Contents

10 Hydrogeology

10.1 Introduction

This chapter of the EIAR consists of an appraisal of the proposed N6 Galway City Ring Road, hereafter referred to as the proposed road development, under the heading of hydrogeology.

This chapter initially sets out the methodology followed (**Section 10.2**), describes the receiving environment (**Section 10.3**) and summarises the main characteristics of the proposed road development which are of relevance for hydrogeology (**Section 10.4**). The evaluation of impacts of the proposed road development on hydrogeology are described (**Section 10.5**) and measures are proposed to mitigate these impacts (**Section 10.6**). The residual impacts are also described (**Section 10.7**). The chapter concludes with a summary (**Section 10.8**) and reference section (**Section 10.9**).

This chapter has utilised the information gathered during the constraints and route selection phases of the proposed road development to inform the hydrogeology impact appraisal. **Sections 4.5**, **6.5.3** and **7.6.3** of the **Route Selection Report** considered the hydrogeology constraints within the proposed road development study area and compared the potential hydrogeology impacts of the proposed route options respectively. These sections of the **Route Selection Report** contributed to the design of the proposed road development which this chapter appraises.

10.2 Methodology

10.2.1 Introduction

This section outlines the methodology used to prepare this chapter of the EIAR and is founded on current legislation and guidelines.

10.2.2 Legislation and Guidelines

This chapter is prepared having regard to the requirements of Section 50 Sub-section (2 and 3) of the Road Act 1993 as amended, and with the following guidance:

- Environmental Protection Agency (EPA) Guidelines on Information to be contained in Environmental Impact Statements (EPA, 2002)
- Environmental Protection Agency (EPA) Advice Notes on Current Practice in the Preparation of Environmental Impact Statements (EPA, 2003)
- Transport Infrastructure Ireland (TII) Environmental Impact Assessment of National Road Schemes – A Practical Guide (NRA, 2008)

- Transport Infrastructure Ireland (TII) Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes (NRA, 2009)
- Institute of Geologists of Ireland (IGI) Guidelines for the Preparation of Soils, Geology and Hydrogeology Chapters of Environmental Impact Statements (IGI, 2013)
- Environmental Protection Agency (EPA) Draft Revised Guidelines on Information to be contained in Environmental Impact Statements (EPA, 2015)
- Environmental Protection Agency (EPA) Draft Advice Notes for Preparing Environmental Impact Statements (EPA, 2015)
- Transport Infrastructure Ireland (2015) Design Manual for Roads and Bridges
- Guidelines on the Information to be contained in Environmental Impact Assessment Reports (Environmental Protection Agency, Draft May 2017)

The main guidelines used in preparing this chapter are the EPA Guidelines on the Information to be contained in Environmental Impact Assessment Reports (EPA, 2002, 2015 and 2017) and the most recent publication by the TII which outlines the assessment methodology for Soils, Geology and Hydrogeology for National Road Schemes (NRA, 2009). The latter guidelines are referred to as TII Guidelines within this chapter.

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

- Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy
- Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration
- European Communities (Water Policy) Regulations 2014 (S.I. No 350 of 2014)
- European Communities (Water Policy) Regulations 2014 (S.I. No. 350 of 2014)
- European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010), as amended
- European Communities Environmental Objectives (Surface Waters) Regulations 2009 (S.I. No. 272 of 2009) as amended
- European Union (Drinking Water) Regulations 2014 (S.I. No. 122/2014)
- European Communities (Quality of Salmonid Waters) Regulations, 1988 (S.I. No. 293/1988)
- Water Services Acts 2007 to 2014

10.2.3 Consultations

Consultation was carried out with relevant bodies to identify any hydrogeological features which may be impacted by the proposed road development. Consultation was undertaken by the design team with additional consultation undertaken by the project hydrogeologists with hydrogeology specialists in the Geological Survey of Ireland, Environmental Protection Agency and the National Federation of Groundwater Schemes.

Those consultations relevant to the hydrogeology impact assessment are:

- Geological Survey of Ireland (GSI) (Department of Communications, Climate Action and Environment (DoCCAE)) Groundwater Division
- Local Area engineers in Galway County Council and Galway City Council. The Water Services Section confirmed the location of the nearest public supply schemes
- National Parks and Wildlife Services (NPWS) part of the Department of Culture, Heritage and the Gaeltacht (DCHG)
- Landowners within the study area potentially affected by the proposed road development
- Environmental Protection Agency (EPA) – EPA was consulted to determine the location of any waste licence or groundwater monitoring locations within the study area. There are no EPA monitoring sites within the proposed development boundary of the proposed road development. There are a number of EPA monitoring sites on the River Corrib as outlined in **Chapter 11, Hydrology**
- Teagasc
- Office of Public Works (OPW)
- National Federation of Group Water Schemes (NFGWS)

Consultation was also undertaken with other environmental experts on the project team in order to assess the potential impact of the interaction with other environmental factors. This included discussions on the following:

- Biodiversity – Consultation on the potential impact on groundwater dependant habitats
- Soils and Geology – Consultation on geotechnical and contaminated land issues
- Hydrology – Consultation on the potential impact on surface water systems
- Drainage – Consultation on design of runoff and groundwater management
- Material Assets – Consultation on the impact on private wells

10.2.4 Study Area

In accordance with the TII Guidelines, the area of hydrogeological study should include all features which may be impacted from the proposed road development. The study area extent is dependent on the hydrogeological characteristics of the bedrock aquifer that the proposed road development traverses e.g. the potential study area for a poor aquifer will be significantly smaller than the study area for a regionally important karst aquifer.

Based upon the screening undertaken at route selection stage the extent of the study area was conservatively taken as being 250m from the proposed development boundary for the western section of the proposed road development (west of the N59 Moycullen Road), where the aquifer is classified as being poorly productive.

The eastern section of the proposed road development (east of the N59 Moycullen Road) includes regionally important karstified aquifers and the extent of the study area was taken as the extent of the groundwater catchments, or sub-catchments as appropriate, that the proposed road development traverses.

Groundwater catchments, referred to as groundwater bodies (GWB) have been mapped by the Geological Survey of Ireland (GSI). The boundaries for these groundwater divides have been refined as part of this assessment to provide a full assessment of all receptors that have the potential to be impacted by the proposed road development.

For some GWB, the project data demonstrates that parts of the GWB are hydrogeologically separate from the rest of the GWB and this has allowed sub-catchments for some of the GSI GWB to be defined. The refined GWB and identification of sub-catchments are presented in the conceptual model in **Section 10.3.3** and the implications for the impact assessment are discussed in **Section 10.3.4** and **Section 10.4**.

10.2.5 Data Sources and Baseline Data Collection

The existing baseline ground conditions within the study area of the proposed road development have been interpreted from desk studies, field studies and commissioned ground investigations. The data sources for each of these are described below.

10.2.5.1 Desk Study

The following sources of information were reviewed in order to evaluate the hydrogeology of the proposed road development:

- Current and historical Ordnance Survey maps available for the study area (1:2,500 and 1:10,560 scales)
- Aerial photography (2012) of the study area
- Aerial imagery from Google (imagery from 2003 to 2017) and Bing accessed in 2017
- Geological and hydrogeological maps of the site area produced by the Geological Survey of Ireland (GSI) (www.dcenr.gov.ie, accessed 2017)
- MacDermot, C.V., McConnell, B. and Pracht, M. (2003) *Geology of Galway Bay 1:100,000 scale Bedrock Geology Map Series*, Sheet 14, Galway Bay, Geological Survey of Ireland

- Pracht, M. and Somerville I.D., 2015. A Revised Mississippian lithostratigraphy of County Galway (western Ireland) with analyses of Carbonate lithofacies, biostratigraphy, depositional environments and paleogeography reconstructions utilising new borehole data. Journal of paleogeography. Volume 4, Issue 1, January 2015, Pages 1-26
- Teagasc and the Environmental Protection Agency Irish Soil Information System (http://gis.teagasc.ie/soils/index.php, accessed 2017
- Ground investigation reports held by the Geological Survey of Ireland for the study area (ref **Appendix A.9.1.1**)
- Flood, P. and Eising, J. (1987). *The use of vertical band drains in the construction of the Galway Eastern Approach Road*. Proceedings of the 9th European Conference on Soil Mechanics and Foundation Engineering, Dublin, Ireland
- Lidar elevation data commissioned by OPW
- N6 Galway City Outer Bypass Scheme (2006 GCOB):
    - Galway City Outer Bypass R336 Western Approach Constraints Study Report 2000
    - N6 Galway City Outer Bypass Constraints Study Report (2000)
    - Galway County Council Galway City Outer Bypass Preliminary Ground Investigation, 2006
    - N6 Galway City Outer Bypass Environmental Impact Statement (2006)
- Data available from the Geological Survey of Ireland:
    - R1340 Galway County Council Eastern Approach Road Galway (N6) (Ballybane – Doughiska), 1993
    - R1365 Thos. Garland and Partners Digital Limited, Galway Industrial Estate, 1983
    - R3176 Dermot Rooney and Associates I.D.A Business Park, Daingean, Galway, 1997
    - R5906 Irish Linen Proposed Irish Linen Factory, Rahoon, Galway, 2005
    - R6136 Galway County Council Residential Development, Headford Road, Galway, 2006
    - R6898 Storm Technology Office Block Development, Daingean, Galway, 2006

10.2.5.2 Field Studies

As part of the environmental studies a number of surveys and walkovers were undertaken to assess the hydrogeological environment. These can be summarised as follows and additional information is provided below:

- Geophysical surveys (Appendix A.9.1)
- Well Condition Survey (Appendix A.10.1)
- Karst Survey (Appendix A.10.2)

Geophysical surveys were commissioned across the route of the proposed road development to provide additional detail on the subsurface ground conditions. These, along with the ground investigations discussed in **Section 10.2.5.3** were used to develop the hydrogeological conceptual model for the study area. The data for the geophysics surveys are presented in **Appendix A.9.1**.

A well condition survey was undertaken in 2014 to determine the condition of existing monitoring wells which were installed as part of the 2006 Galway City Outer Bypass (2006 GCOB) studies. This survey allowed historic wells, some of which required remediation, to be incorporated into the monitoring network for the proposed road development. The report on the condition of these wells is detailed in **Appendix A.10.1**.

Detailed karst surveys were completed for the constraints and route selection studies for the proposed road development in 2014. The karst survey was updated in July 2016 following completion of site walkovers and ground investigations (this updated report supersedes the karst Survey report included in the N6 Galway City Transport Project Route Selection Report, Arup 2016). The karst survey is presented in **Appendix A.10.2**.

10.2.5.3 Commissioned Ground Investigations

Five ground investigations were commissioned for the project. These ground investigations included boreholes, trial pits and window sampling, which are fully described **Chapter 9, Soils and Geology**. The ground investigations also included groundwater monitoring and groundwater testing. The full list of investigation is detailed in the following appendices:

- Groundwater Level Monitoring Report (June 2017) (Appendix A.10.3)
- Water Quality Monitoring Report (June 2017) (Appendix A.10.4)
- Aquifer Testing Report (June 2017) (Appendix A.10.5)
- N6 GCTP Phase I Ground Investigation Contract I, November 2014. Factual Report (Appendix A.9.1.2)
- N6 GCTP Phase II Ground Investigation Contract I, November 2015. Factual Report (Appendix A.9.1.3)
- N6 GCTP Phase III Ground Investigation Contract I, June 2017. Factual Report (Appendix A.9.1.4)

- N6 GCTP Phase III Ground Investigation Contract II, May 2016. Factual Report (Appendix A.9.1.5)
- N6 GCTP Phase III Ground Investigation Contract III, April 2017. Factual Report (Appendix A.9.1.5)

In summary, the hydrogeological investigations for the proposed road development comprised of the following project specific groundwater installations and testing:

- 34 No. groundwater monitoring wells
- 16 No. groundwater level monitoring rounds [1]
- 12 No. groundwater quality monitoring rounds
- 15 No. infiltration test
- 16 No. small scale pumping test and variable head permeability tests
- 3 No. Packer tests
- 1 No. step pumping test

All investigation locations were sited based on the design of the proposed road development. Groundwater level, groundwater quality and aquifer testing in particular was focused on locations of cuttings, structures and receptors.

10.2.6 Technical Limitations

The data included in the hydrogeology assessment includes existing information from earlier investigations in the region as well as dedicated field surveys, walkovers and ground investigations commissioned for the proposed road development. The data collected provides a comprehensive hydrogeological dataset along the route of the proposed road development. As is standard for hydrogeological studies the dataset comprises of point data (boreholes), linear data (geophysics) and surface data (topography, water courses and karst) to develop a conceptual model of the study area.

Where groundwater dependent receptors were identified, the locations were investigated to determine the hydrogeological regime. Due to the ecologically sensitive nature of sites the investigation methodologies selected were those that would not impact on the hydrogeology of a European site. In the absence of site specific data in these sensitive locations, a conservative approach was taken in appraising any potential impacts.

Based on the comparability of the ground investigation and the baseline data collection the information is deemed sufficient to complete the hydrogeology evaluation.

[1] Groundwater monitoring was undertaken between February 2015 and April 2017. This included a total of 16 groundwater monitoring rounds. Measurements on individual wells were also taken during commissioning, well testing and spot checks. In total 54 individual wells were regularly measured, which comprised of 34 project specific wells, 16 (2006 GCOB wells and 4 private wells. Contractors also undertook a period of monitoring following the well installation for this project and their data is presented in the Ground Investigation Reports in **Appendix A.9.1**.

10.2.7 Impact Assessment Methodology

The TII Guidelines have been used to provide the criteria for the impact assessment during construction and operation of the proposed road development.

The rating of potential impacts from the proposed road development on the hydrogeological environment has been assessed by:

1. Classifying the importance of the relevant attributes (**Table 10.1**)
2. Quantifying the likely magnitude of any impact on these attributes (**Table 10.2**)
3. Determining the resultant significance (**Table 10.3**)

Table 10.1: Criteria for Rating Site Attributes - Estimation of Importance of Hydrogeology Attributes (TII, 2009)

Importance	Criteria	Typical Example
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. cSAC or SPA status
Very High	Attribute has a high quality or value on a regional or national scale	Regionally important aquifer with multiple well fields. Groundwater supports river, wetland or surface water body ecosystem protected by national legislation – 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

Table 10.2: Criteria for rating impact significance at EIA stage – Estimation of magnitude of impact on hydrogeology attributes (TII, 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]

1 Additional Examples are provided in the TII Guidance Document

2 refer to Method C, Annex 1, Annex 1 of HA”16/06

3 refer to Method D, Appendix B3/Annex 1of HA216/06

Table 10.3: Rating of Significant Environmental Impacts (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 2009 NRA significance ratings were designed to be in accordance with impact assessment criteria provided in the EPA publication Guidelines on the Information to be contained in Environmental Impact Assessment Reports (Environmental Protection Agency 2002 guidelines). However, it should be noted that the 2017 EPA guidelines include two additional 'Significance' rankings over previous EPA and the current TII guidance. The two additional rankings 'Not Significant' and 'Very Significant' ratings have not yet been incorporated by TII into the Significance ranking matrix (refer to **Table 10.3**) and as such the rating of significance used in this EIAR follows TII 2009 significance nomenclature and does not include 'Not Significant' nor 'Very Significant'. Where 'Not Significant' would apply based on EPA (2017) then Imperceptible is used for NRA (2009) and where 'Very Significant' would apply based on EPA (2017) then Profound is used for TII (2009).

