with the anticipated radius effect of dewatering (and corresponding inflows from the

QBL/Sands) reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions). Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

19.5.3.5.4 AZ2 Airport Section

Dublin Airport

The proposed station is underground at Dublin Airport. The modelled ZOI for this station is R = 83.20m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 32.8m^3/day of groundwater discharge. Dublin Airport Station perimeter will be sealed (D-walls) within the QBL subsoils but predominantly within CWA (Waulsortian Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~79.9m.

In terms of potential impact on nearby waterbodies as a result of dewatering for the Dublin Airport Station, and in the context of the modelled ZOI, the following attributes are of note:

- Cuckoo Stream - open (non-culverted) section located >750m to south, riverbed set in thick sequence of QBL directly overlying tunnel alignment
- Dublin GWB (WFD: Not at Risk) & Industrial Facility (PO480-02) GWB (WFD: At Risk) - Both are Ll bedrock aquifer classifications and crossed by proposed station
- Groundwater wells (GSI, 2022)

In terms of hydrogeology, the predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat Baldoyle Bay SAC/SPA nor does the modelled ZOI intercept any watercourses that potentially receive baseflow and which ultimately discharge to this habitat feature. Dewatering at the Dublin Airport Station during works will be temporary only with the anticipated radius effect of dewatering (and corresponding inflows from the QBL/CWA reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions). For comparison, Table 19.40 indicates the final assessment of potential for groundwater lowering for Metro North as 'Low' with reference also made to the positive effects of cut-off walls and toe grouting in the underlying bedrock.

Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Dardistown

The proposed depot [and retained cut station] is above ground at Dardistown with predominantly in cut and at grade. The modelled ZOI for the future station is R = 24.61m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 34.3m^3/day of groundwater discharge. Dardistown Station perimeter will be sealed accordingly within the QBL subsoils. The modelled R at the completion of the [6.5m] excavation and prior to the final sealed structure is ~23.9m.

In terms of potential impact on nearby waterbodies as a result of dewatering for the [future] Dardistown Station, and in the context of the modelled ZOI, the following attributes are of note:

- Mayne River - open (non-culverted) section located >300m to east, riverbed set in thick sequence of QBL
- Tributaries to Mayne River - open (non-culverted) sections located >130m to east, 170m to northeast -these watercourses are set in QBL and will be diverted as part of the proposed Project
- Dublin GWB - Pl bedrock aquifer classification crossed by proposed depot and station
- Groundwater wells (GSI, 2022)

In terms of hydrogeology, the predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat Baldoyle Bay

SAC/SPA nor does the modelled ZOI intercept any watercourses that potentially receive baseflow and which ultimately discharge to this habitat feature.

Dewatering at the Dardistown Station during works will be temporary only with the anticipated radius effect of dewatering (and corresponding inflows from the QBL) reducing as the 'comparatively shallow' future station construction progresses towards full perimeter and base seal (i.e. full watertight conditions).

The wider area development works will ensure long-term continued flow of headwaters to the Mayne River flowing to the east. The stream located to the north of the proposed depot boundary -which will be diverted as part of the proposals for this site area - is likely set in QBL subsoils and not receiving baseflow from the underlying bedrock (>16m deep). The stream, following full diversion, will continue to flow as before the planned works, is unlikely to be affected by [temporary] dewatering works at the future station and is outside the modelled ZOI for the station dewatering activities anticipated.

Review of publicly available databases on groundwater abstraction indicates the presence of 'industrial boreholes' (>90m deep)/wells >30m deep) within the area to the southeast of the proposed [future] station. However, given that the accuracy of these well points is 100m-200m and >250m and the TOR for the proposed station is <6mBGL it is unlikely that these wells will be impacted by the modelled ZOI for this station excavation which is also basing the estimates of dewatering on the afore-mentioned shallow design for the station. The deep wells in the area mentioned are likely drawing water from the lower bedrock, with the BOD and Top of Weathered Rock assessed at approximately 16.2mBGL. As such, it is unlikely that localised [shallow level and temporary] dewatering of the future station excavation within the QBL deposits, with toe-grouting also reducing inflow effects, will impact on deeper groundwater flows at well points located within the southeast of the Dardistown site area.

19.5.3.5.5 AZ3 Dardistown to Northwood

Northwood

The modelled ZOI for this proposed station is R = 104.97m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 228.6m^3/day of groundwater discharge. Northwood Station perimeter will be sealed (D-walls) within the QBR subsoils and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~62.5m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Santry River - open (non-culverted) section located >380m to northeast, riverbed set in QBR
- Tributary to Santry River - open channel located >360m to the north, set in QBR
- Ballymun Stream -tributary to Santry River - open channel located >400m to southeast, set in QBR
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat North Bull Island SPA nor does the modelled ZOI intercept any watercourses that potentially receive baseflow and which ultimately discharge to this habitat feature. Dewatering at the Northwood station during works will be temporary only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.50m below base of D-wall. Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

19.5.3.5.6 AZ4 Northwood to Charlemont

Ballymun

The proposed station is underground at Ballymun with tunnel alignment. The modelled ZOI for this proposed station is R = 151.33m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 300.7m^3/day of groundwater discharge. Ballymun Station perimeter will be sealed (D-walls) within the QBR subsoils with water-bearing Fluvio-glacial sands (also recorded in the wider area) and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~106.1m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Ballymun Stream - tributary to Santry River - open channel located >600m to north, set in QBR
- Historical underground/culverted river - located >300m to northeast, set in QBR, undefined feature
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered *Imperceptible*. The calculated drawdown does not extend as far as the protected habitat North Bull Island SPA nor does the modelled ZOI intercept any watercourses that potentially receive baseflow and which ultimately discharge to this habitat feature. Dewatering at the Ballymun Station during works will be temporary only with the anticipated radius effect of dewatering reducing as the Station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.5m below base of D-wall. Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Collins Avenue

The proposed station is underground at Collins Avenue with tunnel alignment. The modelled ZOI for this proposed station is R = 213.22m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 200.5m^3/day of groundwater discharge. Collins Avenue Station perimeter will be sealed (D-walls) within the QBR subsoils with water-bearing Fluvio-glacial sands (also recorded in the wider area) and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~147.5m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Tolka River - open channel located >1.6km to south, set in QBR/BoD
- Historical underground/culverted Wad River Diversion running north-south (and also shown as West to East) - located ~50m to east, set in QBR, undefined feature which discharges to the Tolka River to the south
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Temporary *Imperceptible* to *Not Significant* based on proximity to the Wad River Diversion. The calculated drawdown does not extend as far as the protected habitat South Dublin Bay and River Tolka Estuary SPA nor does the modelled ZOI intercept any watercourses that potentially receive baseflow (e.g. Tolka River) and which ultimately discharge to the protected sites. Dewatering at the Collins Avenue Station during works will be temporary only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.50m below base of D-wall. Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Griffith Park

The proposed station is underground at Griffith Park with tunnel alignment. The modelled ZOI for this proposed station is R = 165.71m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 262.8m^3/day of groundwater discharge. Griffith Park Station perimeter will be sealed (D-walls) within the QBR subsoils and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~124.6m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Tolka River - open channel located ~90m to immediate south, set in QBR/BoD
- Historical underground/culverted Wad River Diversion - located ~30m to east, set in QBR, undefined feature which discharges to the Tolka River to the immediate south of proposed station
- Claremont Stream (discharging to Tolka River) -open section located >170m to the west
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Temporary *Imperceptible* to *Not Significant* based primarily on proximity to the Tolka River and Wad River Diversion. The calculated drawdown does not extend as far as the protected habitat South Dublin Bay and River Tolka Estuary SPA but the modelled ZOI could potentially intercept the Tolka River watercourse which may potentially receive baseflow from the BoD layer. However, it is considered that there is no perceptible effect on groundwater body status or habitat requirements here. Dewatering at the Griffith Park Station during works will be temporary only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.5m below base of D-wall. Notwithstanding this, until final sealing of the structure the calculated ZOI is still within distance of the Tolka River. Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Glasnevin

The proposed station is underground at Glasnevin with tunnel alignment. The modelled ZOI for this proposed station is R = 180.88m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 600.7m^3/day of groundwater discharge. Glasnevin Station perimeter will be sealed (D-walls) within the QBR subsoils and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~107.4m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Tolka River - open channel located >900m to north, set in QBR/BoD
- Royal Canal - located ~80m to the immediate south of the proposed station; assumed lined feature and set in QBR (with >15m thick Clay sequence)
- Historical underground/culverted watercourses - located ~300m to northwest (near Prospect Way), set in QBR, undefined features which are likely tributaries of the Tolka River to the north of proposed station.
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat South Dublin Bay and River Tolka Estuary SPA nor does the modelled ZOI intercept any watercourses that potentially receive baseflow (e.g. Tolka River to the north) and which ultimately discharge to this habitat feature. The nearest water feature of interest is the Royal Canal to the immediate south however this is a lined waterbody set in brown Boulder Clay with fluvio-glacial sands recorded at depths >16mBGL. Dewatering at the Glasnevin Station during works will be temporary to short-term only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.5m below base of D-wall. Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Mater

The proposed station is underground at Mater with tunnel alignment. The modelled ZOI for this proposed station is R = 201.5m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 300m^3/day of groundwater discharge. Mater Station perimeter will be sealed (D-walls) within the QBR subsoils and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~140.5m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Royal Canal -located ~515m to the immediate north of the proposed station; assumed lined feature and set in QBR (>15m thick Clay sequence at this point and possible fluvio-glacial sands at depth >6mBGL)
- Historical underground/culverted watercourse - located >650m to south-southwest, set in QBR/QBR with fluvio-glacial sands; This undefined subterranean feature is likely to be the historical Bradoge River which ultimately discharges to the River Liffey to the south of the proposed station.
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat Dublin Bay nor does the modelled ZOI intercept any watercourses that potentially receive baseflow and which ultimately discharge to this habitat feature. The nearest water feature of interest is the Royal Canal at distance to the north however this is a lined waterbody set in brown Boulder Clay with fluvio-glacial sands recorded at depths >16mBGL. Dewatering at the Mater Station during works will be temporary only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.5m below base of D-wall. Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

O'Connell Street

The proposed station is underground at O'Connell Street with tunnel alignment and the site is defined as a station box and 'over site development'. The modelled ZOI for the proposed station box is R = 175.2m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 212.9m^3/day of groundwater discharge. O'Connell Street Station perimeter will be sealed (D-walls) within the QBR (and fluvio-glacial sands) subsoils and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~124.5m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- River Liffey -located ~450m to the south of the proposed station; set in QAG -Alluvial sand and gravels which are likely to be in hydraulic connection with the extensive [underlying] fluvio-glacial sand sequences within the QBR beneath O'Connell Street Station.
- Historical underground/culverted watercourse - located ~280m to west (below ILAC Centre) also set in QBR with fluvio-glacial sands. This undefined subterranean feature is likely to be the historical Bradoge River which ultimately discharges to the River Liffey to the south.
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in the wider area is considered *Imperceptible*. The calculated drawdown does not extend as far as the protected habitat Dublin Bay nor does the modelled ZOI intercept any watercourses that potentially receive baseflow and which ultimately discharge to this habitat feature. The nearest water feature of concern is the River Liffey at distance to the south which is also tidal within the QAG deposits predominantly, but with observed [albeit very minimal] potential tidal oscillation effects within the QBR at this proposed station. Dewatering at the O'Connell Street site during works will be temporary only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.50m below base of D-wall. Note: The modelling for O'Connell Street station box footprint and drawdown/ZOI results presented for this location are appropriate to the site as a whole i.e. irrespective of whether or not the proposed Dublin Central Site 2 (i.e. Phase 1 of the Developer's phased construction strategy) is constructed before the station box (i.e. Phase 2A, Phase 2B and Phase 2B) which is the current proposal for the O'Connell Street over site development.

Table 19.40 indicates the assessment of potential for groundwater lowering for Metro North as 'Medium to High' due to presence of water bearing granular materials and River Liffey recharge source above bedrock. However, reference is also made to the positive effects of ground treatment in the underlying bedrock to further reduce the potential for groundwater inflows, and therefore reducing other associated risks.

Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Tara

The proposed station is underground at Tara Street with tunnel alignment. The modelled ZOI for this proposed station is R = 176.45m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 251.6m^3/day of groundwater discharge. Tara Station perimeter will be sealed (D-walls) within the QAG (alluvial sands & gravels) subsoils and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~134.3m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- River Liffey -located ~140m to the north of the proposed station; set in QAG -Alluvial sand and gravels which are in direct hydraulic connection with the extensive sand & gravel sequences within the QAG recorded beneath/beyond the proposed Tara Station.
- Historical underground/culverted watercourses - located ~60m to the immediate east and west of the proposed station. These are undefined subterranean watercourses and are likely to be the historical Stein River (to west) and Gallows River (to east) both of which ultimately discharge to the River Liffey in this area.
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in close proximity is considered *Temporary*, *Not Significant* to *Slight* in the absence of mitigation. The calculated drawdown does not extend as far as the protected habitat Dublin Bay however the modelled ZOI intercepts the River Liffey (and both historical watercourses) that potentially receives baseflow and which ultimately discharges to this habitat feature farther to the east. However, it is considered that there is no perceptible effect on groundwater body/surface waterbody status, water quality or on habitat requirements here, which will remain unaffected. The three listed water features are of note due to the proximity of the proposed station to each. Tidal effects are recorded within the QAG deposits at this proposed station despite the presence of silt in the granular subsoils and minimal changes in [non-pumped] water levels. Dewatering at the Tara Street site during works will be temporary only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.5m below base of D-wall. Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

St Stephen's Green

The proposed station is underground at St Stephen's Green with tunnel alignment. The modelled ZOI for this proposed station is R = 149.22m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 259.6m^3/day of groundwater discharge. St Stephen's Green Station perimeter will be sealed (D-walls) within the QBR subsoils and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~115m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Historical underground/culverted watercourses - located ~200m to the south and 180m to the east, likely set in QBR subsoils. These undefined subterranean features are likely to be the historical Stein River (to south) and Gallows River (to east) both of which ultimately discharge to the River Liffey to the north.
- St Stephen's Green Ponds located >110m to the west. These are referred to as lakes and confirmed as lined features, set in QBR subsoils. Water levels depend on supply fed from the Grand Canal at Portobello bridge with two outflows/overflows i.e. at the east side to Mount Street and from the north side to DCC storm pipe.
- Grand Canal located >650m to the south-southeast of the proposed station; assumed lined feature and set in QBR (8m - 10m thick Clay sequence at this point).
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in close proximity and the wider area is considered Imperceptible. The calculated drawdown does not extend as far as the protected habitat South Dublin Bay SAC nor does the modelled ZOI intercept any watercourses that potentially receive baseflow and which ultimately discharge to this habitat feature. Table 19.40 indicates the assessment of potential for groundwater lowering for Metro North as 'Low to Medium' due to presence of high permeability of sand and gravel deposits and need for dewatering. However, the final risk is indicated as 'Low' due to the positive effects of retaining walls and ground treatment in the underlying strata to further reduce the potential for groundwater lowering [which ultimately affects the ZOI].