The rating of significant environmental impacts is also assessed in terms of duration and frequency. With each impact described as being momentary, brief, temporary, short-term, medium-term, long-term or permanent. The frequency of effects is also described either in terms of reoccurrence (one, rarely, occasionally, frequently, constantly) 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:

- Momentary effects last from seconds to minutes
- Brief effects last less than one day
- Temporary effects last less than one year
- Short-term effects last one to seven years
- Medium-term effects last seven to fifteen years
- Long-term effects last fifteen to sixty years
- Permanent effects last over sixty years

In line with guidelines, following the assessment of potential impacts, specific mitigation measures are presented to avoid, reduce and remedy any negative impacts on the hydrogeological environment. These are described in **Section 10.6** below. Residual impacts which are the potential impacts which result after mitigation measures have been fully established and are described in **Section 10.7** below. The length of time it takes for each mitigation measure to take effect varies but they are designed to ensure that predicted impacts are minimal.

10.3 Receiving Environment Baseline

This section provides a characterisation of the hydrogeological receiving environment of the proposed road development. The hydrogeological environment is presented firstly in the regional context using publically available information and then secondly in detail for the study area based on information obtained specifically for the project.

Both the regional and site specific assessments document the hydrogeological characteristics of aquifer classification, groundwater vulnerability, recharge and groundwater receptors, such as aquifers, groundwater abstractions and groundwater dependant terrestrial ecosystems (GWDTE) (refer to the glossary of technical terms provided with this EIAR.

10.3.1 Regional Hydrogeology

The hydrogeological study area is divided into two main regions on the basis of the contrasting aquifer properties for the two main geological rock types in the region. As described in **Chapter 9, Soils and Geology**, the bedrock geology may be divided into:

- The Galway Granite Batholith (comprising of granite and orthogranite) underlies the western section of the proposed road development from the R336 west of Bearna Village to the N59 Moycullen Road
- The Visean Undifferentiated Limestone, which underlies the eastern section of the proposed road development from the N59 Moycullen Road to existing N6 at Coolagh

10.3.1.1 Western Section

The GSI bedrock aquifer map for the western section is presented in **Figure 10.1.001**. The GSI classification of the granite and orthogranite (including multiple dolerite dykes) of the Galway Granite Batholith are all classified to be Poor Aquifers that are only productive in local zones (Pl). Poor Aquifers generally provide little groundwater for water supply or for baseflow to surface water bodies. However, they are sometimes used for local supplies to individual houses/farms. The GSI assessment of the Galway Granite Batholith being a Pl aquifer is based on the low occurrence of high yielding groundwater wells and the abundance of surface water features as well as man-made drainage ditches.

Under the Water Framework Directive, the GSI have delineated a number of groundwater bodies (GWB) in Ireland. In the area of the Galway Granite Batholith there are two groundwater bodies, with their boundaries determined based on topography and surface watersheds (refer to **Figure 10.2.001**). The two groundwater bodies are:

1. Spiddal GWB
2. Maam-Clonbur GWB

The GSI describe both groundwater bodies as being overlain by blanket peat except in urban areas where the bedrock is overlain by man-made fill. Where the blanket peat is present then the overburden thickness is generally less than 3m.

The vulnerability of the groundwater body is the term used to describe the ease with which the groundwater in the area can be contaminated by human activities. The vulnerability is determined by many factors including the travel time, the quantity of contaminants and the capacity of the deposits overlying the bedrock to attenuate contaminants. These factors in turn are based on the thickness and permeability of the overburden e.g. groundwater in bedrock which is exposed at the surface. The criteria for determining groundwater vulnerability, as described by the GSI, is shown in **Table 10.4** below.

Table 10.4: GSI Groundwater Vulnerability Mapping Guidelines (DoELG 1999)

Vulnerability Rating	**Hydrogeological Conditions**				
	Subsoil Permeability (Type) and Thickness			**Unsaturated Zone**	**Karst Feature**
	High permeability (sand/gravel)	**Moderate permeability (e.g. Sandy subsoil)**	**Low permeability (e.g. Clayey subsoil, clay, peat)**	**(Sand/gravel aquifers only)**	**(<30m radius)**
Extreme (E)	0 - 3.0m	0 - 3.0m	0 - 3.0m	0 - 3.0m	-
High (H)	>3.0m	3.0 - 10.0m	3.0 - 5.0m	>3.0m	N/A
Moderate (M)	N/A	>10.0m	5.0 - 10.0m	N/A	N/A
Low (L)	N/A	N/A	>10.0m	N/A	N/A

Notes: (1) N/A = not applicable.

(2) Precise permeability values cannot be given at present.

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

The GSI data on groundwater vulnerability shown in **Figure 10.3.001**, shows that bedrock is often at or near surface (X or E category) for circa 25% of the western section of the proposed road development. Where cover is present on the granite bedrock it is generally thin (<3m), with rock outcropping on higher ground, and thick subsoil deposits (up to 6m) on lower ground. Peat bogs occur in a number of locations across the granite landscape, generally in low lying areas or hollows where surface water ponding is present. Where peat is present it will generally allow very limited recharge and promote horizontal flow to drains, ditches and water courses.

The combination of poor aquifer and Blanket bog cover, where rock is not exposed, limits the quantity of recharge that can infiltrate to ground. The recharge quantities are estimated by the GSI and are shown on **Figure 10.4.001**.

Met Éireann reports an annual average of 1,250mm of rainfall for the area and with losses by evapotranspiration accounted for (450mm/yr) then the available effective rainfall is 800mm (**Table 10.5** below). Given a recharge cap of 100m/yr for the Galway Granite Batholith only 12.5% of effective rainfall is available as recharge, with the remaining balance of 700mm/yr flowing to streams as either overland flow or shallow flow through the subsoil. The Galway Granite Batholith is a poor aquifer (Pl) with low recharge acceptance, with groundwater bodies that will match surface water drainage divides.

Table 10.5: Recharge assessment for the Galway Granite Batholith (Pl) (av mm/yr Met Éireann)

Vulnerability	Rainfall (mm/yr)	PE (mm/yr)	Effective Rainfall (mm/yr)	Recharge (mm/yr)	Runoff (mm/yr)
Granite and Orthogranite (irrespective of vulnerability)	1250	450	800	100	700

On the basis of the poor aquifer properties and the low likelihood of local productive zones, then actual recharge quantities for Galway Granite Batholith will not vary significantly from **Table 10.5**.

The GSI overburden thickness for the area shows that rock outcrops on topographic highs but in low lying areas the soils and subsoils are thicker, generally up to 5m thick. Generally, the aquifer properties (hydraulic conductivity and storage) will be low for the Galway Granite Batholith, especially on higher ground, where the rock is most competent. In low lying areas the aquifer properties remain poor but hydraulic conductivity may be locally productive due to weathering along fault lines.

Effective rainfall will generally run off to surface water by means of drains and ditches. In elevated areas the effective rainfall will rapidly run off the steeper gradient. In low lying areas the slight topographic gradients and thicker overburden is likely to cause impoundment of effective rainfall causing perching above the rock head with local ponding to surface.

The GSI descriptions of the Spiddal GWB and Maam - Clonbur GWB (GSI 2004a and 2004b) state that the water table is shallow in the Galway Granite Batholith and yields from wells are low. Groundwater flow paths are only in fractured and weathered zones, typically in the vicinity of faults. These pathways will be short and flow directions will follow topography towards watercourses. The GSI report flow paths in the Spiddal GWB to be up to 100m long whilst the Maam-Clonbur GWB to be 30-300m. Groundwater will discharge to streams and rivers but the baseflow contribution will be relatively low.

10.3.1.2 Eastern Section

The GSI bedrock aquifer map for the eastern section is presented in **Figure 10.1.002**. The GSI classify the Visean Undifferentiated Limestone as being a regionally important karstified aquifer, which is dominated by conduit flow (Rkc).

Regionally important aquifers are important groundwater resources. A regionally important bedrock aquifer is capable of supplying regionally important abstractions (e.g. large public water supplies), or 'excellent' yields (>400 m^3/d). The assessment by the GSI is based upon the occurrence of high yielding groundwater wells, the presence of karst landforms and features but also the relatively low abundance of surface water features and man-made drainage.

Under the Water Framework Directive, the GSI have delineated groundwater bodies (GWB) for Ireland. Those in the Visean Undifferentiated Limestone of the study area (refer to **Figure 10.2.002**) include:

1. GWDTE Lough Corrib Fen 1 (Menlough)
2. GWDTE Lough Corrib Fen 2
3. GWDTE Lough Corrib Fen 3 & 4
4. Clarinbridge
5. Clare-Corrib
6. Ross Lake

The Geological Survey of Ireland (GSI) national dataset for groundwater vulnerability (Refer to **Figures 10.3.001** and **10.3.002**) shows that the subsoil cover has a variable thickness across the Visean Undifferentiated Limestone. Generally, on higher ground the limestone either outcrops or is near surface but there are areas where significantly deeper overburden is identified, such as Coolagh Lakes, Ballindooley Lough, Terryland River and Lough Atalia. During the ground investigation for the 2006 Galway City Outer Bypass (GCOB, 2006) a number of areas with thick overburden were investigated by geophysics and drilling, these included areas near the River Corrib at Menlough as well as the north edge of Ballindooley Lough (**Appendix A.9.1** and **A.9.2**).

Adjacent to Ballindooley Lough, geophysics undertaken for the 2006 GCOB identified that whilst bedrock was near surface in the fields to the northwest and southeast of Ballindooley, in the valley floor itself the overburden was greater than 18m deep. Similar features of bedrock being near surface at one location but then a short distance away being significantly deeply buried were also encountered near the River Corrib at Menlough where drilling proved the overburden to be up to 70m thick. In these areas at Ballindooley and Menlough the morphology of the bedrock topography and burial by overburden can be described as being a buried valley, which is often referred to in academic texts as a palaeolandscape.

Related to the vulnerability mapping is the GSI recharge mapping. **Figure 10.4.002** shows the GSI quantification of recharge for the eastern section. Based on the GSI mapping the limestone aquifer has a significantly high infiltration capacity. Areas of outcrop are attributed a recharge rate of 85% (greater if karst present), with areas of thin overburden attributed 60% if the subsoil is of a moderate or high permeability. Those areas where the overburden is thicker and of low permeability, such as Coolagh Lakes, Ballindooley Lough, Terryland River and Lough Atalia then the recharge coefficient is estimated by the GSI as 15% or less. Due to the generally high recharge acceptance of the Rkc aquifer the GSI do not apply a recharge cap to the annual quantity of recharge. **Table 10.6** below presents regional estimates on recharge and run-off for the eastern section.

Table 10.6: Recharge assessment for the Visean Undifferentiated Limestone (Rkc) (av mm/yr Met Éireann)

Vulnerability	Recharge coefficient	Rainfall (mm/yr)	PE (mm/yr)	Effective Rainfall (mm/yr)	Recharge (mm/yr)	Runoff (mm/yr)
Limestone at (X) or near (E) surface	60-100%	1250	450	800	480-800	0-320
Moderate (M) or high (H) vulnerability	15-60%	1250	450	800	120-800	320-680
Low (L) vulnerability	<15%	1250	450	800	120	680

Limestone bedrock designated as regionally important karst with conduit (Rkc), has triple permeability characteristics, namely that hydraulic connectivity occurs via matrix, fracture and karst pathways (Waltham, 2005). Flow by the matrix of the rock is of a significantly low permeability and often lower than $1x10^{-7}$m/s. Flow by fractures can be variable but typically will range between $1x10^{-4}$m/s to $1x10^{-6}$m/s. Karst flow can be significant if conduits are present and generally flow in conduits is $1x10^{-3}$m/s or lower (Waltham, 2005).

On the basis of the Rkc classification by the GSI the bulk permeability of the aquifer is likely to be high but local areas of low or moderate permeability will exist where the aquifer has not developed karst enhancement Karst features are also discussed in **Chapter 9, Soils and Geology**.

It should be noted that some additional karst features are identified in this chapter which have not been included in **Chapter 9, Soils and Geology** due to the larger study area in the east for the hydrogeological assessment.

The hydrogeological assessment assesses those karst features which are either supporting the hydraulic regime of the area or specific receptors e.g. ecological features and these have been identified and discussed in S**ection 10.3.4**.

As well as supporting specific receptors, karst features such as enclosed depressions support the hydrogeology of an area by providing enhanced recharge (point input) at those locations.

As outlined in **Section 10.2.5.2**, a detailed karst survey of the scheme study area was undertaken as part of the constraints and route selection studies for the proposed road development and was updated for this assessment. The karst survey report is presented in **Appendix A.10.2**.

10.3.2 Local Hydrogeology within the Study Area

As highlighted in **Section 10.3.1** the footprint of the proposed road development is divided into two main geological units, which have contrasting aquifer, vulnerability and recharge characteristics. The western section of the proposed road development is underlain by the poorly productive (Pl), low recharge aquifer of the Galway Granite Batholith and the eastern section is underlain by the regionally important karstified (Rkc), high recharge aquifer of the Visean Undifferentiated Limestone.

When examining the receiving environment of the study area, the proposed road development has been divided into four sections to allow for ease of presentation and description of the underlying ground conditions due to the volume of information available. To allow for consistency, these sub-divisions were also applied in **Chapter 9, Soils and Geology**. The four sections are as follows:

- Section 1: R336 to the N59 Moycullen Road
- Section 2: N59 Moycullen Road to the River Corrib
- Section 3: River Corrib to the N83 Tuam Road[2]
- Section 4: N83 Tuam Road to the existing N6 at Ardaun, Coolagh

The ground investigations undertaken in each of the four sections were tailored to provide data that will allow hydrogeological assessment specific for the proposed road development in that section. For example, aquifer testing and groundwater monitoring wells were sited where cuttings would be required by the proposed road development whereas geophysics was used to determine the depth to bedrock or as an indicator for karst.

The information presented in this section forms the basis for **Section 10.3.3**, which develops a conceptual site model for the study area.

10.3.2.1 Section 1 – R336 to N59 Moycullen Road (Ch. 0+000 – 7+600)

Section 1 of the proposed road development is situated on the Galway Granite Batholith. The topography of Section 1 is undulating with the highest point of 100mOD forming part of a northwest to southeast ridge at Letteragh. This ridge also marks the watershed for surface water and groundwater sub catchments. West of the ridge all the surface water drainage and the Spiddal GWB drain southwards to Galway Bay, whilst east of the ridge all surface water all the Maam-Clonbur GWB drain eastwards to the River Corrib (**Figure 10.2.001**).

Bedrock Aquifer

As identified in the section on regional hydrogeology, the Galway Granite Batholith is a poor aquifer (Pl) that is locally productive in local zones such as faults (**Figure 10.1.001**). Where faults are present then these tend to form areas of deeper subsoil in low lying ground.

[2] Formally known as the N17 Tuam Road

The geophysics undertaken included electrical resistivity tomography (ERT) and seismic surveying, this data is presented in **Appendix A.9.1**. As presented in the **Chapter 9, Soils and Geology**, the ERT survey shows that the bedrock is generally shallow and of high resistivity, indicating competent rock. There are shallow zones where lower resistivity is measured. These may indicate areas of increased weathering along vertical features such as faults where there is a localised linear feature that may have increased storage of groundwater.