The nearest water features of concern include the ponds and the historical watercourses which are lined and culverted, respectively in what is an urban setting. Furthermore, the features are set in brown Boulder Clay recorded at depths >7mBGL. Dewatering at the St Stephen's Green Station during works will be temporary only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.5m below base of D-wall.

Charlemont

The proposed station is underground at Charlemont with tunnel alignment. The modelled ZOI for this proposed station is R = 134.95m from the centre of the station excavation and is based on a conservative modelled outflow value of approximately 202.2m^3/day of groundwater discharge. Charlemont Station perimeter will be sealed (D-walls) within the QBR subsoils and CLU (Lucan Formation). The modelled R at the completion of the excavation and prior to the final sealed structure is ~104.7m.

In terms of potential impact of dewatering on nearby waterbodies, and in the context of the modelled ZOI, the following attributes are of note:

- Historical underground/culverted watercourses located ~125m to the north (historical Stein River, culverted), and ~77m/~335m to the south (tributaries of the Swan River, culverted), likely set in QBR subsoils. These undefined subterranean features ultimately discharge to the River Dodder to the east.
- Greater Dublin Drainage Scheme tunnel located along Grand Parade to the immediate north of the proposed station. This is a 150mm thick concrete sealed structure comprising trunk sewers discharging water to Grand Canal Basin and likely set in QBR in the area of the proposed station.
- Grand Canal located ~30m to the immediate north of the proposed station northern perimeter; assumed lined feature and set in QBR (8m - 10m thick Clay sequence at this point).
- Dublin GWB (Ll bedrock aquifer) and groundwater wells (GSI, 2022)

The predicted effect of Construction Phase dewatering (from either drawdown or water quality effects) on identified water features in close proximity and the wider area is considered *Imperceptible*. The calculated drawdown does not extend as far as the protected habitat South Dublin Bay SAC nor does the modelled ZOI intercept any 'open' /non-culverted watercourses that potentially receive baseflow and which ultimately discharge to this habitat feature. The nearest water features of note include historical and culverted watercourses and the Grand Canal all of which are lined in what is an urban setting. Furthermore, the features are set in brown Boulder Clay recorded at depths >7mBGL. Dewatering at the Charlemont Station during works will be temporary only with the anticipated radius effect of dewatering reducing as the station construction progresses towards full perimeter and base seal (i.e. full watertight conditions) including toe grouting assumed to 1.5m below base of D-wall. Review of publicly available databases on groundwater abstraction does not indicate the presence of private or public wells within the modelled ZOI for this station excavation.

Summary of Impact Assessment:

In general, for the proposed Project the predicted effect of dewatering activities on adjacent identified attributes, as per EPA guidelines, is generally assessed as *Imperceptible* owing in the main to the spatial separation between the dewatered station box and that identified feature, and review of the geological setting in which that feature lies. Notwithstanding this, some locations have been identified as posing a *Temporary Imperceptible* to *Not Significant* effect (i.e. Griffith Park where the Tolka River is in close proximity and set in QBR/BoD deposits) and *Temporary Not Significant* to *Slight* effect (i.e. Tara Street where two historical underground watercourses, and possible historical deviations/tributaries of same, discharge to the River Liffey in close proximity).

In terms of dewatering ZOI and ground settlement, then the lowering of groundwater is intrinsically linked to potential changes in ground stability. However, this is a function of the thickness and type of overburden potentially drained for example. The potential issue of settlement effects has been discussed thus far in this chapter and is covered in greater detail in Chapter 20 (Soils & Geology). With regard to Chapter 26 (Architectural Heritage) and groundwater related attributes (for example historic well, holy wells, grottos), features which are often tied into shallow groundwater, then in terms of settlement analysis for both the proposed tunnel alignment and station boxes, the [settlement] report presents, as a Stage 2a assessment type, analysis on the modelled horizontal and vertical displacement in ground at surface level. In general, in said report the 'category of damage' is predominantly classified as *Negligible* to *Very slight* with rare *Slight* to *Moderate* effects noted.

19.5.3.6 Groundwater Barrier Effect

The groundwater table/piezometric surface in Irish aquifers is generally a smoothed reflection of the topography, usually less than 10m from the ground surface with an annual fluctuation of less than 5m. Water tables are closest to the surface and the annual fluctuations are smallest within the low-lying ground of river valleys for example, and the opposite is the case in areas of elevated ground and/or with distance from surface water features.

Along the proposed Project alignment, a reconstruction of the phreatic level using piezometric data from boreholes drilled in the area has been developed (Appendix A19.10). Groundwater in general is interpreted to flow towards the main rivers and towards the Irish Sea. Spatially, groundwater will also contribute to the recharging of streams and surface watercourses. The groundwater table inclination varies between 10% and 25% with maximum slopes observed around the Tolka River where variations in local topography are also evident. The hydraulic gradient ranges from 0.001 to 0.05. As a consequence, Dublin's stratigraphy may provide a 'multi-layer' aquifer controlled by granular levels and this is a potential source of groundwater during construction of the tunnel section and underground excavations.

The 'barrier effect' of groundwater can pose a serious problem in an urban setting like Dublin City if the tunnel, cut section or underground station cuts through the water table for a considerable linear extent. Tunnels (EPB and Slurry TBM), SCL, cut and cover, retained cut sections, or shallow and deep station excavations (including with deep secant piles/D-wall installations) crosscutting the [interpreted] regional/local groundwater flow regime can create this 'barrier effect' within the main aquifer units crossed by the proposed Project and identified as part of the baseline assessment. These can include the afore-mentioned shallow [superficial] water-bearing aquifers in addition to the underlying bedrock aquifer units. This 'damming' effect can subsequently impact on adjacent building foundations and utilities located up-gradient of the aquifer. Furthermore, it may lead to localised groundwater flooding at surface level. To avoid the risk of dam effects on groundwater levels, tunnel excavation and gradient alteration through the Base of Drift/Upper Weathered Rock (BoD/UWR) is designed to be as reduced as much as practicable. Notwithstanding this, there are long sections of the tunnel that run along this hydrogeological interface, especially between Glasnevin and O'Connell Station.

According to IDOM (Appendix A19.9), the recommended maximum length to avoid a 'Barrier Effect' occurring would typically be 300m. However, this length is not always possible to fulfil in design terms as both tunnel and passenger station depths are determined according to multiple criteria analysis taking into account aspects such as depth of passenger stations, avoiding low points along the alignment for drainage reasons. As a consequence, there are areas where the alignment runs for more than 300m, along or close to the BoD/UWR units. In those cases, the barrier effect should be considered as a risk.

There are four sections along the proposed Project alignment with a potential risk of 'barrier effect, outlined as follows:

1. Chainage 1+000 to 2+800: In this section interpreted groundwater flow paths are cut by the proposed Project with a high angle in the first kilometre and lower angle in the second kilometre. The morphology of the groundwater table is interpreted as controlled by the groundwater discharged in the Broadmeadow River and Ward River (both water features will be crossed by wide spanning viaduct here).

2. Chainage 3+500 to 4+600: In this sector the angle between the interpreted groundwater flow paths and the metro line is in the order of 45 degrees.

3. Chainage 7+200 to 9+950: In this sector the intersection angle between the interpreted groundwater flow paths and the alignment is reduced, with the exception being between chainage: 9+520 and 9+840. The morphology of the groundwater table is possibly controlled by the groundwater discharged in the Mayne River headwaters for example. In this sector, the higher risk of a barrier effect will be located within the deep stations/shaft and Dardistown.

4. Chainage 15+000 to 17+800: In this sector there is a higher risk of the 'barrier effect'. The interpreted groundwater flow paths cut the metro alignment with a high angle and the elevation of the water table is much reduced, to around 0mOD close to the River Liffey. The River Liffey is the most important superficial watercourse in Dublin and the source of historical inundations within Dublin City, (e.g. 2011 'monster rain'). For this reason, the potential 'barrier effect' caused by the proposed Project tunnel and station boxes around the River Liffey can increase exponentially through inundation problems caused by heavy rainfall. The higher 'barrier effect' risk in this sector will be located at the deep stations, namely: Mater, O'Connell Street and Tara.

Diagram 19.16 and Diagram 19.17 below present the hydrogeological plan developed for the proposed Project showing the northern and southern sectors of the alignment, respectively, where the potential barrier effect is considered a hydrogeological risk. The groundwater barrier effect modelling report is presented as Appendix A19.9.

Diagram 19.16: Barrier Effect - Northern Section: Estuary to Collins Avenue (chainage: 1+000 to 13+000)

Diagram 19.17: Barrier Effect - Southern Section: Collins Avenue to Charlemont (chainage: 13+000 to 19+780)

In summary, the 'barrier effect' of groundwater damming can pose a serious problem in any urban setting if the tunnel or underground station cuts through the phreatic level. This obstruction of natural groundwater flow can lead to a rise in the local water levels, with potential effects on building foundations and utilities located upstream of the barrier. In terms of ecological impact, although potential exists for groundwater connectivity [as baseflow] with surface water features, for example at the Broadmeadow River, Ward River, Tolka River and River Liffey, it is not considered likely that any barrier effect on the groundwater flow regime to these rivers could potentially impact on downstream

European sites/nationally designated sites via this connectivity as such habitat requirements are not reliant on nominal changes in water levels.

For a quantification of the potential 'barrier effect' caused by the proposed Project, initial hydrogeological modelling of the four potential sectors identified above was undertaken with MODFLOW, with particular emphasis on the sector around the Broadmeadow River and Ward River as well as the River Liffey. Modelling included assessment of up-gradient groundwater flow/mounding potential at each of the four sectors alongside interpretation of inflows with aquifer characteristics including hydraulic gradient, permeability and recharge as inputs and calibration of simulated groundwater heads against field head measurements. The objective of the exercise was to inform the management of groundwater flow in varying hydrogeology at the 'barrier' extents along the alignment, and to define suitable mitigation measures (refer Section 19.6.3.2) to control same and essentially ensure the continued movement of groundwater at both sides of the retained cut/station boxes in [conductive] QBR sands/gravels, BoD/UWR and underlying limestone.

The four sectors listed above are discussed further in the following sub-sections.

19.5.3.6.1 AZ1 Northern Section

The modelling of the potential interaction between natural groundwater flow patterns and the proposed D-walls within the Seatown - Swords - Fosterstown area (i.e. Chainage 1+000 to 2+800 and Chainage 3+500 to 4+600) indicates that where the D-walls cut into the permeable BoD layer (at retained cuts/station boxes) there is an increasing possibility of the barrier effect occurring. The outputs of the model (using longitudinal east-west profile) indicate an over-elevation of groundwater levels by 1.2m at some points upstream of the D-wall which is higher than the recommended value of 1m beyond which it may be considered necessary to use flow by-pass systems for example in order to mitigate the barrier effect (refer Appendix A19.9).

In general, the modelling results indicate a mean upstream over-elevation equal to ~0.62m and a mean downstream depression in groundwater levels of ~0.24m (for the head observation wells).

With reference to barrier effects and the Broadmeadow River and Ward River, the alignment is at grade north of both watercourses followed by a significantly spanning viaduct over both rivers before reverting to retained cut section father to the south at chainage: 1+910 - this 'above ground/at grade' section of the proposed Project negates any 'barrier effects' on groundwater flow including to both watercourses flowing from west to east. Furthermore, there are no stations/secant piled walls over the extent of the alignment from chainage: 1+360 to chainage: 1+910 including the two river crossings.

19.5.3.6.2 AZ2 Airport Section (& Dardistown)

The modelling of the potential interaction between natural groundwater flow patterns and the proposed diaphragm walls within the Dardistown area (i.e. Chainage 7+200 to 9+950) indicates that as the proposed D-wall installations do not cut into the permeable BoD layer, the barrier effect could be irrelevant. However, and adopting a conservative approach here, the modelling for this sector has considered the diaphragm walls do cut into all levels above/within the BoD layer.

Modelled outputs indicate continuity of groundwater velocity vectors across the alignment and through the BoD layer. Results indicate a mean upstream over-elevation equal to ~0.20m and a mean downstream depression in groundwater levels of ~0.054m (for the head observation wells). The over-elevation of groundwater levels is lower than the recommended value of 1.00m, beyond which mitigation of the barrier effect would be required.

19.5.3.6.3 AZ3 Dardistown to Northwood

Refer also to Sub-section 19.5.3.6.2 above which includes reference to potential barrier effects along the alignment within AZ3 from chainage: 8+660 and 9+950.

19.5.3.6.4 AZ4 Northwood to Charlemont

The modelling of the potential interaction between natural groundwater flow patterns and the proposed D-walls considers the alignment extent between Chainage 15+000 to 17+800 which includes deep excavations at Mater, O'Connell Street and Tara Street. Specifically, the O'Connell Street Station area (with extensive water-bearing fluvio-glacial gravels) was modelled as the proposed D-walls here cut into the permeable BoD level (the line to the north and south of the station is at tunnel alignment).

The outputs of the model (using longitudinal E-W profile) indicate a mean upstream over-elevation equal to ~0.041m and a mean downstream depression in groundwater levels of ~0.024m (for the head observation wells). The modelled over-elevation of groundwater levels is lower than the recommended value of 1m, beyond which mitigation of the barrier effect would be required.

19.5.3.6.5 Summary of Impact Assessment:

Modelling has indicated that where groundwater flow is in parallel to the MetroLink alignment, the potential barrier effect will be less significant. In contrast, if the groundwater flow is more acute or perpendicular to the structure alignment the potential for groundwater damming is more significant. In addition, the modelled trajectories show how groundwater flow is able to 'overcome' the interference imposed by D-walls at stations which indicates less significance in the long-term (Operational Phase).

In summary, in the Dardistown area, with water-bearing fluvio-glacial sands and gravels, the diaphragm walls do not cut into the BoD which significantly reduces the potential for barrier effects on natural groundwater flow patterns here (including where connectivity exists with the Mayne River). Similarly, at O'Connell Street, where the proposed D-walls cut into the permeable BoD level, the mean upstream over-elevation is modelled as low and within tolerated levels with existing groundwater flow patterns 'near parallel' to the station box and tunnel alignment, discharging to the River Liffey to the south. However, there is potential for barrier effects to occur within the Seatown – Fosterstown and modelled for approximate chainages 2+800 to 4+800; this area is located beyond the Broadmeadow River and Ward River both of which may receive groundwater contributions in the form of baseflow. In the absence of mitigation, the predicted magnitude of impact (without mitigation) is considered *Small Adverse* following TII (2009) and Slight to *Significant* in terms of significance and of *Permanent* duration effect.

Note: For comparison, it is noted that some hydrogeological modelling was undertaken as part of the Metro North (RPA, (2009) and included modelling in the [sensitive] area of O'Connell Street (Parnell Square stop) as this area has the most significant (deepest) granular layer. The objective was to demonstrate that the flow of groundwater in the vicinity of the station box and cut-off walls had Negligible permanent consequences on predicted flow orientation - this was the main conclusion of the model outputs, i.e. negligible long-term effects.

19.5.3.7 Groundwater Dependent Terrestrial Ecosystems (GWDTE)/Natura 2000 Sites

The potential impacts to groundwater dependent habitats from the Construction Phase of the proposed development are discussed in Chapter 15 (Biodiversity) and summarised below.

The Rye Water Valley/Carton SAC - which is designated for a groundwater dependent QI Annex I habitat - is the only GWDTE located within the same GWB as the proposed underground section of the proposed Project; this feature is situated >15km farther to the west (Section 19.4.15). The proposed Project alignment/boundary does not directly overlap with any European site including those nearest European sites as Malahide Estuary SAC/SPA and Baldoyle Bay SAC/SPA (located downstream of the proposed Project) and North Dublin Bay SAC, South Dublin Bay SAC, North Bull Island SPA and South Dublin Bay and River Tolka SPA.

Tunnelling and/or deep excavation works during construction of the proposed Project may affect groundwater quality and/or quantity in the receiving environment. Ecosystems may be potentially impacted through accidental contamination of the groundwater which supports them causing a reduction in groundwater quality, any alteration in local groundwater levels through dewatering and/or any reduction in the groundwater contribution to that particular ecosystem. The characteristics which determine the potential impact, as well as potentially to Natura 2000 sites, include the following:

- Proximity to the habitat feature to the proposed Project and its components;
- Hydraulic connection [and degree of same] between the habitat feature and the aquifer type at the proposed alignment which may support these species, i.e. is the identified feature within the same aquifer unit as the proposed alignment, or is there a hydraulic divide between the feature and the proposed Project in the area assessed;
- Groundwater flow direction in the vicinity of the identified habitat feature;
- Level of proposed cut or deep excavation at the corresponding Project chainage which may determine the degree of variation in the groundwater level and also the extent of dewatering which may occur at that point along the alignment (refer Section 19.5.3.4);
- Degree of interpreted 'barrier effect' spatially and where potential exists for groundwater connectivity with surface water features for example at the Broadmeadow River, Ward River, Tolka River and River Liffey. Where connectivity does exist then there is potential for these watercourses to receive baseflow contribution from groundwater. Consequently, where barrier effects impact on the groundwater flow regime and hence impact on these surface water features, there is a potential impact on downstream European sites/nationally designated sites via this connectivity (i.e. there is a potential 'impact pathway').
- Water quality of the habitat feature and the groundwater from which it receives its baseflow; and
- Long-term discharge of surface water run-off to groundwater during operation of the proposed Project -this may result in a reduction in groundwater quality in the receiving environment, also resulting in potential degradation of a GWDTE and any species that it may support.

19.5.3.7.1 Summary of Impact Assessment:

The hydrogeology of potential ecological receptors with dependence on groundwater has been assessed (in the absence of mitigation measures) for the Construction Phase of the proposed Project. The assessment considers receptors within the AZ1 to AZ4 reference area for both the drawdown effects (ZoI) and areas/receptors which are potentially vulnerable to construction-related ground/ water pollution. Potential impacts arising from barrier effects have also been assessed with regard to impact on surface water features which could receive [groundwater] baseflow. The proposed Project does not directly overlap with any European or National site and there are no groundwater dependent terrestrial ecosystems located within the modelled hydrogeological drawdown ZoI of the proposed Project. In summary, the potential for impact on GWDTEs/Natura 2000 sites linked to groundwater quality and/ or flow regime is considered Negligible in terms of magnitude and the significance of the effect is considered to be Imperceptible.

19.5.3.8 Utilities, Roads and Other Diversions

The proposed alignment will cross a number of utilities (including gas, electricity, water main, foul main), road diversion works and other diversions during the Construction Phase with these elements relating to either part of the proposed Project or to independent works, but which are also located within the vicinity of the Project boundary.

An assessment of the utilities impacted by the construction at specific sites (including the Wad River and Diversion) was undertaken and the findings are summarised in a Surface Water Drainage & Flood Risk Assessment Report (Appendix A18.5). This is also discussed in Chapter 18 (Hydrology) under Section 18.4.3.1 in the context of surface water. In addition, Chapter 18 (Hydrology) Section 18.5.3 includes discussion on the ESBN high voltage cable installations as part of a Construction Phase impact assessment. Hydrology is intrinsically connected to hydrogeology, as such the assessment and mitigations discussed in Chapter 18 (Hydrology) are also applicable to this Chapter.

With regard to electrical cable installations, a number of potential works include the substation compound located immediately north of the Naul Road and east of the DANP (AZ2 zone), and the substation at Dardistown Depot (AZ3 zone), together with high voltage cable options, temporary cable connections for the TBM and temporary connections for construction sites. It is the policy of ESB that, in so far as possible, high voltage underground cables shall only be installed under public roads. One of the key advantages of laying cables under roadways is that there is usually no permanent impact on the environment additional to that caused by the presence of the roadway. When an underground cable is laid under an existing roadway the potential for impact is normally only a short-term effect during the Construction Phase and will relate to specific depths typically <3m below ground level. However, in certain situations high voltage cables cannot be installed in existing roadways and have to be installed across waterbodies and drainage ditches. The crossing of streams and rivers shall be carried out by open trench method or trenchless methods (directional drilling) with the approval of Inland Fisheries Ireland (IFI).

With regard to possible road diversions and new junction layouts along/within the vicinity of the proposed Project there are a number of proposed new layouts/alignments to existing roadways, junctions and access roads with general construction works planned at existing surface level with the exception of the Swords Western Distributor Road and the proposed alignment changes at Ennis Lane from the R132 to Estuary Station and P&R for example which include works in areas with M-H aquifer vulnerability and where QBR subsoil/limestone prevail. The typical Construction Phase works associated with these elements can give rise to potential water quality impacts on the underlying subsoils and groundwater, where present, through for example spillages/leaks of site plant and equipment and deliveries.

19.5.3.8.1 Summary of Impact Assessment:

There will be multiple surface water crossings for the proposed Project to facilitate the installation of high voltage underground cables however these will be installed in roadways where possible. Notwithstanding this, some installations may be completed within/beneath nearby watercourses which may/may not have connectivity potential with the underlying hydrogeology. The options provided by ESBN are as follows:

- Option 1 – Open Trench (Damming and Fluming) and Option 2 – Open Trench (Damming and Pumping) -these involve in-stream works and therefore can impact on groundwater baseflow and therefore groundwater quality. However, with the design measures set out in the ESBN report the significance of effect during construction would be 'Not Significant' and for the Operational Phase is *'Imperceptible'.*
- Option 3 – Trenchless Installation – This involves horizontal drilling underneath the waterbody and into the subsoil and/or weathered rock (to unknown depths) for subsequent pipe installation purposes. However, with the design measures set out by ESBN, this significance during construction would be *'Imperceptible'* and for the Operational Phase, the significance is *'Imperceptible'.*
- With regard to the significance of effect during construction of the substation compound structures (designed as self-contained buildings with bunds, with all equipment and materials as new and of the highest quality), this is considered to be *'Not Significant'*.

With regard to road diversions, junction layout changes and other alignments, it is reasonable to assume that such works will be undertaken and completed at/near existing surface level with only deeper 'isolated' excavations where utility works are planned alongside these.

Without adequate design and mitigation measures for the effective management of shallow excavations associated with utility/road works mentioned (and protection of shallow groundwater intercepted during such works) as discussed in Section 19.6 below, the potential impact (TII, 2009) on the underlying aquifer is considered *Negligible to Small Adverse* in terms of magnitude and *Temporary to Short-term* in duration. However, with appropriate design measures in place (for example as provided by ESBN for cable installations) the resulting significance of the effect is *Imperceptible.*

19.5.3.9 Summary of Impact Magnitude and Significance of Effects – Construction Phase

Table 19.42 provides a summary of impact magnitude and significance of effects for those key hydrogeological receptors considered at risk during the Construction Phase.

Table 19.42: Summary of Impact Magnitude and Significance for Hydrogeological Aspects of Receptors at Risk during the Construction Phase of the Proposed Project

Feature	Importance of Hydrogeology-related Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude (TII, 2009)	Hydrogeology Significance of Effects (without mitigation)
Groundwater Resources				
Dublin GWB	Very High	Permanent groundwater quality and quantity impacts	Negligible	Imperceptible
Swords GWB	Very High		Negligible	Imperceptible
Groundwater Supplies				
Wells - Dewatered	Very High (generally)	Potential risk to water levels and quality, temporary	Negligible	Imperceptible/Not Significant
Wells – intercepted by TBM path	Very High (generally)	Well will be lost	Negligible/Small Adverse	Significant/Moderate
Ecological Receptors				
Malahide Estuary SAC/SPA	Extremely High (Ecological evaluation before impact assessment indicates all sites are of 'International Importance'	Potential risk to water quality as a result of [unmitigated] up-stream impacts	Negligible	Imperceptible
Baldoyle Bay SAC/SPA				
North Dublin Bay SAC				
South Dublin Bay SAC				
North Bull Island SPA				
South Dublin Bay & River Tolka SPA				
Surface Water Receptors				
Broadmeadow River (AZ1)	Very High	Potential risk to water quality as a result of [unmitigated] up-stream impacts	Negligible	Imperceptible
Un-named watercourse at chainage: 2+900 ends as culvert, likely to Greenfields Stream (AZ1)	Low to Medium	Potential risk to water quality as a result of [unmitigated] up-stream impacts; potential barrier effects	Negligible	Imperceptible
Ward River (AZ1)	High	Potential risk to water quality as a result of [unmitigated] up-stream impacts	Negligible	Imperceptible
Tributary of River Mayne (AZ2)	Medium to High	Potential risk to water quality as a result of [unmitigated] up-stream impacts	Negligible	Imperceptible

Feature	Importance of Hydrogeology-related Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude (TII, 2009)	Hydrogeology Significance of Effects (without mitigation)
Santry River (AZ3)	High	Potential risk to water quality as a result of [unmitigated] up-stream impacts	Negligible	Imperceptible
Tolka River (AZ4)	High	Potential risk to water quality as a result of [unmitigated] up-stream impacts; potential impacts from dewatering	Negligible	Imperceptible/Not Significant
River Liffey (AZ4)	Very High	Potential risk to water quality as a result of [unmitigated] up-stream impacts; potential barrier effects and impacts from dewatering	Negligible	Not Significant/Slight

Chapter 18 (Hydrology), Section 18.5.3 discusses predicted impacts from the Construction Phase on surface watercourses including those features that could potentially receive accidental run-off from construction compounds, logistic sites and storage depots as well as impacts associated with MetroLink grid connection crossings in identified water courses. In terms of groundwater discharge from dewatering activities, for areas AZ1-AZ4, the discharge of treated and attenuated groundwater will be to defined sewer under formal consent for same.

19.5.3.10 WFD Assessment – Construction Phase

The WFD assessment, in terms of the Construction Phase, has considered the current water status of all relevant water bodies (Section 19.4.6 above), and potential impacts have been considered (Section 19.5.3 above). With mitigation measures in place, it is concluded there will be no degradation of the current water body (chemically, ecological and quantitatively) or its potential to meet the requirements and/or objectives in the relevant second River Basin Management Plan (RBMP) 2018-2021 and *draft* third RBMP 2022-2027. There are no discharges of water during the Construction Phase to ground or to any open waterbody/watercourse and therefore no direct discharges to groundwater (where hydraulic connectivity exists between both types). There are appropriately designed mitigation measures which will be implemented during the Construction Phase to protect the hydrogeological (and hydrological) environment. There is a potential for accidental discharge during the Construction Phase, however this would only be temporary, i.e. a very short-lived event with an effective design quick response time negating any impact on the water quality status of identified waterbodies in the long-term.

There will be limited impact on the surrounding hydrogeological environment from dewatering activities which will reduce for all excavations including retained cuts/cut and cover sections as the features become sealed including with bottom grouting at the deep station box excavations. Once piling is completed (and where applicable, the bottom grout plug is complete) the extent (influence) of dewatering becomes very limited with the calculated zone of influence (ZOI) being relatively small to negligible thereafter. Therefore, the effect on the hydrogeological setting is *Negligible*. Also, there is limited dewatering required for areas within the northern section of the proposed route especially where the track and stations are above ground structures.

Furthermore, the outline CEMP (Appendix A5.1) and project-specific detailed [and live] CEMP - which the works Contractor will develop - will implement strict mitigation measures to ensure the protection of the hydrogeological (and hydrological) environment which will ensure that there will be no negative impact on current trends and as such no negative impact on the WFD classification of identified waterbodies in the context of the Project alignment and boundary.

Overall, the potential effects on the WFD status to the waterbodies are considered *Neutral, Imperceptible to Not Significant and Temporary.*

19.5.4 Operational Phase Impact Assessment

There are a number of Operational Phase activities or features of the proposed Project that have the potential to cause impacts on the hydrogeological environment. The potential impacts of these activities on the hydrogeological receptors identified in Section 19.4 above are discussed below and relate to pre-mitigation impacts. Residual impacts are outlined in Section 19.7.

As with Construction Phase activities, the main impacts to groundwater from the Operational Phase arises from the potential to impact on groundwater levels and groundwater quality, primarily. The proposed Project Operation Phase can potentially alter the existing groundwater regime for example by:

- Lowering of groundwater levels from Operational Phase dewatering (where present);
- Raising of groundwater levels by impeding or impounding groundwater through permanent [unmitigated] 'barrier effects'; and
- Discharge of track run-off and pumped tunnel/cut/Station/portal/shaft water to ground.