Shallow features (<10m) can be observed on the mainline of the proposed road development at Ch. 5+500 and Ch. 7+750, as well as a deeper feature (c.20m) on the N59 Link Road North (LNR) at Ch. 0+250 LNR. These features are likely to be zones locally productive with groundwater. The unconformity contact between the Galway Granite Batholith and the Visean Undifferentiated Limestone is marked by a sharp change in slope at Ch. 8+890, which also conforms to a deep vertical feature in the ERT profile at Ch. 8+920. This feature is developed in the limestone side of the contact with the granite and as such is described in **Section 10.3.3.2**.

The seismic survey is used to identify the top of competent bedrock and as such is a good indicator for the thickness of the combined overburden and weathered layer. The seismic data shows that competent bedrock is generally 2-3m in depth, being slightly deeper (up to 5m) in low lying areas.

Aquifer Properties

Aquifer testing was undertaken in five monitoring boreholes in the Galway Granite Batholith. These tests were small scale pumping tests so that observation could be made on the drawdown in the well as well as monitoring of the recovery as a rising head test. The data from the test as well as analysis of the rising head test are presented in **Appendix A.10.5**. This data shows that the water level in the wells was drawn down fairly rapidly at a low abstraction rate, which is indicative of low hydraulic conductivity. Measurement of the recovery of the wells indicates a range of hydraulic conductivity in the Galway Granite Batholith between $9.7x10^{-7}$ and $4.6x10^{-6}$m/s.

Groundwater Vulnerability

Comparison of GSI vulnerability and information from GI and walkover surveys identifies that at topographic highs rock is generally at or very near surface. Borehole records confirm that the depth to bedrock increases away from topographic highs. The ground investigation and walkover surveys generally confirm with the vulnerability mapping by the GSI for the Galway Granite Batholith (**Figure 10.3.001**). Approximately 40% of the route of the proposed road development in Section 1 has rock at or near surface based upon GSI vulnerability mapping.

As presented in the regional hydrogeology, recharge quantities are low for the available effective rainfall. This is due to the peaty blanket bog which is of low permeability and will promote runoff, but also due to the relatively thin weathered zone and low aquifer properties of the aquifer. The GSI recharge cap of 100mm/yr is considered appropriate based on site observation and the aquifer tests undertaken (**Figure 10.4.001**).

Groundwater Levels

Groundwater level monitoring was initiated in February 2015 for existing wells. New monitoring wells, installed as part of the studies for the proposed road development, were monitored from November 2015. The monitoring continued on all wells to January 2017. Due to the shallow or non-existent nature of the overburden in this area, the monitoring wells all have their response zones in the Galway Granite Batholith.

A review of pre-existing wells was undertaken early in 2014 and the commissioning report from this survey is presented in **Appendix A.10.1**. A report of all groundwater level data used in the assessment is presented in **Appendix A.10.3**. The groundwater level data from **Appendix A.10.3** is presented on the cross-sections as groundwater contours in **Figure 10.6.001** to **10.6.006** for the mainline of the proposed road development and **Figure 10.6.012** for the N59 Link Road (North and South). These profile cross sections confirm that the groundwater along the proposed road development is generally near the surface. A summary table of minimum and maximum groundwater levels monitored in Section 1 is presented in **Table 10.7** below.

In higher ground the water table is within 2m of ground level and on lower lying ground the water table is at ground level. Areas of low lying ground typically include saturated peat with ponding at surface caused by naturally poor drainage. Due to the low aquifer properties of the granite, interaction between groundwater and surface water is minimal. A summary table of minimum and maximum groundwater levels monitored in Section 1 is presented in **Table 10.7** below.

Table 10.7: Groundwater levels measured in the Galway Granite Batholith (Section 1)

Monitoring Borehole	Source	East (ITM)	North (ITM)	Ground Elevation (mOD)	Groundwater Level		
					Min (mOD)	Max (mOD)	Range (m)
RC422	N6 GCOB	524196	724742	21.20	19.45	20.75	1.30
RC435	N6 GCOB	524479	725777	59.19	56.13	56.58	0.45
RC451A	N6 GCOB	525153	726691	71.70	69.43	70.04	0.61
RC 548	N6 GCOB	521102	723826	50.84	49.67	50.73	1.06
RC 687	N6 GCOB	522901	725359	69.56	68.78	69.16	0.38
RC 739	N6 GCOB	524763	725951	59.64	58.45	58.86	0.41
BH-3-04R	N6 GCRR	523646	724287	36.82	36.23	36.70	0.47
BH-3-06R	N6 GCRR	524241	724825	23.09	21.87	22.22	0.35
BH-3-08R	N6 GCRR	524621	725069	42.05	39.85	41.39	1.54
BH-3-10R	N6 GCRR	525321	725604	66.51	63.37	64.66	1.29

Monitoring Borehole	Source	East (ITM)	North (ITM)	Ground Elevation (mOD)	Groundwater Level		
					Min (mOD)	Max (mOD)	Range (m)
BH-3-11R	N6 GCRR	525784	725831	54.24	52.83	53.27	0.44
BH-3-13R	N6 GCRR	526079	726036	58.65	52.85	57.12	4.27
BH-3-16R	N6 GCRR	526765	726611	61.66	57.64	58.45	0.81
BH-3-17R	N6 GCRR	527021	726805	65.33	62.46	62.93	0.47
BH-3-18R	N6 GCRR	527254	726894	70.64	68.03	69.11	1.08
BH-3-20R	N6 GCRR	527214	727669	51.63	47.83	48.61	0.78
BH-3-23R	N6 GCRR	527774	727346	26.93	22.32	23.46	1.14
BH-3-24R	N6 GCRR	528036	727521	25.16	20.97	22.77	1.80

Notes:

Includes groundwater level data from project specific monitoring wells

Groundwater levels are measured on site to the nearest centimetre below top of casing. All effort has been made to ensure the accuracy of the data.

Seasonal fluctuation is generally within 1.5m for higher ground but minimal in lower ground where the water table generally remains at surface throughout the year. Exception to this generalisation is borehole BH-3-11 near the Rahoon Road, which shows up to 4m of seasonal fluctuation. The higher seasonal fluctuation at BH-3-11 is considered to be natural and a factor of the narrow ridge within which the borehole is located.

Groundwater elevations confirm that groundwater flow follows the general topography and surface water drainage. In the Spiddal GWB the groundwater contours conform to the surface water drains and flow towards Galway Bay by seeping into the surface water courses that drain the area. In the Maam-Clonbur GWB the groundwater contours also conform to surface topography and surface water drainage and flow eastwards to the River Corrib.

In the steep eastern granite slopes draining towards the River Corrib there are a number of seepages, which emerge where the topography steepens and intersects the groundwater table. The largest of these is spring at W1000-01 (**Figure 10.5.001**), which is used as a private water supply (see **Section 10.3.4)**. Other smaller seepages occur in both groundwater bodies and these drain to surface water streams and ditches.

Seepages in the Galway Granite Batholith are generally associated with weathering and/or fault zones (refer to **Chapter 9, Soils and Geology**) and generally the seepages dry out in the summer. As per GSI descriptions (2004a and 2004b) these locally productive pathways are considered to be relatively short and to have limited lateral extent. On this basis, they are likely to have limited storage and rely on recharge, which would suggest they will respond to storm events and reduce in flow during the summer (GSI 2004a and 2004b).

Based on GSI descriptions of groundwater bodies in granite the length of the flow paths is considered to have a general maximum of 100m but in extreme cases where significant faulting is present then they may extend up to 300m.

Water Quality

Water sampling from monitoring wells in the Galway Granite Batholith indicates that the groundwater is generally of good quality with moderate levels of calcium and magnesium. There are local detections of bacteria such as faecal coliform, which is most likely agricultural or from poorly operating domestic wastewater treatment plants. Water quality data is presented in **Appendix A.10.4**.

10.3.2.2 Section 2 - N59 Moycullen Road to River Corrib (Ch. 7+600 – 9+300)

Between the N59 Moycullen Road and the River Corrib there is a narrow section of limestone (**Figure 10.1.001**). This strip of limestone bedrock comprises the Ross Lake GWB (**Figure 10.2.001**), which extends 3km northwest to Kentfield.

Input to the aquifer comprises of recharge to the limestone area ($1.5km^2$), and also runoff from the granite slopes of the Maam-Clonbur GWB ($3km^2$), which flows down slope and onto the limestone. There is a significant amount of urban development in this area and it is likely that some streams are culverted below developments to the River Corrib, others may infiltrate into the limestone.

Bedrock Aquifer

The contact between the Galway Granite Batholith and the Visean Undifferentiated Limestone is an unconformity (GSI Geology Memoir). The ERT geophysics data for the contact is shown in geophysics profile 3/5 (GP3/5) confirms the contact between granite and limestone at Ch. 8+890 to be vertical and sharp. The geophysics profile matches a distinct change in the topography and indicates that the contact slopes steeply eastwards.

The depth to rock in the limestone is significantly more variable than the granite bedrock. The vertical nature of the low resistivity feature and general vertical steps in the rock topography indicates that the limestone may be locally faulted and / or fractured.

Groundwater flow is likely to be dominated by fracture flow but the low resistivity feature in the limestone near the contact between granite and limestone indicates likely karstification and possible conduit flow. There are a number of small scale karst landforms located between the N59 Moycullen Road and the River Corrib, which include small enclosed depressions (K10, K11 and K12) and small springs (K2, K7 and K9).

No site specific groundwater level or aquifer properties data were collected in Section 2. As outlined in **Section 10.2.5.3** groundwater level, aquifer properties and groundwater quality monitoring was focused on areas of cutting or dewatering of the bedrock aquifer. This section of the proposed road development is entirely on embankment and geophysics was the primary investigative tool used, with boreholes (BH3/23 and BH3/24) installed to calibrate the geophysical data.

Groundwater Vulnerability

The criteria for determining groundwater vulnerability, as described by the GSI, is shown in **Table 10.4**. Groundwater vulnerability as mapped by the GSI is presented in **Figure 10.3.001**. Comparison of GSI vulnerability and information from GI and walkover surveys indicate that the data sets are consistent in this area.

Key inferences from the vulnerability mapping are: the confirmation that the depth of rock head increases towards the River Corrib and that recharge is higher where the bedrock is shallower (this infers that effective rainfall increasingly runs off to surface water closer to the river) (**Figure 10.4.001**).

10.3.2.3 Section 3 - River Corrib to N83 Tuam Road (Ch. 9+300 – 14+000)

Section 3 of the proposed road development comprises the area between the River Corrib and the N83 Tuam Road. This area encompasses of the GWDTE Lough Corrib Fen 1 Groundwater Body (GWB), GWDTE Lough Corrib Fen 2 GWB, GWDTE Lough Corrib Fens 3 and 4 GWB and the Clare Corrib GWB (**Figure 10.2.001**). The use of GWDTE in naming for these groundwater bodies by the GSI does not signify that the GWB is a GWDTE but rather because GWDTE do receive groundwater from these GWB.

The topography of Section 3 is undulating with the highest point being 40m OD immediately west of Lackagh Quarry. There are also extensive lowland areas at Coolagh Lakes, Ballindooley Lough and Terryland River.

Bedrock Aquifer

As identified by the regional hydrogeology the eastern section of the proposed road development is underlain entirely by the Visean Undifferentiated Limestone, which is a regionally important karst aquifer (Rkc) (**Figure 10.1.002**).

The GSI karst database includes a national record of all karst landforms, which identifies that turloughs, dolines, stream sinks and one cave have been recorded in the area. The karst survey (**Appendix A.10.2**) referred to previously characterises the type of landforms.

Aquifer Properties

The Visean Undifferentiated Limestone aquifer is a regionally important aquifer that is associated with a high permeability and very productive groundwater abstraction wells. Abstraction rates of wells identified in the study area are particularly high confirming the characteristics of the aquifer.

The GSI have characterised the aquifer as having a high recharge coefficient (85%) with high infiltration rates and no recharge cap. The Rkc characterisation by the GSI is due to the presence of karst. Although karst is present (refer to **Appendix 10.2** Karst survey report) observations from quarries and bedrock exposure indicate a moderate to high frequency of fracturing in the bedrock. Based on the relatively high fracture frequency then fracture flow, as opposed to conduit flow, is considered to be the most common pathway in the limestone aquifer.

Aquifer testing was undertaken in six monitoring boreholes in Section 3. These tests were small scale pumping tests so that observation could be made on the drawdown in the well as well as monitoring the recovery as a rising head test. The data from the drawdown test as well as analysis of the rising head test, are presented in the aquifer testing data. This data is variable showing a wide range of response to the drawdown and recovery.

Measurement of the recovery of the wells indicates a non-karst range of hydraulic conductivity in the Visean Undifferentiated Limestone between $3.1x10^{-5}$ and $5x10^{-9}$m/s. The higher permeability is likely to be testing fracture flow or small scale conduit flow in the aquifer, whilst the lower permeability values indicate the borehole mainly represents matrix flow.

Section 3 includes surface karst features, such as enclosed depressions (dolines), estavelles, turloughs, limestone pavement, springs, and one cave. Karst features are presented in **Figure 10.1.002** and detailed in the Karst Survey Report (**Appendix A.10.2**). The karst features located in Section 3 can be divided into those between Menlough and Ballindooley as well as those associated with the Terryland River.

There are a number of karst features between Menlough and Ballindooley including springs, turloughs and enclosed depressions. There are two karst springs (K17 and K25). Of these K17 is a small spring with a discharge too slight to gauge that discharges to Lough Corrib, whilst K25 (referred to as Western Coolagh Spring) is a more significant spring and is the main groundwater supply to the Upper Coolagh Lake.

During the site workover, a pond with a ditch outfalling to the Upper Coolagh Lake was identified as being a potential spring and this is referred to as the Eastern Coolagh Spring (K45). However, this spring is not a karst spring because it sits on clay subsoil as evidenced by GI. Monitoring of the water level between 2014 and 2018 at the Eastern Coolagh Spring showed the water level is static and failed to identify a correlation with groundwater levels in bedrock. The Eastern Coolagh Spring (K45) is instead supplied by a combination of seepage via the subsoil and surface water runoff. There is no bedrock exposed at the Eastern Coolagh Spring and due to the thick cover of clayey subsoil it is unlikely there is any direct discharge from the limestone aquifer to the Eastern Coolagh Spring.

There are three turloughs between Menlough and Ballindooley, two near Menlough (K20 and K31) and one (K72) near Ballindooley. There are a number of enclosed depressions across the area, which are sometimes associated with limestone pavement (for locations of limestone pavement refer to **Chapter 8, Biodiversity**). Other karst features in the area include a small estavelle adjacent to Ballindooley Lough (K86) and a dug karst feature (K92) that like K86 has a free water surface that fluctuates seasonally.

The Terryland River bifurcates from the River Corrib near Quincentenary Bridge and drains eastwards along the low lying ground through Terryland towards Ballybrit. Under normal conditions the Terryland River sinks at two stream sinks, named Pollavurleen West and East (K87 and K96) near Glenanail (Refer to karst study in **Appendix A.10.2**).

Section 3 also includes areas of thick subsoil, including those from the 2006 GCOB investigation at Menlough and Ballindooley Lough that are interpreted as being buried landscapes. Based on geophysics and drilling from the project specific ground investigation, buried landscapes have been identified in the townland of Coolagh (Menlough), Coolagh Lakes, Ballindooley Lough, Castlegar and the N83 Tuam Road (refer to **Chapter 9, Soils and Geology**). Some of these buried landscapes are palaeokarst features, i.e. karst that had developed in the bedrock but subsequently was buried by thick accumulations of sediment.