The quantification of these potential impacts is discussed further in the following sections.

19.5.4.1 Groundwater Resources

The potential impact assessment on the groundwater resources during the Operational Phase considers the impact of any changes in the groundwater regime and groundwater quality can have on the identified [Ll, Pl] aquifer underlying the proposed Project. Operational impacts on groundwater quality are discussed under Section 19.5.4.3. Operational water usage (including for firewater, train washing and effective re-use of water) is discussed in Chapter 4 and Chapter 6. All Operational Phase water will be sourced from public supplies (managed by Irish Water) and all contaminated discharges during both the construction and Operational Phases will be to defined sewer or to wastewater treatment plant (via tanker).

In line with TII (2009) guidance, the magnitude of the impact on the identified bedrock aquifer within the overall proposed Project study area is based on the portion of the aquifer that will be removed during construction. In terms of recharge to groundwater, then in addition to the majority of the area covered by either low permeable subsoils or hardstanding, the overall surface area of the proposed Project at grade is considered negligible when compared with the surface area of the catchment land that provides regional recharge to the aquifer.

19.5.4.1.1 Summary of Impact Assessment:

The volume of the aquifer removed is a very small percentage of the aquifer volume for both Swords GWB and Dublin GWB as is the land take for recharge to groundwater (including where existing recharge rates are low due to subsoil thickness and type) and characteristics of that land area. Hence, and in line with TII (2009) rating, the magnitude of the impact on the aquifers is considered *Negligible* and the significance of the effect is *Imperceptible*.

19.5.4.2 Groundwater Supplies

The bedrock aquifer within the study area is not used extensively for public water supply and there are therefore no likely significant risks to a public supply or group water supply from the proposed Project (refer also Section 19.4.7 above). There are some private supplies recorded by the GSI/EPA (2021) and in addition, other unrecorded wells may also be present spatially within the reference area of the proposed Project. However, there will be no active long-term dewatering of the bedrock aquifer (or water-bearing overburden) required during the Operational Phase of the proposed Project, but some minor i.e. passive dewatering will occur at a number of cut sections within areas AZ1 to AZ3. Notwithstanding this, the drainage associated with the proposed Project (see also Section 19.6) will not cause any significant lowering of regional or local groundwater levels which will adjust temporally.

19.5.4.2.1 Summary of Impact Assessment:

There will be negligible influence of the Operational Phase on the regional or local groundwater levels with no long-term impacts on supply resource due to natural re-stabilisation of groundwater flow patterns and levels generally to pre-construction conditions. As such, in line with TII (2009) rating, the magnitude of the impact on the aquifer and groundwater supplies from it from changing groundwater levels is considered *Negligible* and the significance of the effect is *Imperceptible*.

19.5.4.3 Groundwater Quality & Discharge of Water

During the Operational Phase of the proposed Project, there will be no direct discharges to ground/groundwater. As such, there will be no change to the natural groundwater regime or in the groundwater body status along the full alignment as a result of the overall development. This is in keeping with the objectives of the Dublin City Development Plan (2016-2022) which emphasizes the need to maintain the current WFD 'good' status and guard against contamination and abstraction.

The Operational Phase will include passive drainage features which will include some filtration to ground where local subsoils are assessed as inherently viable for same; these features relate to AZ1 to AZ3 only and are effectively used for attenuated rainwater management. AZ4 is at tunnel alignment with no direct or passive discharges to ground.

Chapter 18 (Hydrology) includes discussion on the use of swales, conveyance channels and wetland ponds to attenuate surface water discharges to identified receiving watercourses within areas AZ1 to AZ3. These features, where unlined, will typically involve some infiltration to ground/groundwater (Chapter 18 Hydrology), Section 18.5.2). Swales (i.e. shallow, broad and vegetated channels designed to store and/or convey runoff and remove pollutants) are used extensively wherever feasible, such as the access roads to the P&R at Estuary Station, access roads along the track between R132 and Naul Road, and the roads between Old Airport Road and proposed Northwood Station which have been designed to incorporate swales to reduce the size of the proposed attenuation ponds. Soakaways at wetland ponds will contain basal granular fill in order to promote infiltration. However, where the nature of the underlying soils is assessed as impermeable, the effectiveness of any infiltration media is therefore uncertain so controlled [lateral] outflows via a 'hydrobrake' system are included in the design to ensure existing greenfield run-off rates are met to identified surface watercourses.

All on-site bulk chemical storage, for example at Dardistown Depot, will be fully contained and bunded and monitored in accordance with approved long-term operational requirements for each site. As each site will mostly be covered in hardstanding with effectively designed drainage, any accidental release from a chemical storage area or other source will be contained and treated prior to discharge from the site. Design measures take due account of the incidence of firewater and containment of same will remain within the sealed structure/tunnel area prior to removal off-site for appropriate disposal. Design measures also include use of adequate containment measures for chemicals within maintenance yards, petrol/oil interceptors in maintenance yards and car parking areas, and proper management and use of [environmentally compatible] herbicides. Apart from oil storage in maintenance yards there is no bulk chemical/oil storage required during operation.

19.5.4.3.1 Summary of Impact Assessment:

There are no likely significant impacts on the hydrogeological environment associated with the operational stage of the proposed Project and these relate in most part to geographical areas AZ1 to AZ4. Without adequate design measures, the potential for impact on groundwater [and surface] water quality is considered *Not significant to Slight.* However, it is not anticipated that any impacts will arise following the implementation of the design measures discussed in Section 19.6.3. As such the magnitude of the impact (TII, 2009) on water quality is considered to be *Negligible* and the significance of the effect is *Imperceptible* of *Long-term duration*. With regard to the significance of effect during operation of the substation compound structures (designed as self-contained buildings with bunds, with all equipment and materials as new and of the highest quality), this is *'Imperceptible'.*

19.5.4.3.2 Groundwater Protection Response (GPR)

The European Communities Environmental Objectives (Groundwater) Regulations 2010/2016, European Communities Environmental Objectives (Groundwater) (Amendment) Regulations 2022, and the WFD (2000/60/EC) set out the approach to groundwater protection and management in Ireland and present a series of policies designed to protect groundwater (TII, 2015). Where discharges to the ground are proposed, for example road drainage which is potentially contaminated, then the methodology and criteria outlined in Groundwater Protection Response (Method C) of the TII (2015) Document DN-DNG-03065 would be followed. This provides for a groundwater risk assessment in relation to potential impacts on groundwater from any [Operational Phase] discharge to ground (as in the case of a proposed road drainage system and use of permeable drainage systems).

With regard to the proposed Project, there will be limited Operational Phase [indirect] discharges to ground in addition to those attenuated discharges to defined watercourses at greenfield run-off rates (Chapter 18 Hydrology), proposed drainage catchment references A1-F). However, in the context of the discharges to ground these will be controlled discharges effectively designed in order to not compromise the achievement of the environmental objectives established for the body of groundwater into which the discharge is approved (refer also sub-section 19.5.4.8). Indirect, controlled discharges will incorporate SuDS features where feasible and include for example swales, attenuation ponds, and geo-cellular drainage systems to aid in natural infiltration of treated water. Such features will be incorporated for example at the Estuary Station Park & Ride, and Dardistown Depot.

Stormwater run-off from the track alignment will be attenuated and treated prior to authorised discharge off-site under formal consent (permits). Water collected from the [sealed] tunnel alignment (including from stations) will be much reduced in terms of volumes by comparison and will be attenuated/treated prior to authorised discharge to sewer. Notwithstanding this, and where there are no predicted significant impacts on the hydrogeological [or hydrological] environment, it is considered best practice to undertake a [simple assessment] Groundwater Protection Response for the MetroLink. This is completed with the aim of presenting the 'higher risk' areas and more sensitive/vulnerable groundwater bodies so as to define areas/locations along the route where a prompt and effective response to an accidental spillage for example, can be clearly recognised in advance and appropriate additional mitigation measures applied as necessary.

Appendix A19.7 presents a summary of the GPR for the Operational Phase of the proposed Project and includes detail on the proposed surface water drainage catchments A-F in the context of the hydrogeological setting. In summary, the significance of the impact (TII, 2009) on the groundwater bodies underlying the Project is considered in the main to be is Imperceptible of Long-term duration.

19.5.4.4 Groundwater Zone of Influence (ZOI)

In the short-term term following completion of the Construction Phase of the proposed Project, groundwater levels will re-stabilise to pre-construction patterns and any ZOI associated with Construction Phase dewatering activities will fully dissipate. This is based on natural re-stabilisation within both the saturated overburden material and underlying bedrock through regional recharge as well as enhanced stabilisation of levels effected through the passive [drainage related] mitigation measures discussed under Section 19.6.3. As such, during the operation stage, as no active dewatering will occur at any 'sealed structure' then there will be no long-term drawdown effects either at or beyond the footprint of any [sealed] excavation point or the [sealed] tunnel itself. There will be no external pumping during operation however only intermittent controlled/attenuated internal sump pumping of water collection from within the tunnel and stations may as required. This will mostly constitute wastewater and will be treated accordingly prior to disposal to combined sewer under formal consent or in the case of track/depot drainage to defined watercourses following effective treatment and attenuation to greenfield run-off rates for example at Estuary Park & Ride.

19.5.4.4.1 Summary of Impact Assessment:

There are no significant impacts on the hydrogeological environment [water levels, flow regime] associated with the proposed operational stage of the proposed Project following the implementation of the design measures discussed in Section 19.6.3. As such the magnitude of the impact (TII, 2009) on water levels beyond the proposed Project boundary is considered to be *Negligible* and the significance of the effect is *Imperceptible* of *Long-term duration*.

19.5.4.5 Groundwater Barrier Effect

The proposed underground station boxes are typically in the region of 25m deep by 30m wide by up to 170m long. As such, and in the context of modelled long-term potential barrier impacts on groundwater flow patterns the dimensions of the station boxes are considered to be insignificant when compared with the scale of the regional hydrogeological regime within which they are located (Massarsch, 2010). Additionally, the deep station boxes to the north and south of the main drainage feature in the area, namely the River Liffey, are generally aligned north-south following the north-south alignment of the proposed Project, which is similar to the regional scale pattern of groundwater flow towards the River Liffey and, therefore, will not act as a significant barrier to groundwater flow.

Within AZ1 Northern section, modelling of the potential interaction between natural groundwater flow patterns and the proposed piled walls within the Seatown - Fosterstown area (i.e. between chainage: 2+800 and chainage: 4+800) indicates that where the walls cut into the permeable BoD layer (at retained cuts for example) there is an increasing possibility of the barrier effect occurring. Another example of the modelled barrier effect potential is the retained cut/ cut and cover extent from chainage: 2+157 to chainage: 2+274 within predominantly [saturated] QAG subsoils. These effects naturally relate to the Operational Phase. In the context of potential barrier effects at the Broadmeadow River and Ward River, the alignment is at grade north of both watercourses with a significantly spanning viaduct over both rivers before reverting to retained cut section farther to the south of the watercourses at chainage: 1+910 - this 'above ground/at grade' section of the proposed Project will negate any 'barrier effects' in the long-term.

Section 19.5.3.6 references hydrogeological modelling completed for Metro North for comparative purposes and to indicate that the current design presents more contemporary and advanced mitigation measures in order to counteract such effects, but which takes due cognisance of historical information gathered at the time of the EIS for Metro North. Section 19.5.3.6 also concluded negligible permanent consequences on predicted flow orientation as a result of deep underground structures.

With regard to the tunnel structure the natural groundwater regime will be revert to pre-construction characteristics. As the tunnel, cut sections and station box structures will all be sealed entities then groundwater levels will 'adjust' during winter periods of elevated levels followed by recessions in groundwater during the summer or low flow season. The inclusion of effective design mitigation measures as drainage blankets and piped systems will alleviate any long-term impact of barrier effects as the natural groundwater regime is allowed to flow below and around all cut/station box/shaft/portal structures and above/below tunnel alignment.

19.5.4.5.1 Summary of Impact Assessment:

There are no significant impacts on the hydrogeological environment (regional groundwater flow regime and barrier effect) associated with the proposed Operational Phase of the proposed Project. Without adequate design measures, the potential for effect on groundwater flow as a result of barrier effects (i.e. specifically modelled as such between Seatown and Fosterstown) is considered Not significant to Slight. However, it is not anticipated that any impacts will arise following the implementation of the design measures discussed in Section 19.6.3. As such the magnitude of the impact (TII, 2009) on regional water levels/flows beyond the proposed Project boundary is considered to be *Negligible* and the significance of the effect is *Imperceptible* of Long-term duration.

19.5.4.6 Groundwater Dependent Terrestrial Ecosystems (GWDTE)/Natura 2000 Sites

As discussed in Section 19.5.3.7, the proposed Project alignment/boundary does not directly overlap with any European or National site (or GWDTE -and no such attribute within the greater study area). Furthermore, as there will be no on-going active dewatering activities for the proposed Project and hence no drawdown effects which would otherwise create a ZOI laterally, there is no long-term impact on baseflow to watercourses that discharge to the European sites identified farther downgradient to the east of the alignment. In addition, following Section 19.5.4.5 above, there will be no long-term barrier effect at watercourses located upgradient of and ultimately discharging into sites of European interest.

19.5.4.6.1 Summary of Impact Assessment:

The potential for operational impact on GWDTEs/Natura 2000 sites linked to groundwater quality or baseflow is considered *Negligible* in terms of magnitude (TII, 2009) and the significance of the effect is considered to be *Imperceptible* of *Long-term duration*.

19.5.4.7 Summary of Impact Magnitude and Impact Significance - Operational Phase

Table 19.43 provides a summary of impact magnitude and impact significance for those key hydrogeological receptors considered at risk during the Operational Phase.