Groundwater Vulnerability

The GSI vulnerability mapping for Galway is presented in **Figure 10.3.002**. Buried features are identified on these maps as where present they will modify the vulnerability locally to low. A number of areas where buried features have been identified, for example the buried features at Menlough and N83 Tuam Road, the GSI vulnerability had been mapped as high or extreme. In light of the buried features, their vulnerability is considered to be low. These areas also have significantly reduced recharge and a corresponding increase in run-off (**Figure 10.4.002**).

Groundwater Levels

Groundwater monitoring has been undertaken in the Menlough and Ballindooley area since February 2015 for existing wells and since November 2015 for new monitoring wells installed as part of the environmental studies for the proposed road development. A review of the condition of existing monitoring wells is presented in **Appendix A.10.1** and the groundwater level data for Section 3 is presented in **Appendix A.10.3**. This data is plotted in **Figures 10.6.007** to **10.6.010** Summary groundwater levels for Section 3 of the proposed road development are presented below in **Table 10.8**.

Table 10.8: Groundwater levels measured in the Visean Undifferentiated Limestone (Section 3)

Monitoring Borehole	Source	Easting ITM	Northing ITM	Ground Elevation (mOD)	Groundwater Level		
					Min mOD	Max mOD	Range m
Western Coolagh Spring	N6 GCRR (SW-2-4)	529045	727934	5.41	5.70	6.37	0.67
Eastern Coolagh Spring	N6 GCRR (SW-2-5)	529900	728162	7..06	7.65	7.78	0.13
MW 01	2006 GCOB	528670	727956	16.14	10.61	13.89	3.28
MW 02	2006 GCOB	528715	728095	13.37	6.15	7.90	1.75

Monitoring Borehole	Source	Easting ITM	Northing ITM	Ground Elevation (mOD)	Groundwater Level		
					Min mOD	Max mOD	Range m
MW 03	2006 GCOB	528920	727970	6.70	5.80	6.46	0.66
BH-3-27R	N6 GCRR	528960	728133	9.10	5.90	6.41	0.51
RC133	2006 GCOB	529325	728185	11.66	5.73	8.16	2.43
BH972	2006 GCOB	529462	728292	12.33	5.70	8.20	2.50
BH-3-29R	N6 GCRR	529489	728334	13.73	Dry (<6.93)	9.23	>2.40
RP-2-05D	N6 GCRR	529701	727145	19.96	5.73	7.78	2.05
RP-2-05S	N6 GCRR	529704	727141	20.22	8.86	12.01	3.15
BH04	N6 GCRR	530151	728400	32.17	8.20	15.74	7.50
BH05	N6 GCRR	530187	728378	34.14	8.08	19.46	11.40
LQ MW6	Private	529919	727971	15.40	12.11	13.20	1.09
LQ MW5	Private	530389	728285	7.40	10.71	19.17	8.46
LQ MW4	Private	530522	728557	16.76	8.71	15.41	6.70
RC 1104	2006 GCOB	531165	728927	9.39	7.24	7.83	0.60
BH-3-31R	N6 GCRR	531274	728424	11.08	9.45	9.78	0.33
RC206	N6 GCRR	531237	729433	28.49	19.29	21.11	1.82
RP-2-03	N6 GCRR	531478	728278	22.44	4.95	9.09	4.14
RP-2-01	N6 GCRR	531726	728689	21.38	7.86	10.28	2.42
RC 1206	N6 GCRR	531986	729388	27.67	17.05	19.45	2.40
BH-3-32R	N6 GCRR	531971	728318	24.43	Dry (<9.43)	10.24	>0.81
RC 1211	N6 GCRR	532454	729601	25.91	20.25	22.03	1.78
BH-3-34R	N6 GCRR	532405	728275	32.57	19.69	25.91	6.22
BH-3-35R	N6 GCRR	532851	728226	17.52	7.91	9.15	1.24

Notes:
Includes groundwater level data from project specific monitoring wells
Groundwater levels in LQMW4 are the same as LQMW1, 2, 3 and 4.
It was not possible for IGSL to access to BH-2-32R during May, August, September and November 2016. Water levels for April, June and July are reported. As the groundwater levels recorded during these months are representative of low groundwater levels only 'not representative'(NR) is reported for the maximum groundwater level.
Monitoring wells LQMW5 and BH05 both straddle a thin black argillaceous limestone that overlies a clay wayboard in the geology sequence, which perches recharge above the main groundwater body. The groundwater levels recorded in LQMW5 and BH05 represent

interaction between the main groundwater body and recharge. The water levels in LQMW5 and BH05 are not representative of groundwater levels in the main groundwater body.

Groundwater levels are measured on site to the nearest centimetre below top of casing. All effort has been made to ensure the accuracy of the data.

Figures 10.6.007 to **10.6.110** show the groundwater level between River Corrib and the N83 Tuam Road to form an undulating groundwater table with low points at the River Corrib, Coolagh Lake and RP-2-03 at Castlegar. These low points in the groundwater table form areas where groundwater flows towards. Between these groundwater low points are groundwater highs. The main groundwater high in Section 3 is plotted between Menlough and Lackagh Quarry. At this location the water table forms a divide between westward groundwater flow towards Coolagh Western Spring, which feeds Coolagh Lakes, and eastward flow to the groundwater low at monitoring well RP-2-03. A second lesser groundwater high occurs between Coolagh Lakes and the River Corrib. This local water table high forms a groundwater divide between Coolagh Western Spring and the River Corrib.

The range in groundwater levels shown in **Table 10.8** shows differing seasonal variability in the Visean Undifferentiated Limestone across Section 3. Discounting those monitoring wells where the recorded range was not representative (refer to notes in **Table 10.8**) (BH-3-29R, BH3-31R LQMW5, BH05 and BH-3-32R), then the minimum and maximum ranges recorded are 7.54m (BH04) and 0.51m (BH-3-27R). BH04 is located close to the groundwater dive between Menlough and Lackagh Quarry, whilst BH-3-27R is located close to Western Coolagh Spring. Based on the data presented, those monitoring locations close to discharge points (rivers and springs) show the least seasonal fluctuation, whilst those near groundwater divides have the greatest seasonal fluctuation.

The data collected for the project and the identification of groundwater divides presented in **Figure 10.6.007** to **Figure 10.6.010** provides significant new data for the extent and boundaries of the groundwater bodies as defined by the GSI. **Section 10.3.3** of this chapter provides reinterpretation for the extents of the GWDTE Lough Corrib Fen 1 (Menlough) GWB, GWDTE Lough Corrib Fen 2 GWB, GWDTE Lough Corrib Fen 3 & 4 GWB and the Clare-Corrib GWB.

Water Quality

Water sampling from monitoring wells in the Menlough and Ballindooley area indicates that the groundwater is generally of good quality with high levels of calcium and magnesium. There are local detections of bacteria such as faecal coliform, which is most likely agricultural or from poorly operating domestic wastewater treatment plants. Water quality data is presented in **Appendix A.10.4**.

10.3.2.4 Section 4 – N83 Tuam Road to existing N6, Coolagh (Ch. 14+400 – 17+500)

Section 4 of the proposed road development extends between the N83 Tuam Road and the existing N6 at Coolagh, Briarhill (**Figures 10.2.002**). This section of the proposed road development traverses the GSI GWDTE Lough Corrib Fens 3 & 4 GWB and the Clarinbridge GWB. There is a significant amount of urban development in this area, which includes the Galway Racecourse. There are no surface water features apart from seasonal pluvial flooding on the existing N83 Tuam Road during winter.

The ground investigation identified that the subsoil at the N83 Tuam Road overbridge has a thickness in excess of 30m which is confirmed by boreholes (RC-3-62 & BH-3-35) and geophysics (GP-3-13 and GP-3-14) (**Appendix 9.2**). There is significant thickness of subsoil in the valley floor (below the fields) but bedrock is shallow along the School Road in Castlegar (BH3/33 and BH3/34) and Galway Racecourse (BH3/36, BH3/47). This indicates that a significant buried landscape is located along the existing N83 Tuam Road. The pluvial flooding that occurs seasonally along the N83 Tuam Road occurs where the areas of thick subsoil are present. Trial pits and soakaway tests into the valley floor of the N83 Tuam Road (SW3/02, SW3/15, SW3/16, SW3/17, SW3/18) confirm that the subsoil is of clay and as such of low permeability.

The buried landscape identified at the N83 Tuam Road is the only feature observed in Section 4. East of the feature the bedrock rises steeply and forms high ground that forms the Galway Racecourse and business parks in Ballybrit and Parkmore.

Bedrock Aquifer

Section 4, like sections 2 and 3 is classified by the GSI as being a regionally important karst aquifer with conduit (Rkc) (**Figure 10.1.002**). Ground investigations (GI) include geophysics, drilling and trial pitting Groundwater monitoring wells have been installed into boreholes and included as part of the groundwater monitoring network. Section 4 is generally absent of karst, with only a number of small scale features, which are shown in **Figure 10.1.002**. The recorded karst features include:

- Two small enclosed depressions east and north of the Galway Racecourse (K104 and K131)
- Three shallow enclosed depressions north of the existing N6 Coolagh Roundabout ((K172, K175 and K179)
- Small seepages and small enclosed depressions west of the existing N6 Coolagh Roundabout (K126, K129, K130, K132, K134 and K135)
- Further south and downgradient of the existing N6 Coolagh Roundabout an old quarry has some small scale inflows (K160 and K173), there are some shallow enclosed depressions (K112, K140, K142, K145, K151, K152, K154, K159, K163) and there is one spring (K182)

- Further east and downgradient of the existing N6 Coolagh Roundabout there are a number of small scale karst features, including enclosed depressions (K198, K201, K202, K203, K213, K211, K222 and K215) and one spring K215

Aquifer Properties

The Visean Undifferentiated Limestone aquifer is a regionally important aquifer that is associated with high permeability and highly productive groundwater abstraction wells.

Aquifer testing was undertaken in four monitoring boreholes located in Section 4. These tests consisted of three small scale pumping tests and one 72-hour pumping test. The data from and analysis of the tests is presented in the aquifer testing report **Appendix A.10.5**. It is noted that the 72-hour test undertaken in December 2016 failed to last the intended duration as the well became dry after a short period and did not recharge. A summary of the aquifer properties is presented below in **Table 10.10** and **Plate 10.1**.

This aquifer data shows a range in hydraulic conductivity in the Visean Undifferentiated Limestone of Section 4 between $1.7x10^{-6}$m/s and $4.2x10^{-7}$m/s. The higher permeability values are likely to be testing fracture flow, whilst the lower permeability values indicate mainly matrix flow with only small scale fractures intersected.

Groundwater Vulnerability

The criteria for determining groundwater vulnerability, as described by the GSI, is shown in **Table 10.4**. Groundwater vulnerability as mapped by the GSI is presented in **Figure 10.3.002**.

GSI vulnerability shows the rock within three meters of surface at the N83 Tuam Road to the Galway Racecourse and then mainly at or near surface from Briarhill to the existing N6. Information from ground investigations and walkover surveys indicates that the bedrock is significantly deeper than this at N83 Tuam Road where the deep buried valley is present and slightly deeper on the higher ground where thicknesses range from at surface to within 8m below ground level.

The GSI show that recharge estimates indicate a recharge coefficient of 30% for the limestone with thicker subsoil and 85% for the limestone at or near surface, with no recharge cap applied. Recharge acceptance of the Briarhill area is considered to have high recharge acceptance of 172-649mm/yr.

Groundwater Levels

Groundwater monitoring wells are located along the route of the proposed road development from N83 Tuam Road to the existing N6. The location of these wells and the water level data is presented in **Appendix A.10.3** and groundwater levels are presented **Figure 10.6.010** and **Figure 10.6.011**. The groundwater level for Section 4 of the proposed road development has a higher elevation than elsewhere on the limestone section of the proposed road development. A summary of the groundwater levels is presented below in **Table 10.9**.

Table 10.9: Groundwater levels measured in the Visean Undifferentiated Limestone (Section 4)

Monitoring Borehole	Source	East ITM	North ITM	Ground Elevation (mOD)	Groundwater Level		
					Min mOD	Max mOD	Range m
BH-3-36R	N6 GCRR	533125	728205	24.43	42.55	43.83	1.28
RC-2-02	N6 GCRR	533685	728102	25.91	39.30	39.89	0.59
BH-3-38R	N6 GCRR	534249	727541	32.57	39.17	39.32	0.15
BH-3-40R	N6 GCRR	534439	727295	17.52	37.51	38.36	0.85
BH-3-48R	N6 GCRR	534397	727197	51.78	29.50	30.12	0.62
BH-3-41R	N6 GCRR	534580	727065	54.92	42.55	43.83	1.28
BH-3-42R	N6 GCRR	534756	726840	45.17	39.30	39.89	0.59

Notes

Includes groundwater level data from project specific monitoring wells

Groundwater levels are measured on site to the nearest centimetre below top of casing. All effort has been made to ensure the accuracy of the data.

The water level data collected for the project and the identification of groundwater divides presented in **Figure 10.6.010** and **Figure 10.6.011**, provides significant new data for the extent and boundaries of the groundwater bodies as defined by the GSI. **Section 10.3.3** of this chapter provides reinterpretation for the extents of the Lough Corrib Fen 3 & 4 GWB, the Clare-Corrib GWB and the Clarinbridge GWB.

Water Quality

Water sampling from monitoring wells in Section 4 indicates that the groundwater is generally of good quality with high levels of calcium and magnesium. There are local detections of bacteria such as faecal coliform, which is most likely agricultural or from poorly operating domestic wastewater treatment plants. Water quality data is presented in **Appendix A.10.4**.

10.3.3 Conceptual Site Model

This section considers all desk study data together with the project specific surveys and ground investigations to develop a conceptual model for the hydrogeology of the study area. The conceptual model includes a refinement of the existing GSI groundwater bodies map based on interpretation of the project data. The updated map showing revised extents of groundwater bodies is used in the individual assessments for groundwater receptors, which follows this section.

The Galway Granite Batholith and Visean Undifferentiated Limestone contrast strongly in terms of aquifer classification, recharge and flow pathways and as such are considered as two distinct aquifer units.

The Galway Granite Batholith is classified as a poor aquifer (Pl) by the GSI and the investigation undertaken as part of this project confirms this. Aquifer testing has shown that the rock type generally has a low permeability but can locally have zones where permeability is higher.

The Visean Undifferentiated Limestone is classified by the GSI as a regionally important karst aquifer (Rkc) that includes conduits. The ground investigation has shown that the Visean Undifferentiated Limestone has a wide permeability range and whilst there are zones of karst there are also areas where no karst features exist.

An overview of the Galway Granite Batholith and Visean Undifferentiated Limestone aquifer is presented below, which is based on the regional and local data presented in **Section 10.3.1** and **Section 10.3.2**. The hydrogeology for the Galway Granite Batholith and the Visean Undifferentiated Limestone are then discussed in detail individually below.

Groundwater flows can be more complex in limestone than granite due to karst pathways and the ground investigation data includes aquifer testing of both rock types to calculate their range of hydraulic conductivity. The aquifer testing is presented in **Plate 10.1** below for granite and limestone. This data shows that whilst the granite has a relatively narrow range of values, the limestone spans a significantly wider range. For the limestone areas, this data (as well as the spatial distribution of karst features) is used to identify those areas where karst flow paths through the aquifer are likely but also areas where such pathways are not present. These assessments are based on a combination of trial pits, window samples, drilling, surface geophysical surveys, pumping test and groundwater monitoring and interpretation.

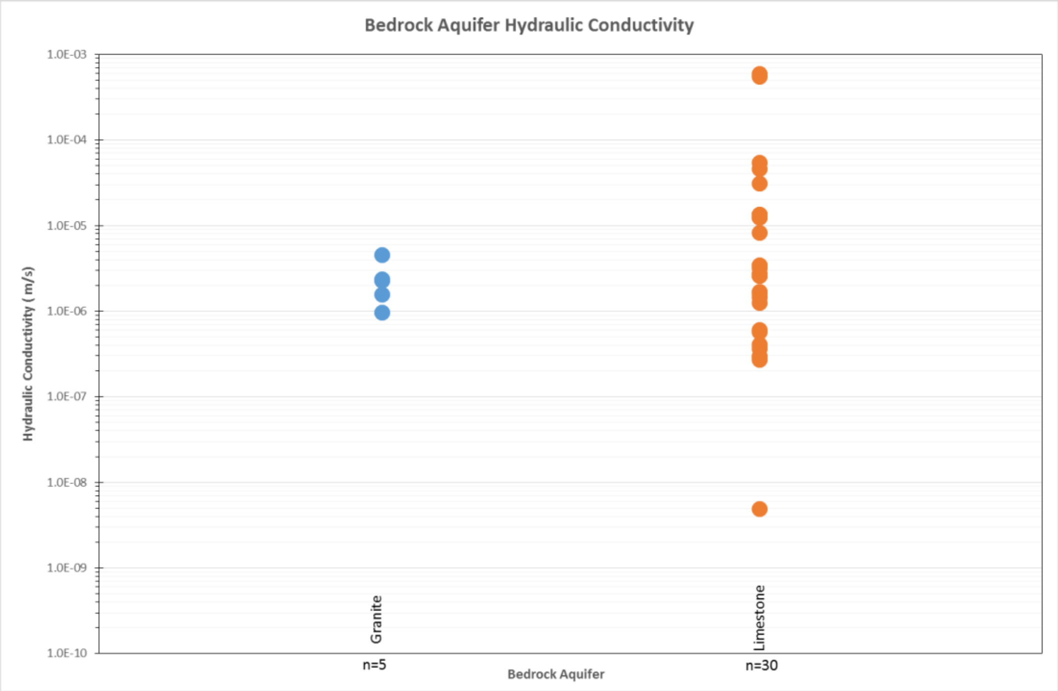
The karst survey (**Figure 10.1.002**) undertaken is used as an indicator that karst pathways are present within groundwater bodies. The observation of conduit flow at Western Coolagh Spring (K25) data and presence of karst features in the area are indicative that karst pathways are likely within GWDTE Lough Corrib Fen 1 (Menlough) GWB. Similarly, the karst survey identifies karst landforms across the Clare-Corrib GWB, which is also likely to have conduit pathways in the GWB. However, the survey identified only small scale karst features in the Clarinbridge GWB, which comprised of small or shallow enclosed depressions and seepages rather than springs.

Aquifer testing was undertaken for both the Galway Granite Batholith and Visean Undifferentiated Limestone across the proposed road development. The data from one pumping test, 15 small scale pumping tests with recovery, three packer tests and 15 soakaway tests are presented in **Appendix 10.5**. **Plate 10.1** below shows the distribution of hydraulic conductivity and **Table 10.10** shows the distribution for both granite and limestone. This data shows that those groundwater bodies that do not have karst, the Galway Granite Batholith and the Visean Undifferentiated Limestone within the footprint of the proposed road development within the Clarinbridge GWB have a relatively narrow range of hydraulic conductivity. In contrast the Visean Undifferentiated Limestone aquifer has significant karst in the GWDTE Lough Corrib Fen 1 (Menlough) GWB, the GWDTE Lough Corrib Fen 2 GWB and the Clare-Corrib GWB. In these areas where karst is present then the range of hydraulic conductivity is wider. Notably the maximum hydraulic conductivity is an order of magnitude higher. The highest recorded values for hydraulic conductivity are those measured in karst (5.3 x 10^{-4}m/s).

Table 10.10: Distribution of calculated hydraulic conductivity

Geological Unit	GWB	Min hydraulic conductivity m/s	Max hydraulic conductivity m/s
Galway Granite Batholith	Spiddal Maam - Clonbur	9.7 x10-7	4.6 x10-6
Visean Limestone Undifferentiated	Lough Corrib Fen 1 (Menlough) Clare-Corrib	5.0 x10-9	3.1 x10-5
Visean Limestone Undifferentiated	Clarinbridge	4.2 x10-7	1.7 x10-6

Plate 10.1: Distribution of calculated hydraulic conductivity



10.3.3.1 The Galway Granite Batholith Aquifer

The GSI descriptions for groundwater bodies in the Galway Granite Batholith such as the Spiddal GWB (GSI 2004a) and the Maam-Clonbur GWB (2004b), describes the aquifer as being a poor aquifer with low storage and short groundwater pathways.

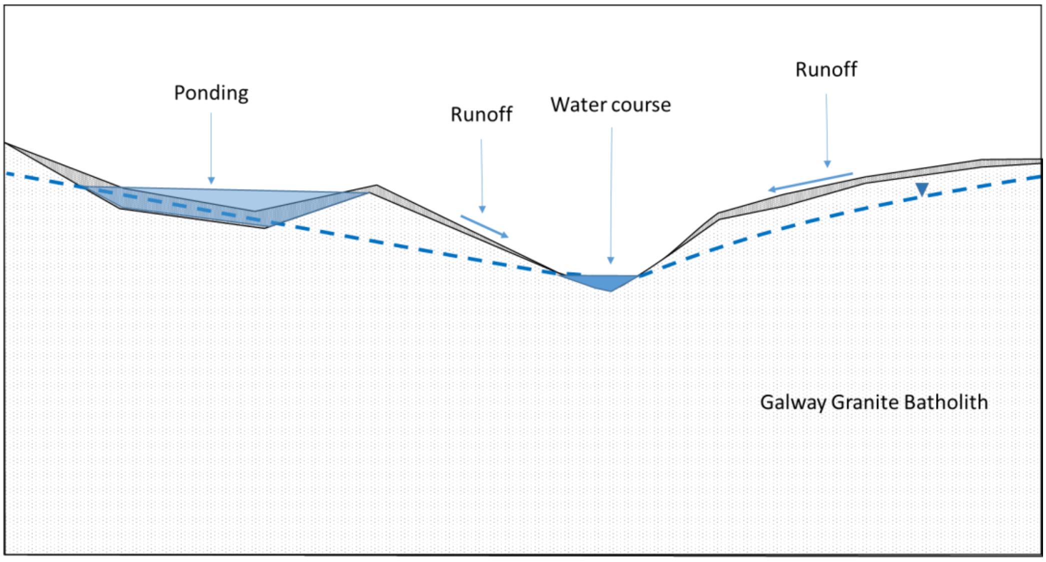
The water level data presented in **Section 10.3.2**, identifies that the groundwater table remains close to the surface and generally follows topography. On this basis groundwater levels will lower towards the coast and the River Corrib. The groundwater divide between the GSI Spiddal GWB and Maam-Clonbur GWB matches the watershed between Galway Bay and the River Corrib, which extends along the high ground at Letteragh and west of Dangan.

The GSI vulnerability data and ground investigation data for the project confirm that subsoil overlying the granite thins on higher ground and is up to 3m thick in low lying ground. The soil and subsoil comprises of glacial tills with high fines content, which is confirmed by particle size distribution (PSD) data that is presented in **Appendix A.9.1**. This data indicates that the permeability or the subsoils is in the low to moderate range (DELG, 1999).

The groundwater level data collected for this project agrees with the GSI division of groundwater bodies and on this basis the extent and naming of these remains unchanged. Based on GSI (2004a and 2004b), groundwater flow in the Galway Granite Batholith is isolated to weathered zones and fracture zones. None of the groundwater level data presented is indicative of high permeability zones.

The Galway Granite Batholith includes areas where there is poor drainage and water ponding at the surface, these areas include the Moycullen Bogs (NHA) and a number of other wetland areas (refer to **Chapter 8 Biodiversity**). The Moycullen Bogs comprise of a main area in the west near Lough Inch and two isolated areas at Tonabrocky and Letteragh (ref **Figure 10.5.002**). Where the surface water ponding occurs there is often little or no seasonal variation in the water level, with most areas remaining ponded throughout the summer.

Plate 10.2: Hydrogeological conceptualisation of runoff and surface water ponding on the Galway Granite Batholith



The undulating topography of the Galway Granite Batholith includes areas of topographic highs where bedrock is near surface and topographic lows where the subsoils are thicker (up to 3m). On the topographic highs rainfall runs off as overland flow whilst it is the lying ground where surface ponding as discussed above tends to occur.

The GSI vulnerability data and the project ground investigation data together with the Ordnance Survey topographic data show that the granite has an undulating rock topography (**Plate 10.2**). As the granite is of low permeability it will perch surface water and where drainage is poor, surface water can be impounded and ponded.

Connectivity between groundwater and the ponded surface water will be slight. As such, the water ponding on the surface at the Moycullen Bogs is not groundwater from the bedrock but water ponded on the top of the bedrock that has saturated the subsoil, has no natural discharge point, so breaches the ground surface.

10.3.3.2 The Visean Undifferentiated Limestone Aquifer

The GSI subdivided the aquifer of the Visean Undifferentiated Limestone into the following groundwater bodies.

- GWDTE Lough Corrib Fen 1 (Menlough)
- GWDTE Lough Corrib Fen 2
- GWDTE Lough Corrib Fen 3 & 4
- Clarinbridge
- Clare-Corrib
- Ross Lake

Each of the groundwater bodies are characterised below and discussed in terms of their interaction with surface water. In all cases the extent of the GWB is reviewed based on the project groundwater monitoring data. In most cases there has been refinement to the extent of groundwater bodies. The GWB retain the names provided by the GSI, however, the prefix of GWDTE is removed from those GWB named so by the GSI.

Ross Lake Groundwater Body

The Ross Lake GWB encompasses the limestone on the western side of the River Corrib. The Ross Lake GWB as mapped by the GSI is presented in **Figure 10.2.002**. The extent of the Ross Lake GWB was revised based upon the ground investigation for the proposed road development and the revised extent is presented in **Figure 10.5.002**.

The GWB receives recharge from rainfall but also runoff from the adjacent granite. There are several drains and ditches that cross from the granite and onto the Ross Lake GWB. As such, the surface catchment for the Ross Lake GWB includes runoff within the local catchment for the River Corrib. As the GWB boundary conditions are physical (i.e. bedrock contact and river) they do not fluctuate seasonally.

GWDTE Lough Corrib Fen 1 (Menlough) Groundwater Body

The GWDTE Lough Corrib Fen 1 (Menlough) GWB extends east from the River Corrib to the townland of Coolough. The eastern extent of the GSI GWDTE Lough Corrib Fen 1 (Menlough) GWB (**Figure 10.5.002**) has been revised westwards to the townland of Coolough to accommodate the groundwater divide identified between it and the Clare-Corrib GWB, which has been refined based on groundwater monitoring for this project.

This GWB has been divided into two areas, namely Lough Corrib Fen 1 Menlough and Lough Corrib Fen 1 Lackagh (note that in the revised mapping of the GWB the term GWDTE has not been used in the GWB title), on the basis of the thick silt and clay subsoils (up to 106m deep) that occur in the townland of Coolough. These thick subsoils deposits, which underlie Coolagh Lakes and form a deep valley fill/palaeokarst feature west of Lackagh Quarry, compartmentalise the GWB so that Lough Corrib Fen 1 (Menlough) lies north of Coolagh Lakes and Lough Corrib Fen 1 (Lackagh) forms a small GWB (<0.04km^2) between Coolagh Lake and Lackagh Quarry. It is noted that Lackagh Quarry lies within the revised Clare-Corrib GWB and not the revised Lough Corrib Fen 1 (Menlough) GWB or Lough Corrib Fen 1 (Lackagh) (**Figure 10.5.002**).

Groundwater flows westwards within the Lough Corrib Fen 1 (Menlough) from the groundwater divide with the Clare-Corrib GWB to the Coolagh Lakes and the River Corrib. Lough Corrib Fen 1 (Menlough) GWB supplies groundwater to Coolagh Lakes via the Western Coolagh Spring (K25). Due to the compartmentalisation of the aquifer by buried valleys/palaeokarst, the groundwater in Lough Corrib Fen 1 (Lackagh) GWB is largely contained. Due to the thick clay subsoil there are no observed discharges from the limestone bedrock to the Eastern Coolagh Spring and the compartmentalisation prevents discharge to Western Coolagh Spring. Instead, groundwater flow from Lough Corrib Fen 1 (Lackagh) is likely to flow eastwards to Lackagh Quarry during peak groundwater levels. There is a potential for seepage from the limestone aquifer through the clayey subsoil to the Eastern Coolagh Spring but due to the low permeability and thickness of the clayey subsoil, these potential seepages are of a very low flow rate. If present, seepages from the subsoil to the Eastern Coolagh Spring would represent a very small fraction of the groundwater contribution to Coolagh Lakes compared to the karst inflow at Western Coolagh Spring (K25), which provides the main groundwater contribution flow to Coolagh Lakes. As described in **Section 10.3.2.3** the Eastern Coolagh Spring (K45) is not a karst spring because it sits on thick clay subsoil as evidenced by ground investigations (GI).

Coolagh Lakes lie in a low-lying area that are shown by GSI data as well as records from 2006 GCOB GI and observations from the site walkover to be underlain by thickness of low permeability overburden and that the overburden adjacent to Upper Coolagh Lake comprises of silt and clay. On this basis, groundwater inflows through the base of the lakes are unlikely and the only significant groundwater input is the karst inflow via the Western Coolagh Spring (K25). Groundwater contribution to Coolagh Lakes from the Eastern Coolagh Spring and any other potential seepages (such as underwater springs from the margin of the Clare-Corrib GWB) are very limited due to the thick clay subsoil that fills the buried valley and forms a very low permeability barrier to the limestone aquifer.

Plates 10.3 and **10.4** below show the interactions between the Coolagh Lakes and Western Coolagh Spring at high and low groundwater levels. During periods of high groundwater levels groundwater contributes flow to the lakes (**Plate 10.3**), while during the summer the groundwater level lowers to just above the lake level and the springs have minimal flow. **Plate 10.4** below, shows the relationship between groundwater levels and surface water levels in the springs that feed Coolagh Upper Lake.