Table 19.43: Summary of Impact Magnitude and Significance for Hydrogeological Aspects of Receptors at Risk during the Operational Phase of the Proposed Project

Feature	Importance of Hydrogeology-related Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude (TII, 2009)	Hydrogeology Significance of Effects (with mitigation)
Groundwater Resources				
Dublin GWB	Very High	No permanent groundwater quality and quantity impacts, no direct discharge to ground	Negligible	Imperceptible
Swords GWB	Very High		Negligible	Imperceptible
Groundwater Supplies				
Wells - Dewatered	Medium - High (generally)	No potential impact on public water supply. No long-term dewatering hence no impact where well location is undisturbed, water level recovery.	Negligible	Imperceptible
Wells – intercepted by TBM path	Medium - High (generally)	No potential impact on public water supply. Any existing well will be lost but potable supply available locally.	Negligible	Imperceptible
Ecological Receptors				
Malahide Estuary SAC/SPA	Extremely High (Ecological evaluation before impact assessment indicates all sites are of 'International Importance'	No long-term dewatering and not within drawdown ZOI. Long-term mitigation of potential barrier effects were identified up-gradient.	Negligible	Imperceptible
Baldoyle Bay SAC/SPA				
North Dublin Bay SAC				

Feature	Importance of Hydrogeology-related Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude (TII, 2009)	Hydrogeology Significance of Effects (with mitigation)
South Dublin Bay SAC North Bull Island SPA South Dublin Bay & River Tolka SPA		No direct discharges to groundwater (where baseflow exists). Any accidental discharge would be attenuated and diluted prior to reaching SAC/SPA boundary. Long-term treated and attenuated surface water prior to discharge under consent		

19.5.4.8 WFD Assessment – Operational Phase

The WFD assessment for the long-term [operational] phase of the proposed Project has considered the current water status of all relevant water bodies (Section 19.4.6 above), and potential impacts have been considered (Section 19.5.4 above). With mitigation measures in place, it is concluded there will be no degradation of the current water body status (chemically, ecological and quantitatively) or its potential to meet the requirements and/or objectives and measures in the relevant second [current] RBMP 2018-2021 (River Basin Management Plan) and *draft* third RBMP 2022-2027. There are limited discharges of [treated] water during the Operational Phase to pre-defined open waterbody/watercourse features and no long-term groundwater dewatering for the Project. The Operational Phase discharges will be adequately treated via SuDS measures, hydrobrake (or equivalent) and oil/water interceptor to ensure there is no long-term negative impact to the WFD water quality status of the receiving watercourse and any corresponding effects on groundwater where potential hydraulic connection prevails for example. The SuDS and proposed measures have been designed in detail with the ultimate aim of protecting the hydrogeological (and hydrological) environment. The SuDS and Project design measures will be maintained correctly as per approved specifications to ensure long-term/on-going integrity of same. Furthermore, there will be limited volumes of chemicals and fuel storage for this development as the MetroLink is powered by electricity supply.

In summary, it has been assessed that that the proposed Project will not cause any impact on current trends, and as such no significant deterioration or change in water body status or prevent attainment or potential to achieve the WFD objectives. Overall, the potential effects on the WFD status to the relevant waterbodies are therefore considered *Neutral, Imperceptible to Not Significant and Permanent.*

19.6 Mitigation Measures

19.6.1 Introduction

This section presents the proposed mitigation measures for hydrogeology. Mitigation measures follow the principles of avoidance, reduction and remedy. As set out above, appropriate measures have been incorporated into the design of the proposed development to avoid impacts where possible.

The following outlines additional mitigation included in the construction and operation of the proposed Project development in order to protect the receiving water environment. These measures should be read in conjunction with measures outlined in Chapter 15 (Biodiversity) and Chapter 18 (Hydrology).

Note: During Preliminary Design development some of the risks/impacts listed under Section 19.5.3 and 19.5.4. above have been mitigated within the design, for example, in mixed face geological conditions design changes have been introduced for the vertical alignment where it became possible to better *manage this hazard. Nevertheless, this risk cannot be totally avoided as it would require an excessively deep alignment that would lead to deeper stations which would have implications [other than cost] on general passenger welfare.*

19.6.2 Mitigation During Construction

Stringent mitigation measures are proposed and include for the management of the groundwater regime within the vicinity of the proposed Project as well as control of potential polluting activities associated with the Construction Phase. These are discussed below and include both standard mitigation measures and aquifer-specific mitigation measures employed for the protection of the hydrogeological environment in line with the requirements of the WFD.

The contractor will be required to implement the outline CEMP (Appendix A5.1) for the proposed Project. This document includes specific measures and plans for the proposed Project which will be sufficiently developed and implemented in order to protect the water environment; key measures are also summarised below. The outline CEMP (Appendix A5.1) includes specific reference to the following guidance documents: CIRIA C532, C648, and C649.

19.6.2.1 Groundwater Inflow into the Tunnel Section

Where there is no pressurised tunnel front, then the potential for groundwater inflow during tunnelling works increases in the context of both superficial and bedrock source groundwater. To counteract and avoid this potential risk, the TBM will be advanced in a pressurized form.

This tunnelling technique will maintain stability in the tunnel and avoid/ limit the degree of groundwater inflow i.e. the choice of a closed face TBM mitigates the risk of groundwater ingress to the bored tunnel during tunnelling irrespective of the volume of water encountered. The use of EPB and Slurry TBM modes will therefore minimise the negative impact on tunnel excavation associated with dewatering of high pressurized groundwaters in the Boulder Clay/BoD/UWR units. In effect, the tunnel will be virtually watertight as the tunnel lining will be designed with gaskets to deal with the prevailing groundwater conditions. Furthermore, as the average tunnel depth for the proposed Project across Dublin is 8m to 10m below existing ground level to the crown (top) of the tunnel, and the tunnelling methodology comprises continuous sealing as the TBM advances, it is therefore unlikely that any of the historical watercourses (Chapter 18: Hydrology), Section 18.4.4) will be affected in terms of adding to groundwater inflow potential along tunnel sections.

For SCL tunnelling, advance probing will be used to ascertain ground conditions in advance. If groundwater is encountered it can either be drained if perched and of limited volume, or if wider connectivity is determined then permeation/fissure grouting would be undertaken through the face to control inflow to manageable levels. This will all be subject to daily review and planning prior to each advance to ensure the safety and security of the works.

19.6.2.1.1 Tunnel Eyes

Groundwater ingress control measures for tunnelling also include grouting of the tunnel eyes before/after the passage of the TBM. The tunnel eyes and internal measures proposed for O'Connell Street Station in Diagram 19.18 below. The schematic indicates that the level of the soft tunnel eyes in the north headwall will be in QBR (Boulder Clay/Fluvio-glacial Sands & Gravels and in the south transverse wall will be within the transitional rock and argillaceous limestone (CLU, Lucan Formation).

Prior to the TBM passing through the station, the area outside the two tunnel eyes normally requires grouting to prevent ground or groundwater flowing into the station when the TBM breaks in or out. As the tunnel eye is within the boulder clay and interface between the BoD and the UWR in the case of O'Connell Street, grouting will be required including the interface between the diaphragm wall and the ground. Typically, the grouting (if required) would form a zone approximately 20m x 20m centred on tunnel axis for a distance of 15m back from the D-wall to safeguard TBM entry / exit. Grouting will typically be undertaken from surface (vertical drilling) or subsurface (horizontal drilling) or a combination of both.

If grouting is required, this will consist of the permeation or fissure grouting of a block/area of sufficient size such that:

- On TBM breaking into the station - that a tunnel ring is fully grouted within this block before the TBM cutterhead breaks the D-wall and enters the station box; and
- On TBM breaking out of the station - that a tunnel ring is fully grouted within the D-wall before the TBM cutterhead leaves this block and exists the station box.

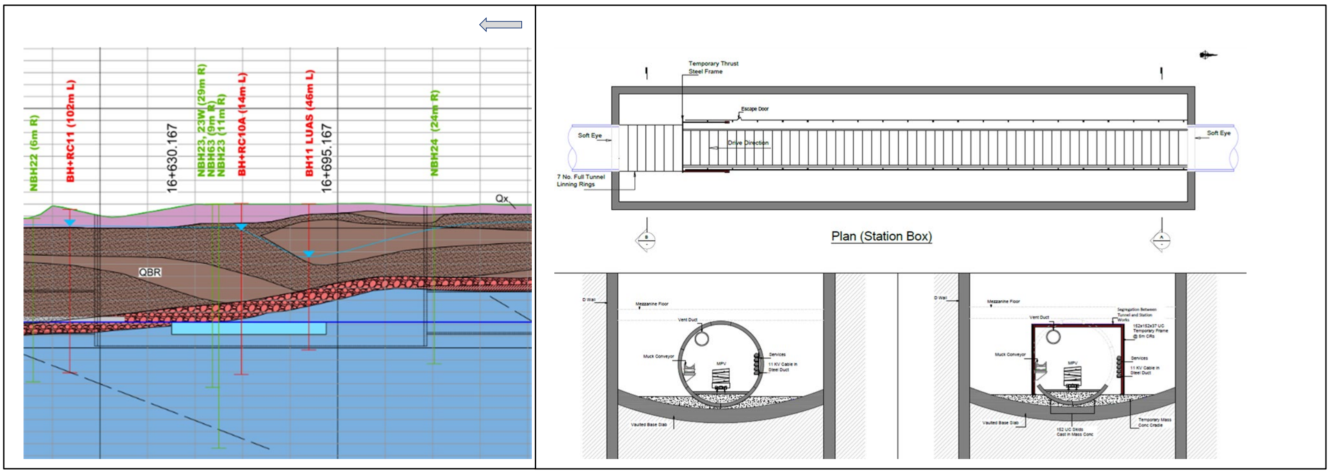

Diagram 19.18: Station following the TBM Passage through the Initial Station and Anticipated Geology

This methodology permits the pressure in the TBM cutterhead to be lowered to zero before break-in and raised to full pressure after break-out, without the risk of the inflow of ground/groundwater. Following the passage of the TBM past this section of the alignment, the tunnel eyes will be re-grouted with bentonite/concrete mix as backfill. This methodology will vary according to each station through which the TBM passes and based on prior and full assessment of ground conditions.

19.6.2.1.2 Settlement Risk

Settlement risk analysis comprising building damage assessment and the potential issues with regard to ground settlement is discussed in detail in Appendix A5.17.

19.6.2.2 Groundwater Inflow into Cut Sections and Within Deep Station Excavations

To manage the risk of settlement, the excavation of the cut sections and deep stations for the proposed Project must avoid affecting the phreatic water levels as much as possible. In order to maintain the existing phreatic levels during this proposed type of excavation it will be necessary to excavate within a water-resistant 'closed box', i.e. the excavation of the cuts/underground stations is designed with a water retaining (if not waterproofed), sealed enclosure which will be formed by employing the use of either secant pile (for example at cuts) or D-wall (at deep station boxes). This methodology will allow any inflow of groundwater into the excavation to be managed by pumping (dewatering) or other appropriate and effective control means; any defects will be rectified by grouting or structural repairs as needed.

The vertical height of the perimeter secant pile wall (for cuts) and the D-wall (for station boxes) will be calculated to avoid pressurised flow (see Diagram 19.19 below). D-walls or secant piles will be extended deep enough to lengthen the groundwater flow path in order to minimise ingress. This approach will be augmented, where necessary, by permeation/fissure grouting around the toe of the walls to further extend this groundwater flow path.

Diagram 19.19: Secant Piles in a Shaft and a D-Wall in an Underground Station for Avoiding Groundwater Influx

The thickness of the wall and the number and position of the anchors and/or other retaining systems will be calculated according to details collated on geotechnical ground parameters, depth of the excavation and size of the station box. Dewatering will be internal to the station box in advance of excavation works. Dewatering will be undertaken to below base slab formation and maintained until the base slab is cast, fully cured and there is sufficient weight in the box to negate the risk of 'flotation' effects.

To control the possible variations in the phreatic level a perimeter of vertical bored holes will be used with two principal functions, namely; (1) to monitor the piezometric level outside the excavation footprint, and (2) to maintain and stabilise the phreatic level by injecting pressurised water where deemed feasible. The perimeter boreholes will be designed according to pumping test analysis and hydraulic modelling (Plaxis-2D) already performed for the cut sections and stations on the proposed Project. Periphery borehole spacing, liner diameter and depth, and screened geology will be specifically designed for each works area with boreholes extending to a minimum depth of 5m below the lowest level of the cut/station excavation.

The main geological layer for groundwater transmission is recognised as the interface between the Boulder Clay and the bedrock, i.e. BoD and UWR. To restrict flow from this layer into the base of the excavation beneath the toes of the D-walls along fissures in the rock, permeation grouting will be undertaken at the toe of the D-walls. The permeation grouting consists of the drilling of holes through reservation tubes cast into the D-walls during construction.

In order to confirm the adequacy of the cut-off achieved by toe grouting, one or more site specific pumping tests will be carried out in advance of excavation to ensure that no excessive external drawdown is likely to occur. Deep wells will be installed as discussed above to lower the groundwater level within the footprint of the box, and piezometers inside and outside the footprint will be monitored to determine the drawdown of the groundwater level and hence the adequacy of the cut-off.

In the event of an inadequate cut-off being achieved, then further permeation grouting will be undertaken. This may involve drilling of additional grout injection holes within or outside the box footprint. The results of further grouting activities will be checked by further deep well pumping checks.

An example of toe grouting at the base of the excavation is presented below as Diagram 19.20.

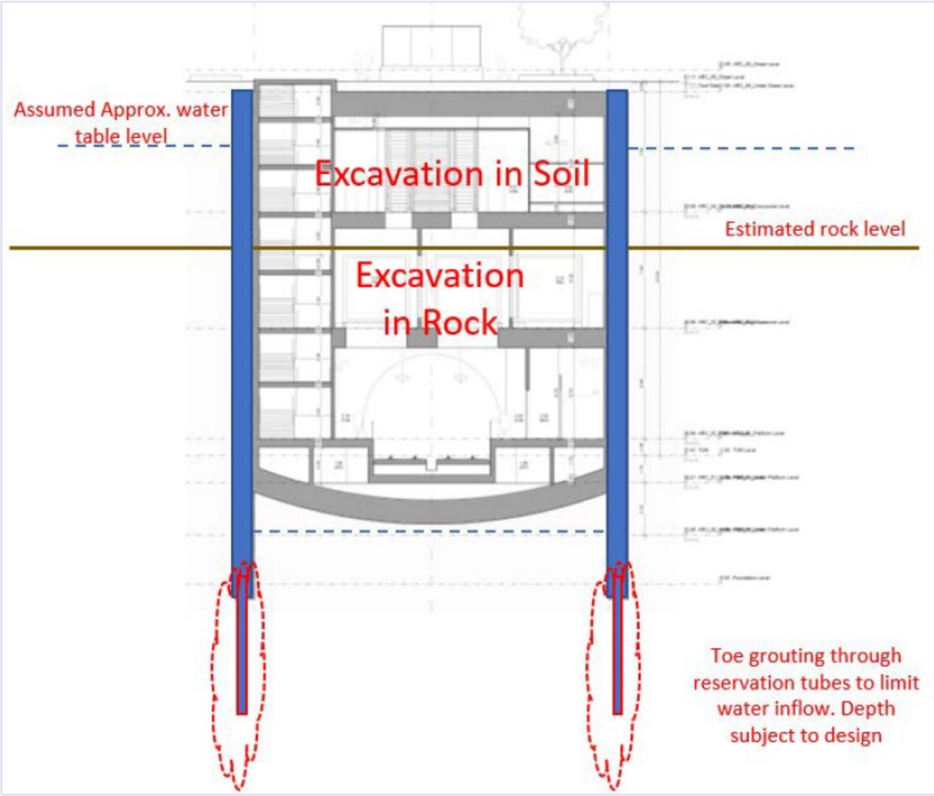

Diagram 19.20: Toe Grouting to Limit Groundwater Inflow into the Excavation through the Base

Should karst features be encountered during construction works, for example within the Waulsortian (CWA) limestone near Dublin Airport, these will be assessed by a suitably qualified hydrogeologist and an engineering geologist. It will be necessary to delineate fully the extent of these features and characterise them at the relevant chainage of the proposed Project, i.e. identify the structural control of the karstic porosity, the size of the voids and the potential water inflow in the karstic system.