Plate 10.3: Schematic north south cross-section through Coolagh Lakes (groundwater high)

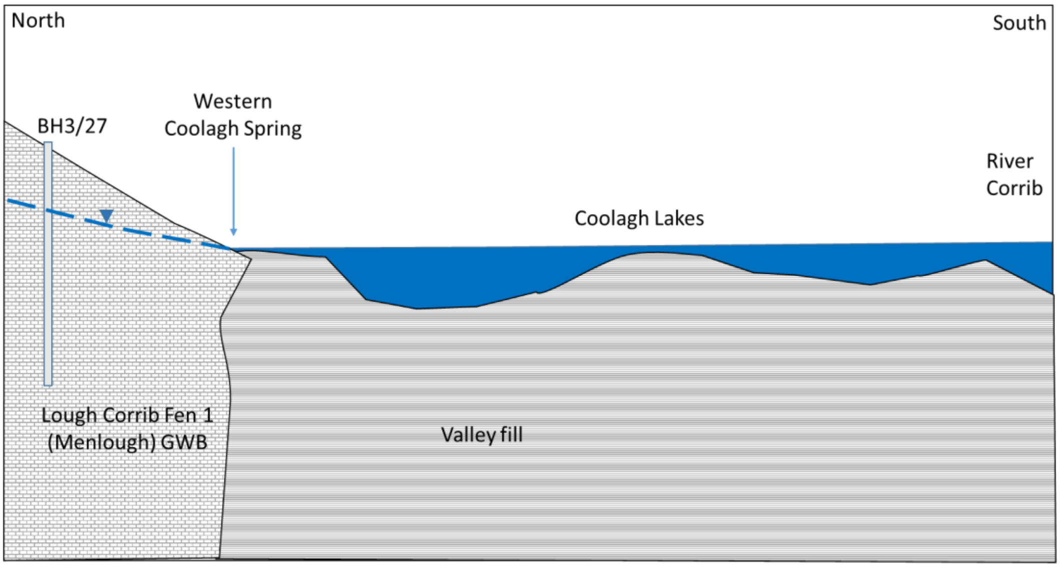
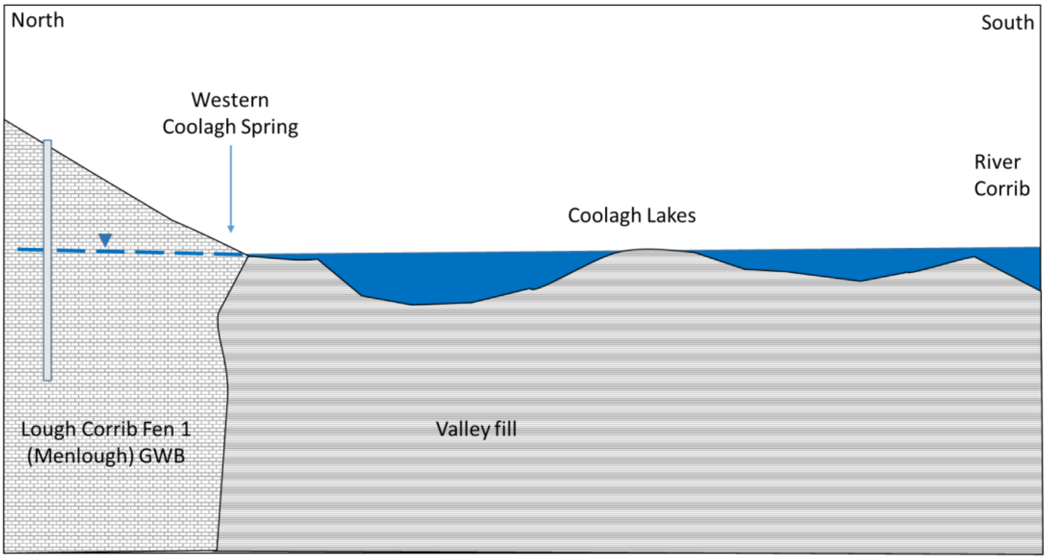
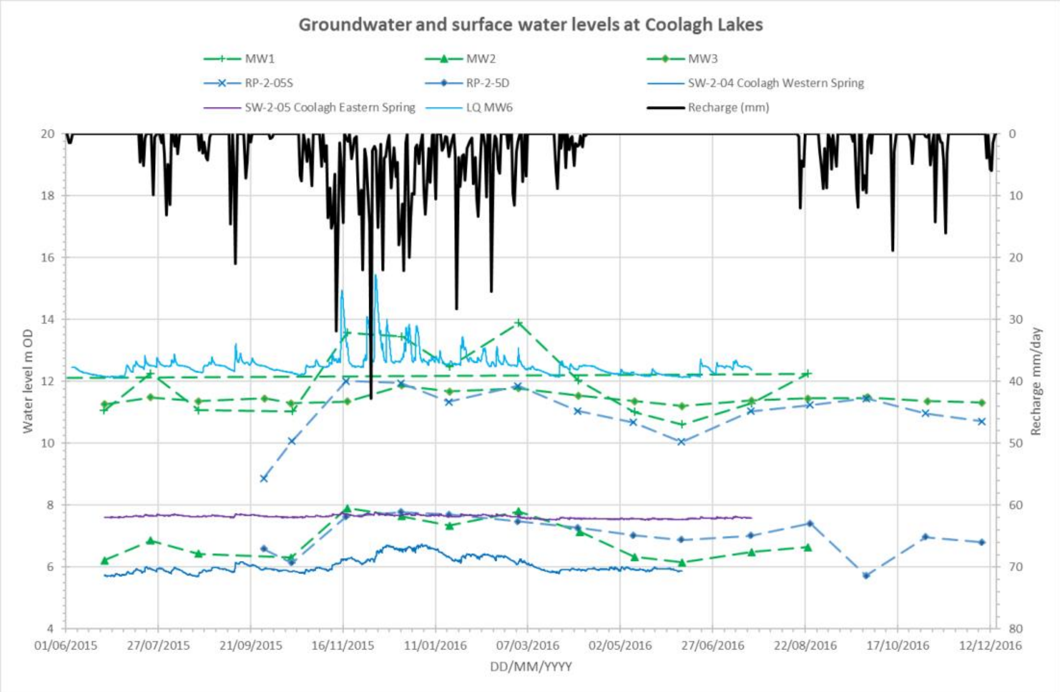


Plate 10.4: Schematic north south cross-section through Coolagh Lakes (groundwater low)



Groundwater hydrographs for the GWB are presented below (**Plate 10.5**), and show the groundwater responses in the aquifer locally as well as levels at the Western Coolagh Spring and Eastern Coolagh Spring.

Plate 10.5: Groundwater and surface water levels at Coolagh Lakes



Western Coolagh Spring is the main water inflow to Coolagh Lakes and has a seasonal variance in water level of 0.7m. Western Coolagh Spring is a karst resurgence in the eastern side of a shallow valley at the head of Upper Coolagh Lake. At this location groundwater flow rises from conduit in limestone bedrock. Flow is turbulent, with flow velocity up to 0.3m/sec (flow of 35l/s) estimated during the winter of 2016. During the summer time the flow at the spring is low (<1l/min). There are a number of seepages associated with Western Coolagh Spring in the western side of the shallow valley. Western Coolagh Spring is the collective of the main spring and the smaller seepages.

Eastern Coolagh Spring is separate from Western Coolagh Spring, being located 850m away in a north eastward direction and 3m higher in elevation. It has a very slight seasonal variable of 0.1m and with no measureable flow. Due to the geological setting of the Eastern Coolagh Spring with clayey subsoil, this feature is not considered is not considered to be a karst feature. As discussed there is potential for seepage from the clayey subsoil inputs to Coolagh Lakes at Eastern Coolagh Spring as well as seepage from elsewhere around the periphery of the lake shore. However, even if seepages are present, the potential seepages rates will be very low when compared to Western Coolagh Spring, even when considering the total seepage flow for the full extent of the lake periphery. This hydrogeological assessment however is based on the precautionary principle and assumes that these seepages occur even though they were not observed.

The extent of the Lough Corrib Fen 1 (Menlough) GWB is shown in **Figure 10.5.002**. The GWB is bound to the west by the River Corrib, to the east by a groundwater divide with the Clare-Corrib GWB, north by a divide with the Lough Corrib Fen 2 GWB and south by thick clayey subsoil deposits on which the Coolagh Lakes have formed.

The Lough Corrib Fen 1 (Lackagh) GWB is relatively small in size ($0.7km^2$) and is also internally subdivided by features such as the thick clayey subsoil deposits that infill the palaeokarst west of Lackagh Quarry. The boundaries, as well as thick subsoil deposits within the GWB, isolate the potential surface catchments for both the Western Coolagh Spring and Eastern Coolagh Spring, and on this basis their catchments can be defined.

The sub catchment for Western Coolagh Spring is defined as the surface area of the Lough Corrib Fen 1 (Menlough) GWB from the eastern GWB boundary (BH4) to the topographic high at MW3. At MW3 there is a small groundwater ridge that allows a divide between groundwater that flows to Western Coolagh Spring and groundwater that flows the River Corrib. As MW3 lies 200m east of the River Corrib the extent of the groundwater sub catchment that drains to the River Corrib is limited to the 200m wide strip adjacent to the river (less than $0.1km^2$).

The pond at Eastern Coolagh Spring has the potential to receive seepage from the subsoil surrounding the feature. The extent of the catchment is restricted to the area in the valley floor. Any groundwater flow from the limestone aquifer to the Eastern Coolagh Spring would have to seep through the clayey subsoil and hence be of a very low quantity.

The groundwater levels in the GWB (**Plate 10.5**) show that as well as having the largest sub-catchment in the Lough Corrib Fen 1 GWB, the Western Coolagh Spring is also the lowest measured point of the groundwater table. On this basis the Western Coolagh Spring (as well as Coolagh Lakes and River Corrib) is the main receiving water. Based on the descriptions presented, the Western Coolagh Spring is considered to be the sole significant groundwater contributor to Coolagh Lakes.

The western boundary of the Lough Corrib Fen 1 (Menlough) GWB is physically bound by a river. The seasonal variance is very slight due to the level of the river. However, the eastern boundary of the Lough Corrib Fen 1 (Menlough) GWB is a groundwater divide and the seasonal fluctuation in groundwater levels has the potential to cause the divide to shift laterally.

Due to the compartmentalisation of the Lough Corrib Fen 1 (Lackagh) GWB, flow is prevented from draining to Western Coolagh Spring and only small scale seepage via the clayey subsoil is possible at the Eastern Coolagh Spring. The compartmentalisation of the aquifer means that during peak levels the groundwater in the Lough Corrib Fen 1 (Lackagh) may flow eastwards towards Lackagh Quarry.

Based on the maximum and minimum groundwater levels data presented in **Table 10.8** and **Figure 10.6.107** to **Figure 10.6.110** the groundwater divide occurs at near BH4 during the winter. During the summer the groundwater table gradient flattens and the divide migrates north westwards by an estimated 250m (based on the seasonal groundwater level data for BH4 and LQMW4, refer to **Appendix 10.3**).

On the basis of the above descriptions, the Lough Corrib Fen 1 (Menlough) GWB is the sole significant groundwater contributor (via Western Coolagh Spring (K25)) to Coolagh Lakes. The Coolagh Lakes discharge to the River Corrib, both of which are part of the Lough Corrib cSAC and therefore the Lough Corrib Fen 1 (Menlough GWB contributes to this cSAC. As the River Corrib discharges into Galway Bay this GWB also contributes (indirectly) to Galway Bay Complex cSAC and Inner Galway Bay SPA.

GWDTE Lough Corrib Fen 2 Groundwater Body

The GSI mapping of the extents of GWDTE Lough Corrib Fen 2 is shown in **Figure 10.2.002**. Based on the groundwater level data collected for the proposed road development the southern boundary of the GWB as per GSI is set 0.3km too far south. Based on the water level data for the proposed road development the GWB extent has been updated and is shown in **Figure 10.5.002**. Note that in the revised mapping of the GWB the term GWDTE has not been used in the title.

Although the proposed road development does not extend into this GWB (**Figure 10.5.002**) the divide between the GWB and the adjacent GWDTE Lough Corrib Fen 1 GWB lies in close proximity to it. On this basis this GWB is considered as one of the GWB traversed by the proposed road development.

The seasonal fluctuation in the GWB as 2.5m, as recorded in monitoring well RC133, which is located close to the groundwater divide (**Table 10.8**). Based upon slight seasonal variation and relatively low hydraulic gradients in the area the groundwater divide is considered to be stable and not fluctuate laterally.

Lough Corrib Fen 2 GWB contributes to Lough Corrib. The only surface water recorded in the GWB is Turlough K20 and spring K17.

GWDTE Lough Corrib Fen 3 and 4 Groundwater Body

Based on groundwater level data collected for the proposed road development, the southern extent of the GSI Lough Corrib Fen 3 and 4 GWB has been reduced and been moved north by over 2km. The revised groundwater bodies are presented in **Figure 10.5.002**, although it is noted that based on the revised extent, this GWB no longer extends onto the figure. Note that in the revised mapping of the GWB the term GWDTE has not been used in the title.

Clare-Corrib Groundwater Body

The GSI mapping of the GWB is shown in **Figure 10.2.002**. Based on the groundwater level data collected for the proposed road development, the extent of the Clare-Corrib GWB has been revised with the GWB extended further west, as far as the townland of Coolough, near Menlough, and further east to the N83 Tuam Road (**Figure 10.5.002**).

There are a number of features in the GWB that have ponded water and these have the potential to interact with groundwater. These pond features include Ballindooley Lough (which comprises of the main Ballindooley Lough and a number of smaller surface water bodies immediately to the south), a small surface water body at Ballinfoyle, an enclosed depression referred to as K97 in the karst survey (refer to **Appendix 10.2**), and the Terryland River, including adjacent ecology have been identified in the **Chapter 8, Biodiversity** as being potential water dependant habitats. The hydrogeological aspects of these features are presented below.

Ballindooley Lough

Geophysics undertaken south of Ballindooley Lough for this project and north of the Ballindooley Lough for 2006 GCOB indicate that thick subsoils underlie the extents of Ballindooley Lough. From this data it is inferred that a feature, such as a buried valley, underlies the length of the lake. The subsoils below the lake explain the permanent perching of the surface water level when groundwater levels are low.

The groundwater data shows that Ballindooley Lough lies up gradient of the proposed road development. The data also shows the lough to be perched during the summer when groundwater levels (RP-2-01 & RC1104) drop below the lake water level (**Plate 10.6** and **10.7**). On this basis, during low groundwater levels the perched water in Ballindooley Lough and the groundwater in the limestone aquifer form separate and distinct water bodies.