In the case of excavations (cuts, stations, portals, shafts, bridge abutment excavations) the karst feature shall be excavated and backfilled with clean coarse, non-calcareous, fill material to ensure a continued high permeable zone and effectively sealed over this if required. If encountered during diaphragm walling, then the bentonite support fluid will control the temporary impacts and the concreting of the panel would fill any void. This will prevent runoff draining into the feature and therefore protect against accidental construction site spillages. On this basis, construction run-off will not discharge to a potential karst pathway and will receive natural attenuation and dilution within the aquifer. With specific regard to karst features being intercepted in excavations for earthworks and infiltration basins/soakaways it is vital to ensure the hydraulic connectivity of the feature using imported, clean granular material as engineered fill and then seal the feature from the excavation using a liner (geotextile and/or concrete depending on the site specifics). This will ultimately prevent any pollutant linkage between the excavation and the karst feature/bedrock aquifer. In the event that the feature cannot be excavated for whatever reason, the main mitigation measure will then be to fill the karstic tube(s) and the ground porosity with grouting and/or aqua-reactive foam.

Note: No evidence of karst had been observed in Metro North and AGI boreholes even if, according to available bibliography, the Waulsortian Formation may be 'prone to karstification processes'.

With specific regard to retained cuts and cut & cover sections, where the secant piled wall solution is adopted, this will ensure the impermeability of the excavation during the construction period [and during the Operational Phase]. The construction method comprises a first series of non-structural piles (non-reinforced) to be drilled and cast. Then, a second phase of structural piles (reinforced) intersecting the previous series produces continuity of the wall and provides enough structural resistance to applied loads and mitigates against groundwater ingress potential. As part of the Preliminary Design, a number of combinations of geological units [case scenarios] are considered and representative of more 'onerous' ground conditions including determination of the superficial deposit thickness/type overlying weathered/more competent rock, water levels and pile embedment length with depths of up to approx. 15m below existing ground level considered (refer also Jacobs IDOM, 2021h, Section 3, and Table 3.5 for retained cut and cut & cover locations). The structural function of the bottom slab at any cut section will be, in addition to transmitting the loads from the track to the natural rock or ground, to resist the associated water pressures at that location. Finally, two lining walls will be placed in the inner faces of the piled walls to improve the finishing of the structure and to protect the finished work against possible leaks i.e. water ingress from the surrounding natural ground.

19.6.2.3 Drawdown Effects and ZOI

Dewatering of the [Ll, Pl] bedrock aquifer will be necessary and the ZOI has been determined by modelling (following outputs of [Plaxis2D and MODFLOW] modelling) undertaken for the proposed Project. It is planned to undertake additional further site-specific data collection prior to commencement of works to allow site specific additional mitigation measures (such as monitoring) if required. As such, further groundwater level monitoring will be undertaken in NBH boreholes installed as part of the current proposed Project to define the contemporary groundwater levels in the area of interest at the time of construction and allow monitoring of groundwater levels pre, during and post construction. Where other periphery wells may need to be installed (for example where previously access to drilling sites was not feasible) these will be drilled before commencement of construction/during the Construction Phase and will be monitored for a nominal period of 12 months. This data will be added to the current database for hydraulic testing completed to date for the proposed Project in areas of cuts and deep excavation boxes in particular.

In terms of the ZOI associated with dewatering, it is important to note that the modelled outflows (m^3/day) are highly sensitive to the permeability input value. Site-specific experience within the Dublin area (Appendix A19.11) indicates that flow rates could be much lower in reality and where this is the case then the modelled ZOI beyond the footprint of the excavation will be less. As such the assessment has considered a conservative scenario.

Mitigation of the conservatively modelled impacts associated with interpreted ZOI may include re-injection to ground through existing boreholes or newly drilled re-injection well points strategically placed and designed for the purpose of mitigating against localised geotechnical issues for example settlement, rather than as wider area recharge to ground wells. This is achievable where the local ground conditions have been assessed as suitable for effective local reinjection to ground around the station for example and there is sufficient surface area available for the new re-injection and monitoring wells in addition to the necessary cleaning plant required to treat the water to permitted discharge standards prior to any re-injection in that area. In general, it is noted that re-injection within Dublin is feasible and on-going in places for example of 20 no. active dewatering sites five no. (i.e. 25%) involve recharging to ground (with the highest re-injection volume being 15l/sec; Appendix A19.11). This mitigation, where required for example in order to control the variation of the local water table in anticipation of potential localised settlements and nearby off-site structural damage, is considered very feasible once new wells are carefully positioned, designed, installed, operated, monitored and maintained. In the event where high volumes of groundwater enter the excavation and which will need pumping out, then this dewatering will be mainly directed to defined sewer as mentioned and following the necessary treatment.

19.6.2.4 Substantial Water Inflows Under Pressure

Dewatering of highly pressurised groundwaters both during deep excavation and during TBM advance works will be undertaken in the Boulder Clay and also within BoD and UWR units, for example at chainage: 7+450 to chainage: 7+650 (CTO, UWR, BoD, QBL) and at a depth of approx. 23mBGL, and between chainage: 7+650 to 9+500 (CTO, QBR, QBL) at a depth range of 17.0mBGL to 24mBGL (saturated sand lenses). The groundwater control measures to mitigate this impact will consist of D-wall/secant pile wall perimeter pumping wells which will assist in maintaining dry working conditions during construction, and advance probing ahead of the tunnel face using Best Practice guidelines and methodologies including appropriate risk assessments in order to ensure identification of potential groundwater volumes and pressures as well as prevention of any flooding potential at the TBM with depth.

To minimise this negative impact on the tunnel excavation, it will be essential to maintain a pressurized front, with a pressure higher than the interpreted groundwater flow pressure at the TBM front.

There is also a risk of significant inflows at the contact of the CWA and CTO limestone and fracture zones, for example at chainage: 7+150 to chainage: 7+450 and tunnel depth to TOR at 22m-24mBGL. Existing faults for example at chainage: 12+200 to chainage: 12+400 may increase water inflows, locally. The use of a variable mode boring machine (i.e. EPB and Slurry TBM type) will aid in minimizing the negative impact on tunnel excavation from dewatering of high pressurized groundwaters (which relate to both hydrogeological and geotechnical 'hot spots') in the Boulder Clay/BoD/UWR or rock units. To further mitigate the effects, works will include for advance probing (i.e. probe drilling be completed to all open face excavations and where risk mitigation cannot be completed or controlled) and other field assessment techniques ahead of the TBM tunnel face in these areas.

19.6.2.5 Wells Intercepted by/ or in Vicinity of the Tunnel & Excavations

Other general risks related to tunnelling along the alignment will be duly addressed in the detailed CEMP procedures and emergency and contingency plans for the proposed Project. These include mitigating against historical, i.e. unknown or unrecorded groundwater abstraction and/or monitoring wells, disused wells as well as unknown shafts encountered along the full alignment (i.e. not just the tunnelling sections). Mitigation measures will be in place for identified un-grouted and poorly grouted/backfilled boreholes such as the Well Drilling Guidelines produced by the Institute of Geologists of Ireland (IGI 2007) for effective borehole decommissioning.

With regard to the tunnel boring with an variable density machine and the potential risk of significant water/mud release at ground level if the pressurized tunnel front cuts through an unknown well, this will be managed through TBM design and TBM operating parameters designed to suit the prevailing hydrogeological conditions. Furthermore, this will all be detailed in the contractors TBM Management Plan.

In advance of Detailed Design (and despite the low probability of encountering groundwater supply wells in an urban setting as indicated in this assessment), the assessed risks associated with the interception of unknown wells by the tunnelling works (but also during works at grade) will be further considered through more in-depth studies into the prevalence of historical/active wells (however few in number) within the study area. The use of surface geophysics (electrical tomography, Ground Penetrating Radar (GPR) will be considered in areas where the likelihood of unknown wells is foreseen. There is also the possibility of installing some 'geophysical tools' within the cutter head of the TBM which could be precise enough to detect wells at the tunnel face and indicate same in advance of contact.

With regard to known groundwater well locations, where these are intercepted by the proposed Project they will be duly recorded by an experienced Hydrogeologist and tested to confirm existing yield rates in advance of being decommissioned which will follow good practice [IGI] guidelines as mentioned. Subsequently, a replacement supply well will be sited accordingly, designed, drilled, installed and tested prior to follow-on commissioning or the supply replaced by a connection to public supply.

Specific regard is made to groundwater supply wells identified as lying outside of the proposed Project boundary/alignment but within the drawdown ZOI which may be impacted by reduced groundwater levels during construction dewatering activities at station boxes/cut sections. All identified operational wells within 150m of the proposed Project boundary (or 50m from the calculated drawdown ZOI, if greater) will be monitored for water level on a monthly basis for 12 months before construction, during construction and for a nominal period of 12 months after construction is completed. If the level monitoring indicates that the proposed Project has impacted on a supply or geothermal well (refer Section 19.4.7) then appropriate mitigation will be applied such as replacement well installation or deepening of wells as appropriate.

To ensure the protection of quality of identified groundwater potable supplies, all abstraction wells were identified as lying within 150m of the proposed Project boundary will be monitored for water quality on a monthly basis. This will include for standard drinking water quality parameters on a monthly basis for 12 months before construction, during construction and for a nominal period of 12 months after construction. If the monitoring indicates that the proposed Project has negatively impacted on a water supply source, then appropriate further mitigation measures will be applied such as well replacement or connection to public supply mains.

19.6.2.6 Water Quality Management

Specific measures will be put in place to ensure effective protection of the underlying aquifer as well as downgradient surface water features which, through hydraulic connectivity potential, could receive baseflow from these aquifer bodies. Measures applied will include the following:

- A Sediment Erosion and Pollution Control Plan will be implemented for all Construction Phase works. This includes measures to manage soil and silt-laden water on site, accidental leaks/spills to ground and water quality monitoring to ensure compliance with environmental quality standards specified in the relevant legislation cited under Section 20.2.1 above with regard to groundwater. The European Communities (Environmental Objectives (Surface Waters)) Regulations, 2009 (S.I. No. 272 of 2009 and amendments), and the European Communities (Quality of Salmonid Waters) Regulations, 1988 (S.I. No. 293 of 1988) will also apply. As part of the outline CEMP (Appendix A5.1), the plan for erosion and sediment control will also deal specifically with the potential impacts of the material deposition areas included for the Construction Phase of the proposed Project.
- All construction staff will be suitably trained to respond to accidental discharge/leaks and appropriate spill management kits will be in place to allow rapid response on site. An Incident Response Plan will be in place detailing the procedures to be undertaken in the event of spillage of chemical, fuel or other hazardous substances or wastes, logging of non-compliance incidents and any such risks that could lead to a pollution incident at any point along the proposed alignment.
- The provision of boundary treatments such as silt fencing and berms will be installed prior to the commencement of any construction works in order to enhance the protection of identified water features (for example Broadmeadow River, Ward River and Santry River) during the full Construction Phase, this relates primarily to Hydrology but is also of relevance here. A silt fence along the relevant boundary line of the construction works area in the context of the identified surface water feature will be required, this will be constructed of a suitable geotextile membrane to ensure water can pass through, but that silt will be retained. Typically, an interceptor trench will be required in front of this silt fence. The silt fence should be capable of preventing 425micron and above sediment from passing through. It should also be resistant to damage during deformation resulting from loading by entrapped sediment and repaired/replaced as necessary by the contractor as part of the on-going monitoring programme.
- Temporary stockpiles are required during the proposed Project works and these will be located outside of specific buffer zones; leachate generation will be prohibited. Stockpiling of excavated material will be managed on a site-per-site basis and designated areas will be suitably sized and isolated from open excavations as well as identified storm/combined sewers in the area. If any potentially contaminated material is encountered, it will need to be segregated from clean/inert material, tested and classified as either non-hazardous or hazardous in accordance with the EPA publication entitled 'Waste Classification: List of Waste & Determining if Waste is Hazardous or Non-Hazardous' using the HazWasteOnline application (or similar approved classification method). The material will then need to be classified as clean, inert, non-hazardous or hazardous in accordance with the European Communities Council Decision 2003/33/EC, which establishes the criteria for the acceptance of waste at landfills.
- If it is not possible to immediately remove contaminated material, then it will be stored on, and covered by, to prevent rainwater infiltrating through the material. The time frame between excavation and removal of all natural or contaminated excavated material will be recorded, and volumes kept to an absolute minimum.
- Specific to AZ2, Chapter 20 (Soils & Geology) presents a number of mitigation measures which will be in place to counteract the following with regard to contaminated land:

- The presence of unknown contaminants within the subsurface leading to impact potential on the hydrogeological environment (i.e. apply measure SG5 and SG6 reducing the significance criteria from Medium to Low residual impact).
- Potential impacts of water pollution through the disturbance of made ground material (i.e. apply measure SG9 reducing the significance criteria from Mild to Negligible residual impact).
- Potential impacts of water pollution through run-off from stockpiled material and mobilising of contaminants (i.e. measure SG10 reducing the significance criteria from Medium to Low residual impact). Guidance on water pollution controls will also follow CIRIA documents (refer Section 19.10).

▪ With regard to TBM consumables and management thereof including negating/limiting any impacts of the hydrogeological environment, the follow is of note:
- Annulus grouting: No grout will be lost to the ground, all grout will remain in the annulus between the cut ground and the outside diameter of the tunnel lining.
- Spoil conditioning additives (liquid foam) including polymers: The foam has a life of a few hours to a few days and breaks down in the spoil pile. While there are many different brands of soil conditioning foam agent all brands used will be biodegradable with no harmful residual chemicals.
- Main bearing grease –Grease used in the lubrication process and labyrinth seal will be 'lost' in the spoil and removed with the arisings; both greases are biodegradable.
- Tail seal grease – This grease does not come into contact with the ground when the TBM is mining. As the TBM pushes forward, the tunnel rings are exposed at the end of the tail can but are immediately covered by the annulus grout.
- Bentonite - This is blended from naturally occurring materials and is non-hazardous. As with the slurry itself, very little is left in the ground as it is continuously re-cycled and mixed with fresh slurry as the tunnel and pipelines are extended. Under Irish regulations it is classified as a non–hazardous waste.

▪ With regard to the Southern section TBM (City drive) proposals to bury the machine south of Charlemont Station, the following measures are proposed to mitigate against any potential water (or soil) quality impacts on the hydrogeological (and hydrological) environment:
- Once the TBM has built and grouted the last ring, the TBM grouting system will be modified by adding additional pipes to pump grout into the cutter head and around the shield. At the same time, temporary power and ventilation will be installed to the back of the gantries, the main electrical power disconnected and cable and service pipes removed from the tunnel wall. All pipes will be blown clean before removing to ensure prevention of slurry spillage in the tunnel invert. HV cable will be rolled onto drums using the reverse of the process to install them. Communication and low voltage cables will be left in place until the work is complete.
- All pipelines, for example tail seal grease, main bearing grease, water lines, grout lines and foam lines on the backup gantries will be blown out to clean any material from them. Hydraulic connections will be blanked off after pumping the oil into tanks for removal from the tunnel. The gantries will be split and each one towed back to the portal where it can be lifted out.
- After all gantries have been removed, the main section of the TBM shield will be dismantled. Hydraulic oil will be pumped from all the rams including those on the erector into tanks which will be taken to the portal. Electric drive motors, electrical switches, cables, grout lines, grease line and all hydraulic hose will be removed from the machine and loaded onto flat beds for transport to the portal. Any valves that can be removed will also be taken off at this stage.
- With all the major and minor parts removed, the TBM will be de-greased and cleaned with all de-greaser solution contained and pumped into bunded containers. Following final checks, the TBM will be signed off as ready to be concreted. A bulkhead with concrete injection ports and breather pipes will be assembled as per a temporary works design. Concrete will be pumped into the chamber and air will be displaced through the breather pipes. Once concrete is seen flowing from the breathers, concreting will stop with the TBM now encased in concrete.

▪ Site-specific constructability reports prepared for the proposed Project will clearly specify how water emanating from site activities will be managed from source to final approved discharge point -this includes details on effective attenuation and suitable land take to accommodate the respective attenuation and treatment systems proposed. Under no circumstances will treated water be discharged to ground or public sewer without the respective water quality meeting the statutory limits as set under the relevant EU Environmental Objectives for groundwater and surface water (see also Section 19.3.1). As with any underground construction, pumping will be required to manage both stormwater collection and/or any inflows of groundwater into the cut section/station box within each site boundary. Water will be pumped through a temporary construction site attenuation tank/siltbuster, prior to discharging through a series of treatment tanks with storage (i.e. typically 900m3 attenuation volume equivalent to one day's discharge where a 'conservative inflow' of ~10l/sec is assumed) as required.

- Final discharged volumes will occur in a controlled manner following appropriate Local Authority discharge permit criteria and irrespective of whether this discharge is to sewer (as proposed) or watercourse (in the event of accidental release). Monitoring (to include for pH, electrical conductivity and suspended solids associated with construction type water) will be undertaken on a daily basis to confirm suitability for discharge as pre-defined under the Water Quality Management Plan within the outline CEMP (Appendix A5.1). In the event that monitored discharge water exceeds approved discharge limits this will be re-circulated at the site and treated accordingly or will be disposed of offsite to an appropriate disposal facility. There will be no direct discharge to any identified water feature.
- In terms of managing any firewater that may arise during the Construction Phase, the following will apply:
  - In the event of an emergency, the response will involve tankering of contaminated water from the respective site to an approved facility for disposal. The management of water potentially contaminated with fire-related products will be detailed in the project-specific appropriately detailed CEMP.
- Where excavations include significant placement of concrete and/or bentonite (typically inert component of grout material), there is potential for alkaline discharges to occur. When this concreting is being carried out, the discharge water will require additional treatment including for pH neutralisation. As mentioned, a continuous pH monitor will be installed on the discharged water from the treatment plant. It is proposed that discharge water pumped out during the concrete works where it exceeds the range of 6-9 pH units is either re-circulated for further treatment, removed off site for appropriate treatment and disposal, or treated on site and discharged into pre-identified foul sewer, with due permission from Irish Water. There will be no direct discharge to any identified water feature.
- To minimise the potential for [accidental] discharge of silt-laden water or contaminated water entering identified storm drains or water courses, a 'treatment train' will be incorporated in the construction design. This is further discussed in Chapter 18 (Hydrology), Section 18.5.1. The design of each treatment train will depend on the activity at each construction compound and be made 'fit for purpose'.
- Refuelling of construction vehicles and the addition of hydraulic oils or lubricants to vehicles will take place in a designated and controlled area away the buffer zone(s) applied for each site. Prior consultation with IFI and NPWS will be undertaken ahead of commencing any Construction Phase works near watercourses or in areas where groundwater is interpreted to provide baseflow to downstream water features; such consultation will be on-going process and form part of the Water Quality Management Plan within the CEMP for the proposed Project during all relevant site works.
- Protection measures will be put in place to ensure that all hydrocarbons used during the Construction Phase are appropriately handled, stored and disposed of in accordance with the TII document 'Guidelines for the crossing of watercourses during the construction of National Road Schemes', (TII/NRA, 2008). All chemical, oil storage tank(s) and associated refilling locations will be contained within effectively bunded areas to conform to the current Best Practice Guide BPGCS005 - Oil Storage Guidelines (published by Enterprise Ireland) and set back a minimum of 10m from water courses (rivers, streams, field drains). Construction works will follow the afore-mentioned site-specific Water Quality Management Plan as part of the CEMP for the proposed Project - Note: this will apply to all works areas, logistics sites and storage compounds.
- As per site constructability reports for the proposed Project, the majority of construction works areas will need temporary site connections to foul drains (for office and welfare foul discharge) which may include discharge to foul sewer in agreement with Irish Water, or in some cases this water will be collected on site and appropriately disposed of offsite. It is likely that any 'grey water' from site works will be collected and prior assessed for potential re-use, requiring appropriate cleaning and storage tanks. There will be no direct discharge of grey water to any identified water feature.

- All design measures set out in the ESB Advanced Work Package (DN0566) will be implemented during the installation of underground cables (typically <3m depth) which cross waterbodies and/or drainage ditches including where potential groundwater baseflow exists. Where the open trench (with 'damming and fluming' or 'damming and pumping') method is used for the crossing of streams and rivers this approach will be implemented only with the approval of IFI prior to the commencement of any construction works. Where applicable, the construction will take place outside the salmon spawning period from October to April unless otherwise agreed with IFI.
- Construction compounds will not be constructed on lands designated as Flood Zone A or B in accordance with the OPW 'Planning System and Flood Risk Management Guidelines' (OPW, 2009). All watercourses within compound areas will be fenced off at a minimum distance of 5m.

Note: Chapter 18 (Hydrology), Section 18.5.1 includes for mitigation measures during construction with regard to the hydrological environment. Given the interaction potential between both surface water and groundwater, then these measures are also applicable here for the hydrogeological environment.

19.6.2.7 Water Use Management

All contractors will prepare a Water Management Plan in terms of water usage. This plan will apply commitments made within the proposed Project contract towards the minimisation of water use, conservation of water and water efficiency measures on the proposed Project work sites. To ensure that the Water Management Plan remains relevant, adequate and effective as the works progress it will be reviewed and updated as necessary:

- Following any change that has a significant impact on water usage;
- As instructed by the proposed Project Manager, and
- At least every six months.

The Water Management Plan will set out a number of key objectives and targets towards conserving and minimising water use, as the following examples:

- Eliminate - eliminate water use by identifying if the water-using process or activity is really necessary and/or if there is a cost-effective alternative to using water;
- Substitute - identify and use alternative 'non-potable' sources and eliminate inappropriate use of drinking (potable) water. Utilise a rainwater harvesting system where possible to collect run off from site temporary accommodation. Assess whether rainwater or grey water can be used for the activity/process;
- Reduce - explore options that improve efficiency, e.g., by regular maintenance of water-using equipment (to ensure they are working to maximum efficiency), installing metering and monitoring supplies, and updating fittings and/or processes on a regular basis;
- include surplus water extracted from ground dewatering activities which would normally require filtering through settlement or flocculation tanks prior to discharge to sewer. This source could be tankered to other sites for general use; and
- Disposal - dispose of excess water legally and responsibly to ensure prevention of flooding, pollution or inconvenience to stakeholders.

Minimisation of the use of water will be considered during planning for each stage of the works, incorporated into relevant procedures and method statements, and with steps to eliminate or minimise water usage incorporated and utilised where possible. Mains water connections will be fitted with meters such that potable water usage is monitored and managed. Where practical and possible, water will be reused on-site. Construction activities on the proposed Project identified as having the potential for high water use will be specifically targeted against opportunities to reduce water use, utilising the hierarchy of objectives listed above. Appendix A5.11 presents additional details on minimisation of water consumption and specific examples for the construction of piling and diaphragm walls, tunnelling and dust suppression.

19.6.3 Design Measures and Mitigation During Operation

19.6.3.1 Management of Discharge Water Quality

Chapter 18 (Hydrology), Section 18.6.2 includes for mitigation measures during operation of the proposed Project with regard to the hydrological environment and water quality. Given the interaction potential between both surface water and groundwater, then the measures related to water quality are also applicable here for the hydrogeological environment. An overview with specific regard to groundwater is provided as follows.

- The potential for impact on groundwater quality as a result of stormwater discharge to ground is low during operation based on the minimal use of lubricants and chemical for operational maintenance and presence of hardstand. There is no requirement for bulk chemical storage other than storage at the Dardistown Depot. All chemicals will be stored on impermeable hardstand and under cover within designed maintenance compounds. A programme of regular inspection of operational design discharges will be undertaken as part of the long-term operation and maintenance programme.
- Oil and petrol interceptors will be included prior to outfalls for water collected at the Dardistown Depot, the Park & Ride area, maintenance areas, track drainage and along surface water routes. As such there is no likely discharge to ground.
- All wastewater arising from the tunnel alignment (including from the tunnel itself, emergency access and ventilation shafts, portals) and foul water from Station boxes will ultimately be discharged to public foul sewer under formal consent by Irish Water. No wastewater will be discharged to ground during operation.
- Chapter 18 (Hydrology) Section 18.6.2.3 discusses the management of firewater during the Operational Phase of the proposed Project with emphasis on fire detection and automatic shut off systems including containment and subsequent off-site disposal. The procedures with regard to firewater management are also applicable to the hydrogeological environment and are specified with the fire safety strategies for the MetroLink project.
- During the Operational Phase of the proposed Project, on-going inspection (at a minimum three- to five-year frequency) and maintenance will occur to ensure that the swales/wetland ponds/infiltration basins continue to operate as intended for the design life of the proposed development, with particular emphasis on areas AZ1 to AZ3. A number of measures were incorporated into the design of the proposed Project to minimise their impact (refer also Chapter 4). Essentially, design of all attenuation features will include for specific catchment and containment area, hydrocarbon interceptor and hydrobrake to mitigate any impact on receiving water features, including where these potentially interact with groundwater and downstream sites of ecological significance.
- Care will be taken in reworking acceptable and certified as suitable for re-use excavated subsoil material post Construction Phase. Where this occurs for example during landscaping works, in order to minimise the potential for groundwater infiltration and generation of runoff to ground.

19.6.3.2 Mitigation of the 'Barrier Effect'

Specific hydrogeological modelling has been carried out in order to assess the potential 'Barrier Effect'. The outputs of the modelling completed to date have significantly assisted in determining the actual effects of the hydrogeological barriers that might be caused by the underground infrastructure of the proposed Project. Appendix A19.10 presents the hydrogeological plan which also indicates areas where groundwater flow paths run parallel to MetroLink alignment (for example near chainage: 2+160) which indicates that the barrier effect will not occur.

Note: Barrier effects mostly relate to the Operational Phase however the effects will arise immediately following commencement of Construction Phase works in those sections of the proposed alignment where interception of regional groundwater flow paths by cut sections/station boxes/tunnelling occur.

As a mitigation measure it is proposed to install drainage wells on each side of the cut section and station box locations based on the results of modelling of groundwater flow patterns and the impacts of the proposed Project on this regional/local flow regime. For example, as mentioned within AZ1 Northern

Section, modelling of the potential interaction between natural groundwater flow patterns and the proposed piled-walls within the Seatown - Fosterstown area (i.e. between chainage: 2+800 and chainage: 4+800) indicates there is a possibility of the barrier effect occurring which will require effective mitigation measures.

In the Seatown-Fosterstown sector an upstream mean elevation in the head within observation wells of 0.60m was modelled (refer Appendix A19.8 and Appendix A19.10), reaching at some points an elevation equal to 1.20m. For this reason, in order to avoid the potential barrier effect, it may be necessary to incorporate a by-pass system approximately between the chainage references 2+800 to 4+800. To incorporate a by-pass, a collection and diffusion system based on pairs of drainage wells located every 100m along the alignment and connected to each other by means of a pipe through the cross-section of the alignment there. The pipe will rest on the intermediate slab or be set into the bottom slab. Assuming the placement of a by-pass through a 200mm diameter pipe placed every 100m, then a pipe flow equal to 1.13×10^{-3} m^3/s can be considered for the section calculation.

In general, as part of mitigating the barrier effect, the use of drainage wells would typically be located hydraulically up-gradient and down-gradient of the structure and the inclusion of a design 'drainage blanket' below the ground slab may also be considered where feasible. This version of a by-pass blanket would serve to hydraulically connect both sides of the cut/station retaining walls which will allow groundwater to pass freely under the cut/station box feature thereby maintaining flows with depth and alleviating up-gradient pressures. An example of this effective mitigation feature is shown below in Diagram 19.21 for the Bogota (Colombia) Metro Preliminary Design developed by IDOM in 2015.