Plate 10.6: Schematic east west cross-section through Ballindooley Lough showing the interaction of groundwater with the lake during high groundwater levels

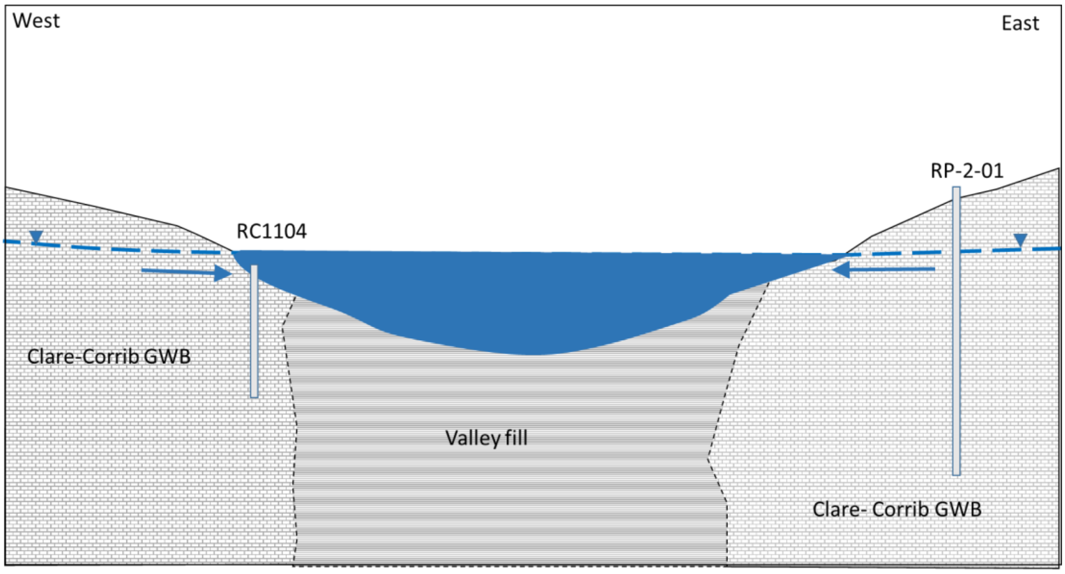
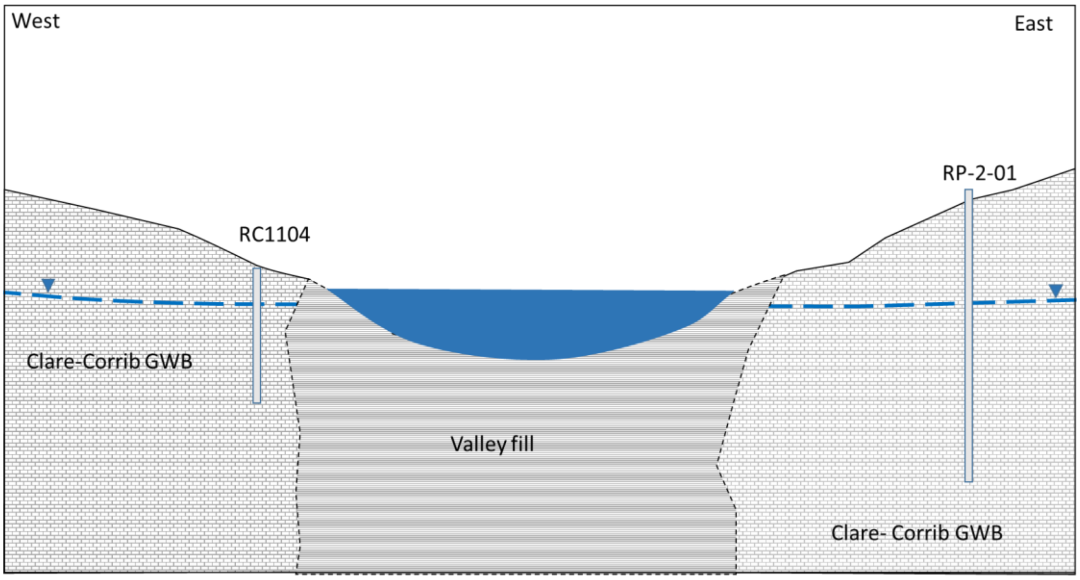


Plate 10.7: Schematic east west cross-section through Ballindooley Lough showing the interaction of groundwater with the lake during low groundwater levels



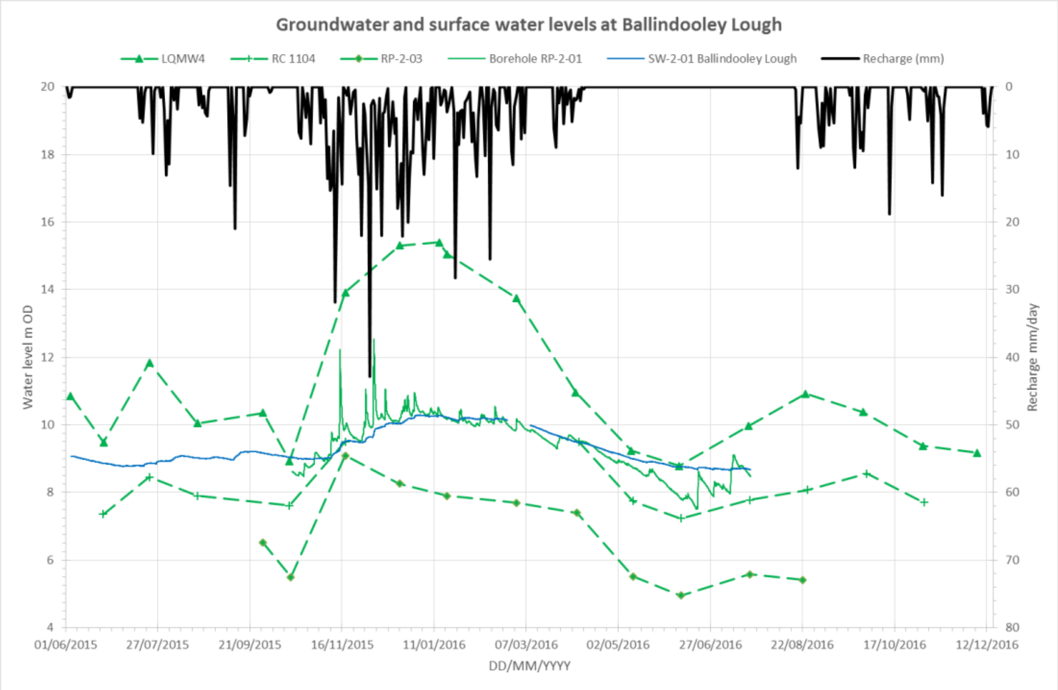
During the winter, the lake level in Ballindooley Lough and the groundwater level in the limestone aquifer are in continuity. On this basis, Ballindooley Lough only receives groundwater during high groundwater levels.

Bathymetry of Ballindooley Lough shows that the lake has a max depth of 10m (-2.5m OD). Based on the geophysics data and the analyses that the summer lake water level is distinct from groundwater, then the base of summer water level in Ballindooley Lough lies on low permeability subsoil and not limestone.

The hydrographs for the GWB below in **Plate 10.8** show that the groundwater level in wells surrounding Ballindooley Lough are continuous with the level of Ballindooley Lough during the winter. However, in the summer the groundwater level lowers below the permanent water level of the lough perching it.

Also notable are the groundwater levels in monitoring well RP-2-03 located 300m south of Ballindooley Lough (**Figure 10.6.009**) are significantly lower than other groundwater levels in the area and the surface water level at Ballindooley Lough. The lower water table in RP-2-03 indicates the direction of flow southwards within the groundwater body.

Plate 10.8: Groundwater and surface water levels at Ballindooley Lough



<u>Enclosed depression (Doline) K97</u>

Doline K97 was identified by the karst survey. It is a c.40m circular enclosed depression, with soft clay in the base, that is located near Castlegar (**Figure 10.1.002**). This doline is included in this assessment as it was originally highlighted as potentially being a turlough, however as outlined below and in **Chapter 8, Biodiversity** it has since been confirmed as not meeting either the ecological or hydrogeological criteria for a turlough.

Based on the above groundwater levels it is clear that there is a distinct difference in groundwater level to the west (Monitoring well BH3/34) and to the east (monitoring well RC-2-01 & RC-2-03) (Refer to **Plate 10.9** and **Plate 10.10**).

The ground investigation data shows that the feature K97 is located within thick subsoil. BH3/32 shows silt and clay subsoil to 23m below ground level (bgl) and geophysics GP3/32 (ERT) (**Appendix 9.1**) shows low resistivity material to a depth of greater than 20m. However, to the east of the site BH3/33 (no piezometer) and geophysics GP3/13 show bedrock to be with 3m of the surface.

Plate 10.9: Schematic east west cross-section through enclosed depression K97 showing the interaction of groundwater with the feature during high groundwater levels

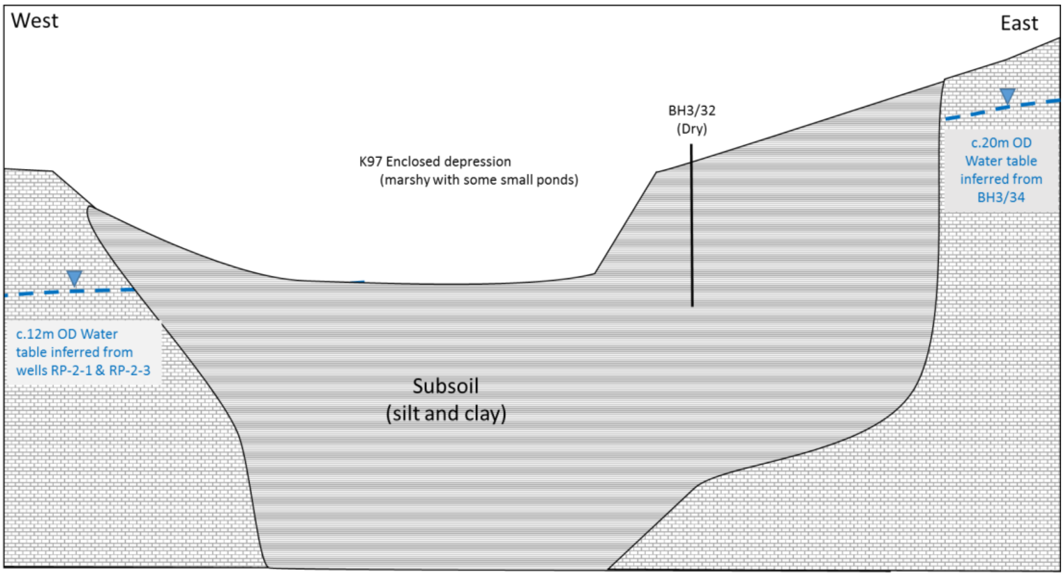
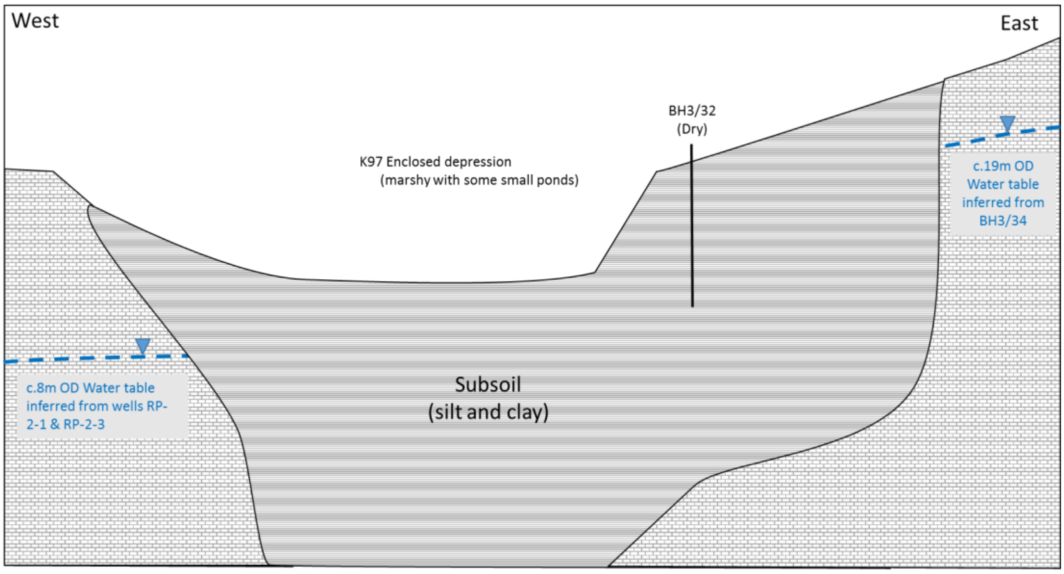


Plate 10.10: Schematic east west cross-section through enclosed depression K97 showing the interaction of groundwater with the feature during low groundwater levels



Due to the low permeability nature of the subsoils it is very unlikely that there is a groundwater contribution to the base of the depression. Water ponding in the base is likely to be entirely due to incident rainfall, captured by the depression. The hydrogeological descriptions provided strongly indicate that the feature does not receive groundwater.

Surface water at Ballinfoyle

The surface water feature at Ballinfoyle (N97) lies in the valley floor approximately 600m southwest of Ballindooley Lough, adjacent to and immediately east of the N84 Headford Road at Ballinfoyle (**Figure 10.1.002**). The feature is square in shape measures with 80m long sides and is located within silt/clay subsoils.

It is a seasonal lake that fills during the autumn and drains during spring. Groundwater levels on the north-western side (monitoring wells LQMW1-4) rise above the feature's floor and cause it to flood during the winter. Notably the groundwater level on the south-eastern side remains below the feature's floor at all times (monitoring well RP-2-03). The disparity in groundwater levels across the feature (refer to **Plate 10.11** and **Plate 10.12**) indicates a barrier to groundwater flow and based on the location along the trend of the valley at Ballindooley it is likely that this feature is located on thick clay subsoil.

Based on the groundwater level data, this feature receives groundwater from the bedrock aquifer to the northwest during the winter. The ponding occurs in the feature due to the subsoil deposits that underlie the feature. As the feature is not located on limestone the feature does not have the hydrogeological characteristics of a turlough and is surface water ponding.

Plate 10.11: Schematic east west cross-section through Feature (N97) showing the interaction of groundwater with the feature during high groundwater levels

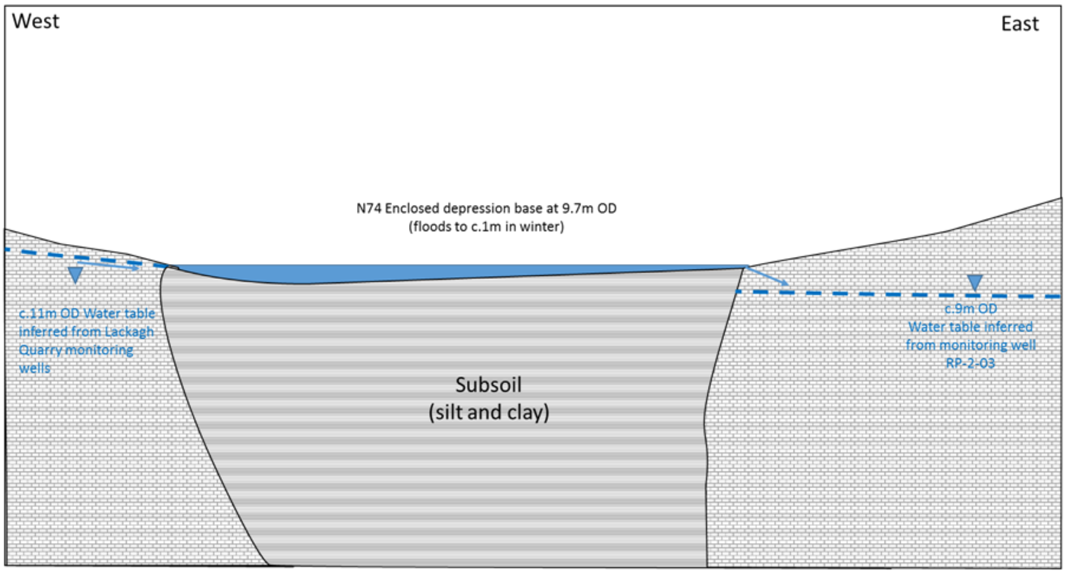
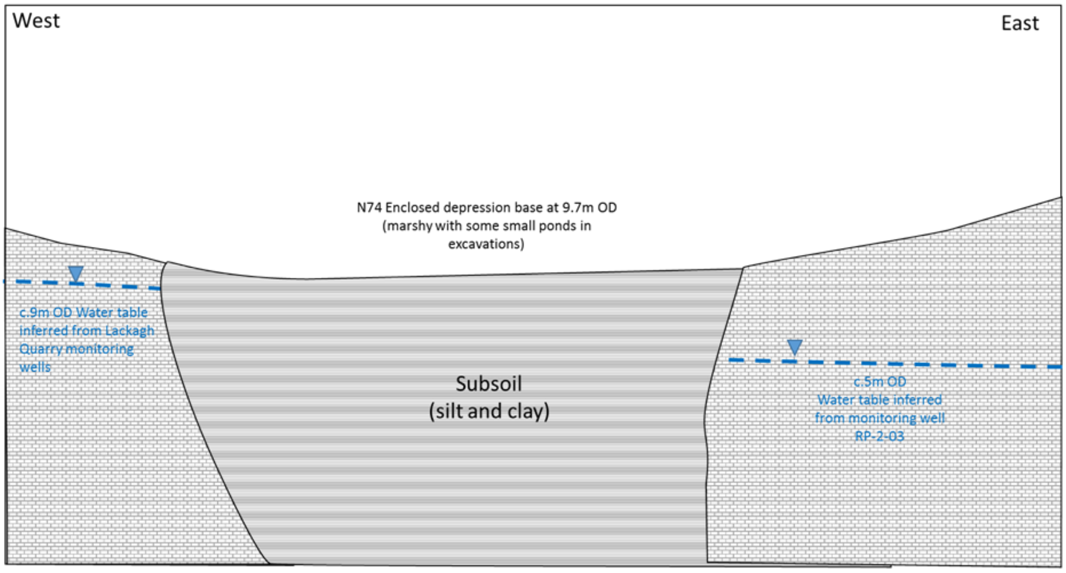


Plate 10.12: Schematic east west cross-section through Feature (N97) showing the interaction of groundwater with the feature during low groundwater levels



Terryland River

Under normal conditions the Terryland River sinks at two stream sinks, named Pollavurleen West and East (K87 and K96) near Glenanail (Refer to karst study in **Appendix A.10.2**) (**Plate 10.13**). However, during high groundwater levels, the Terryland sinks become resurgences and discharge groundwater to the Terryland River that flows back and joins the River Corrib (**Plate 10.14**).