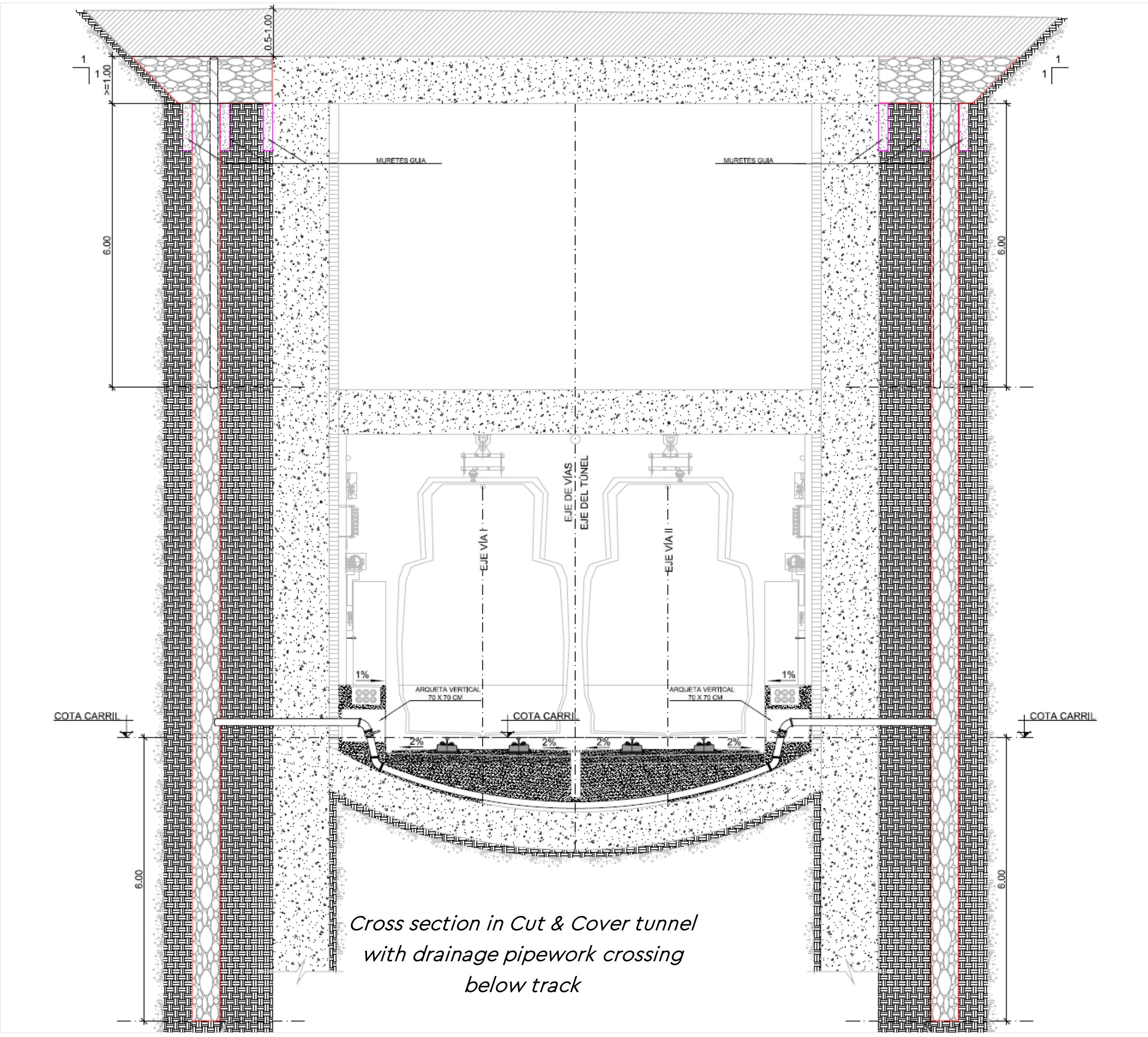

Diagram 19.21: Example of Drainage Wells/Screens Designed at Bogota Metro (Preliminary Design by IDOM in 2015)

19.7 Residual Impacts

19.7.1 Introduction

The residual impacts are those that would occur after the mitigation measures, as outlined in Section 19.6 above have taken effect. The following is a summary of the residual impacts associated with the hydrogeological (and hydrological) environment:

- No significant local impacts to river or stream morphology are expected, based on the design measures included in the proposed Project (Chapter 18 Hydrology) which will effectively minimise the potential for scouring and therefore any impact on the existing surface water flow regime in those receiving water courses which may also discharge to groundwater or receive contributions from groundwater as baseflow. The residual effect on river and stream morphology is considered as *Imperceptible to Slight* and of *Permanent* duration.
- There is potential for accidental spillages related to the Operational Phase (for example of limited storage of fuels/fuel delivery at the Dardistown Depot) which could result in negative water quality changes to receiving surface waters and groundwaters depending on the incident. However, as the proposed trains are electrically operated, and the final design will ensure for effective mitigation measures to be in place in the long-term for all stations, depot/compounds, and so on then the potential for contamination is considered to be low. Maintenance depots and car parking areas will have oil/petrol interceptors included in their design as a precursor for the management of

accidental discharges locally. The residual effect in this regard is considered to be *Imperceptible* and of *Permanent* duration.
- There are no protected wetlands/GWDTEs/SACs or SPAs within the area of influence of the proposed Project alignment with the significance for hydrogeological aspects of receptors at risk during the Operational Phase of the proposed Project considered as *Imperceptible* after mitigation. As such, there are no residual hydrogeological effects on European sites.

19.8 Difficulties Encountered in Compiling Information

In general, no significant difficulties were encountered in undertaking this hydrogeological assessment. Some items of note however are outlined and relate specifically to the collection of field data as follows:

- Ideally, any groundwater monitoring programme would be carried out in both summer and winter months, respectively in order to gain a greater understanding of aquifer characteristics including groundwater level variation and any changes in groundwater quality between these seasons. Groundwater sampling in 2021 was carried out during what is traditionally referred to as the high water table season including in January and March of this year. Notwithstanding this and given the relatively dry weather conditions experienced over the past twelve months, some shallow screened monitoring wells were recorded in the field as dry/damp only with insufficient water to allow a representative sample to be collected. For example, NBH60 and NBH61 at Dublin Airport, NBH215 at Mater and NBH63 at O'Connell Street.
- In general, there were no significant access constraints when arranging to sample at the selected monitoring wells located along the project alignment. NBH72(S) at Estuary required a delayed site visit due to landowner access approval. As such, this well was sampled on 7 May 2021 as opposed to the other wells which were completed in March 2021 (i.e. as part of Round 2).
- It is noted that some groundwater monitoring wells needed to be re-located at the time of the drilling part of the Ground Investigation works (for example AWN01 and AWN02 boreholes drilled as part of GI Phase 5). Re-locating the boreholes was primarily due to access constraints at the time of mobilisation. Specifically, ground conditions in terms of inaccessible fields or locations that posed a risk due to overhead lines, buried services or proximity to structures. Notwithstanding this, the alternatives chosen were deemed acceptable by the team in terms of representing viable exploratory locations within the proposed alignment.

19.9 Glossary of Technical Terms

Acronym	Meaning
Aquifer	A subsurface layer or layers of rock that store and transmit water in significant quantities.
Base flow	That part of the stream discharge that is not attributable to direct runoff from precipitation or melting snow; it is usually sustained by groundwater discharge.
Baseline monitoring	The establishment and operation of a designed surveillance system for continuous or periodic measurements and recording of existing and changing conditions that will be compared with future observations. For example baseline groundwater monitoring.
Catchment	The entire surface area feeding water to a given surface or groundwater feature.
Conduit flow	Groundwater flow though large conduits within the rock mass typical of karstic aquifers.
Cumec (m3/sec)	A cubic metre per second, as a unit of rate of flow of water

Acronym	Meaning
Discharge area	An area in which water is discharged to the land surface (ground), surface water, or atmosphere.
Drawdown	A withdrawal of water from a reservoir or repository and reduction in monitored levels.
Electrical Conductivity	Measure of the ability of material to conduct an electrical current. For water samples, it depends on the concentration and type of ionic constituents in the water and temperature of the water; and it is expressed in siemens/micro-siemens per metre.
Epikarst	The thin zone near the karst surface. It includes solutionally modified (karren) bedrock surfaces and overlying regolith. The epikarst frequently supports a perched aquifer and serves to retard and store infiltrating rainwater. It also serves as a habitat for a variety of organisms that live in the interstices.
Fault	A planar fracture in rock in which the rock on one side of the fracture has moved with respect to the rock on the other side.
Fracture	A discontinuity across which there has been separation.
Groundwater	That part of the subsurface water that is in the saturated zone, i.e. below the water table
Groundwater vulnerability	Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.
GWDTE	Groundwater Dependent Terrestrial Ecosystems
Hydraulic barrier	A general term referring to modifications of a groundwater flow system (for example to restrict or impede movement of contaminants).
Karst	Terrain created by limestone solution and characterised by a virtual absence of surface drainage, a series of surface hollows, depressions and fissures, collapse structures and an extensive subterranean drainage network.
Karstification	Formation of the features of karst topography by the chemical, and sometimes mechanical, action of water in a region of limestone, dolomite, or gypsum bedrock.
Made Ground	Deposits/reworked subsoils which have accumulated through human activity and may consist of natural materials, e.g. clay and/or manmade materials
Outcrop	An exposure of bedrock at surface
Permeability	A measure of the ability of a given rock or overburden material to transmit water
Phreatic Water Table	Natural water table where all pores and fractures are saturated with water.
Potentiometric surface	A hypothetical surface representing the level to which groundwater would rise if it were not retained/inhibited by a confining layer.

Acronym	Meaning
Recharge	The addition of water to the zone of saturation; also, the amount of water added to the [defined] system.
Rockhead	A raised rocky area or prominence; a summit or extremity of rock. The upper surface of bedrock.
Run-off	Water leaving a drainage area or water running across the land surface.
Saturated zone	The zone below the water table in which all pores and fissures are full of water. Also known as the phreatic zone.
SuDS	Sustainable drainage systems (SuDS) are a natural approach to managing drainage in and around properties and other developments. They work by slowing and holding back the water that runs off from a site, allowing natural processes to break down pollutants.
Unsaturated zone	The zone between the land surface and the water table, in which pores and fissures are only partially filled with water. Also known as the vadose zone.
Water table	The surface in an unconfined aquifer or confining bed at which pore water pressure is atmospheric.
Zone of Contribution	The groundwater catchment area that contributes water to a well.

19.10 References

APEX, (2007). *Final Report on the Geophysical Survey for the Dublin Metro*, APEX Geoservices Limited; Report for IGSL, ref: AGL06203, issued 12-03-2007.

CIRIA, (2001). *C532 - Control of Water Pollution from Construction Sites Guidance for Consultants and Contractors*; Publication by CIRIA, London, 2001.

CIRIA, (2006). *C648 - Control of Water Pollution from Linear Construction Projects, Technical guidance;* Publication by CIRIA, London, 2006.

CIRIA, (2006). *C649 - Control of Water Pollution from Linear Construction Projects, Site guide;* Publication by CIRIA, London, 2006.

CIRIA, (2015). *C753 - The SuDS Manual*, Publication by CIRIA, London, 2015.

DCC, (2016). Dublin City Development Plan, 2016-2022; Written Statement, Volume 1, Appendices, Volume 2.

DCC, (2022). Draft Dublin City Development Plan, 2022-2028; Available on-line at: https://www.dublincity.ie/residential/planning/strategic-planning/dublin-city-development-plan/development-plan-2022-2028 [Accessed 28 July 2022].

- EPA, (2015). *Advice notes on current practice in the preparation of Environmental Impact Statement*, Draft, published by the Environmental Protection Agency, October 2015.

EPA, (2022). Environmental Protection Agency on-line database; Available on-line at http://gis.epa.ie/GetData [Accessed 27 May 2022].

- EPA, (2022a). Guidelines on the Information to be contained in Environmental Impact Statements, published by the Environmental Protection Agency, May 2022.
- FCC, (2022). Fingal Development Plan 2023-2029, Written Statement, February 2022.

GSI, (n.d.). *Dublin Groundwater Body: Summary of Initial Characterisation*, drafted by Geological Survey Ireland.

GSI, (2022). Geological Survey Ireland on-line database; Available on-line at: www.gsi.ie [Accessed 10 July 2022].

IGI, (2007). Guidelines for Drilling Wells for Private Water Supplies, published by the Institute of Geologists in Ireland; Available on-line at: https://igi.ie/publications/guidelines/

IGI, (2013). Environmental Impact Assessment (EIS) Guidelines, (2013), published by the Institute of Geologists in Ireland; Available on-line at: http://igi.ie/publications/guidelines/

IGSL, (2008). *Groundwater Investigation Report, Dublin Metro North Main Ground Investigation*; 14/08/2008.

Kelly, C. et al, (2015). *Irish Aquifer Properties – A reference manual and guide*, Authors: Kelly, C., Hunter-Williams, T., Misstear, B.M., and Motherway, K. Prepared on behalf of the Geological Survey Ireland and the Environmental Protection Agency.

Massarsch, (2010). Expert's Report for An Bord Pleanala on Environmental Impact Statement for Metro North -Assessment of the Environmental Impacts in relation to Ground Vibrations and Ground-borne Noise, Geotechnical, Hydrogeological and Related Issues. Report by K. Rainer Massarsch, July 2010. Ferievagen 25, SE 168 41 Bromma, Sweden.

NFGWS, (2022). National Federation of Group Water Schemes, Available on-line at: https://nfgws.ie/ [Accessed 28 June 2022].

NPWS, (2022). National Parks and Wildlife Service, Available on-line at: www.npws.ie [Accessed 28 July 2022].

OPW, (2009). *The Planning System and Flood Risk Management Guidelines* for Planning Authorities, Technical Appendices, Dated November 2009; Government of Ireland.

OSi, (2022). Ordnance Survey of Ireland, Available on-line at: www.osi.ie [accessed 28 July 2022]:

- TII, (2009). Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes, published by Transport Infrastructure Ireland (formerly National Roads Authority), 2009.
- TII, (2015). *Road Drainage and the Water Environment* (DN-DNG-03065) report by Transport Infrastructure Ireland, March 2015
- RPA, (2009). Metro North Oral Hearing Application -Further Information Request, Item 19: Groundwater and Geohydrology. Peer Review report for Railway Procurement Agency.