The switching between sink to resurgence makes these estavelles. Whilst the sinks are located near limestone outcrop, the Terryland River flows for its length along a low-lying area that has thick overburden. The low permeability of the subsoil here carries the surface water across the valley until the limestone is met at the southern side of the valley.

Plate 10.13: Schematic north south cross-section through Terryland River showing the operation of the estavelles at Pollavurleen West and East during high groundwater levels

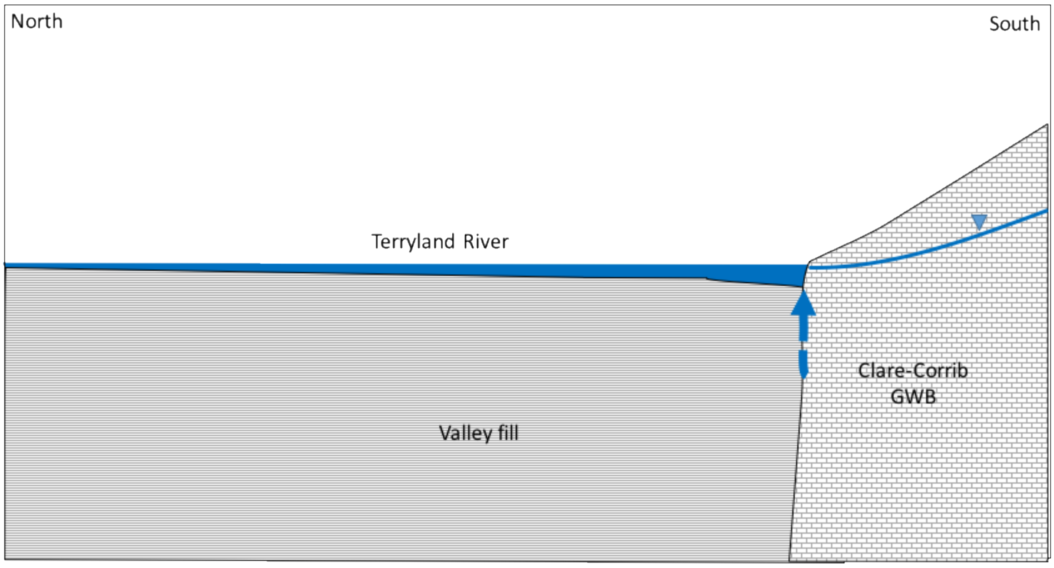
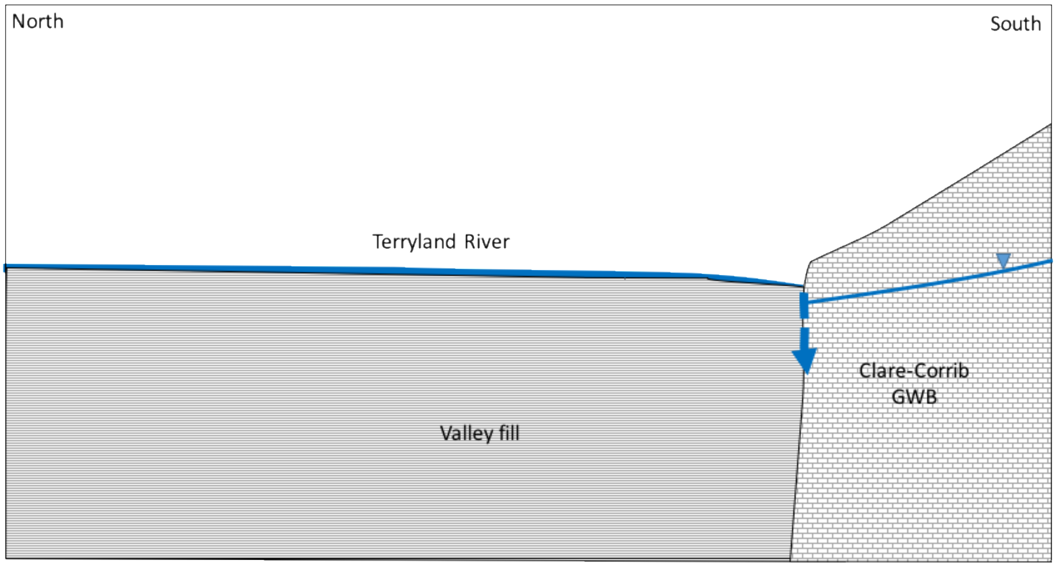


Plate 10.14: Schematic north south cross-section through Terryland River showing the operation of the estavelles at Pollavurleen West and East during low groundwater levels



There are a number of Annex 1 habit that occur in the valley of the Terryland River on the thick subsoil deposits. As these features are not located on bedrock but on the thick subsoil, these features are dependent on pluvial flooding and are not groundwater dependent.

Clarinbridge Groundwater Body

The Clarinbridge GWB as delineated by the GSI is a large groundwater body that extends from Galway City eastwards past Galway Airport to Athenry and then south from Athenry to Clarinbridge and as far south as Ardrahan. As the Clarinbridge GWB extends over a number of rivers and streams it can be subdivided into several smaller groundwater bodies that are distinct and isolated from each other. One of these smaller sub-catchments of the Clarinbridge GWB is the area of the higher ground between Galway Airport and Ballybrit.

The divide between the Clarinbridge GWB and the Clare-Corrib GWB is marked by the thick overburden deposits along the line of the N83 Tuam Road. These thick low permeability superficial deposits have been proven to a minimum depth of 30m. Conceptually these thick low permeability deposits form a hydraulic barrier between the Clare-Corrib and Clarinbridge groundwater bodies.

The groundwater level monitoring data collected in the Clarinbridge GWB for the proposed road development has a shallow water table relative to the rest of the study area. The shallow groundwater table is generally within 4m of the surface and follows topography, lowering gradually southwards towards Galway Bay. The seasonal fluctuation in the aquifer is of the order of 2m. The characteristics of the Visean Limestone Undifferentiated in the GWB indicate lower aquifer properties, with fracture flow and only small scale surface karst landforms present.

10.3.4 Groundwater Receptors

There are a number of receptors within the study area which are connected to or dependent upon groundwater to maintain their hydrogeology. The types of receptors that could be affected by the proposed road development are:

- Groundwater resources and abstractions
- Groundwater dependent habitats
- Groundwater dependent surface water features

The individual receptors identified under these headings are described below and an outline of the receiving environment for each is provided. Based on the conceptual model outlined in **Section 10.3.3**, a number of these will not be affected by the proposed road development and a full impact assessment will not be required. These are clearly identified and those which do require an impact assessment are assessed in full in **Section 10.5**.

The importance of these groundwater receptors is ranked according to TII Guidelines on the attribute classification criteria presented in **Table 10.1**. Potential hydrogeological impacts are defined as any negative changes to the baseline groundwater quantity and / or groundwater quality.

10.3.4.1 Groundwater Resources

As outlined in **Section 10.3.1** and presented on **Figure 10.1.001**, the west of the study area, the aquifer is classified as a Pl aquifer and in the east of the study area, the aquifer is classified as a Rkc aquifer. These aquifers have an importance ranking of Low and Extremely High respectively in line with TII importance ranking criteria presented in **Table 10.1**.

10.3.4.2 Groundwater Supplies

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 include Inner and Outer Protection areas. There are no Source Protection Areas within the study area for the proposed road development.

Figures 10.5.002 shows the locations of all wells recorded by the GSI. However, as it is not a requirement for wells to be registered with the GSI the GSI list of wells is not necessarily complete. Local authority and National Federation of Group Water Schemes (NFGWS) records were also consulted to determine the locations of groundwater abstractions.

During consultations with landowners they were asked if they had a private well supply and this information has been incorporated into this assessment (refer to **Section 10.2.5**). Where no information is available on the construction or abstraction details of these private well supplies, a conservative approach has been undertaken (i.e. the assumption has been made that they are shallow wells so more vulnerable to pollution).

The GSI database identifies one major groundwater abstraction in the Galway Granite Batholith at Knocknacarra (W50-01) which is a group water scheme that supplies approximately 50 houses. The GSI database also lists one private supply well (W50-09) and one spring supply (W1000-01). The site walkover and consultations with landowners has not identified any additional wells in the Galway Granite Batholith.

Based on TII importance ranking criteria, the importance ranking for the major abstraction at Knocknacarra (WS50-01) is ranked as Medium and the well (W50-09) and spring (W1000-01) are ranked as Low. All of the groundwater supplies identified in the Galway Granite Batholith are within 1km beyond the study area extent and are identified as part of the desk study. These groundwater abstractions are included in the assessment as a conservative measure to ensure that the catchments for each well is appropriately assessed.

The Visean Undifferentiated Limestone has four large groundwater abstractions within the study area, these comprising of one commercial groundwater abstraction (W50-12) on the N84 Headford Road and three groundwater abstractions for Galway Racecourse (W50-13, 14 and 15).

W50-12 is an industrial supply well for a commercial water bottling facility and has an abstraction rate of approximately 250m^3/day. TII criteria only applies to domestic wells, however for this assessment commercial supplies are considered equal to domestic supplies with the average metered (residence) water consumption ranging between 274 to 383 litres per day (Central Statistics Office, 2015[3]). On this basis, W50-12 has an equivalent supply of up to 1,000 houses and is ranked as having an importance ranking of 'High'.

Galway Racecourse wells W50-13 and W50-14 provide a cumulative 2,000m^3/day of groundwater that is primarily for use for watering of the track but is also used to supply drinking water for the horses and water to wash down the yard. The cumulative abstraction of W50-13 and W50-14 has a combined equivalent of >2,500 houses and a 'Very High' importance.

Galway Racecourse well W50-15 abstracts 380m^3/day for potable use. Based on TII criteria for domestic wells W50-15 has an equivalent of 1,400 houses and is ranked as having a 'High' importance.

The Visean Undifferentiated Limestone is tapped into for 20 private domestic wells. These comprise of W50-02, 03, 04, 05, 06, 07, 08, 10 and 11, W100-01,02,03, 04, 05 and 06, W500-1 and W1000-02, 03 and 04.

One geothermal well has been identified (G50-01), which located on Ballybrit Crescent. The geothermal well is of a closed loop design developed within the Visean Undifferentiated. Consultation with the landowner identified that the well relies on an open borehole design, which uses the thermal conductance of the groundwater from the bedrock to heat the closed loop piping.

Based on TII importance ranking criteria, domestic abstraction wells have an importance ranking of 'Low'. Domestic closed loop geothermal wells are assessed as being comparable to domestic abstraction wells and also have an importance ranking of 'Low'.

10.3.4.3 Groundwater dependant Habitats

A full review of ecological features and designated ecological sites in the study area are detailed in **Chapter 8, Biodiversity**. The habitats listed in this section are those identified in **Chapter 8, Biodiversity** as being water dependant. Those habitats dependent on hydrogeological characteristics include groundwater dependant terrestrial ecosystems (GWTDE) receptors that are dependent on emergent groundwater but also features such as limestone pavement and associated ecosystems, which are dependent on well drained karst bedrock.

European sites comprise of (candidate) Special Areas of Conservation ((c)SAC) and Special Protection Areas (SPA), whilst National sites comprise of National Heritage Areas (NHA) and potential Heritage Areas (pNHA). As detailed in TII Guidelines, those sites that are designated as European sites status are ranked of

[3] Central Statistics Office. Statistical Release 25 April 2017. Domestic Metered Public Water Consumption.

international importance whilst those designated as National sites are ranked of national importance.

Habitats outside of European and National sites are ranked dependent on hydrogeological characteristics. Annex 1 habitats are attributed as 'Very High' owing to their national importance.

European sites

This section identifies those European sites that have the potential to be impacted from a hydrological perspective. All European sites within 30km of the proposed road development have been considered using the precautionary principle. The European sites beyond 15km do not have a groundwater connection from the proposed road development and are not considered further.

The screening of all European sites within 15km of the proposed road development is presented below in **Table 10.11**. Those European sites that are located in separate and distinct groundwater bodies or sub catchments are not considered further as there is no groundwater connection from the proposed road development.

Table 10.11: Screening of European sites by proximity to the proposed road development

Site Name	Proximity to Proposed Road Development	Screening	Result
Black Head-Poulsallagh Complex cSAC	11km	Site lies in separate groundwater body	Not considered further
Moneen Mountain cSAC	13km	Site lies in separate groundwater body	Not considered further
Castletaylor Complex cSAC	14km	Site lies in separate groundwater body	Not considered further
Galway Bay Complex cSAC	0.2km	Site lies adjacent to groundwater body that the proposed road development traverses	Impact assessment required
Lough Corrib cSAC	0km	Site lies adjacent to groundwater body that the proposed road development traverse	Impact assessment required
Rahasane Turlough cSAC	13km	Site lies in separate groundwater body sub catchment	Not considered further
Lough Fingall Complex cSAC	11km	Site lies in separate groundwater body sub catchment	Not considered further
Gortnandarragh Limestone Pavement cSAC	14km	Site lies in separate groundwater body sub catchment	Not considered further

Site Name	Proximity to Proposed Road Development	Screening	Result
Kiltiernan Turlough cSAC	14km	Site lies in separate groundwater body sub catchment	Not considered further
Ross Lake and Woods cSAC	10km	Site lies in separate groundwater body sub catchment	Not considered further
East Burren Complex cSAC	13km	Site lies in separate groundwater body	Not considered further
Connemara Bog Complex cSAC	6km	Site lies in separate groundwater body	Not considered further
Ardrahan Grassland cSAC	15km	Site lies in separate groundwater body sub catchment	Not considered further
Inner Galway Bay SPA	1km	Site lies adjacent to groundwater body that the proposed road development traverses	Impact assessment required
Lough Corrib SPA	0.1km	Site lies adjacent to groundwater body that the proposed road development traverses	Impact assessment required
Rahasane Turlough SPA	13km	Site lies in separate groundwater body sub catchment	Not considered further
Cregganna Marsh SPA	4km	Site lies in separate groundwater body sub catchment	Not considered further
Connemara Bog Complex SPA	9km	Site lies in separate groundwater body	Not considered further

Based on the above regional screening there are four European sites that are either located within or receiving groundwater from catchments that the proposed road development traverses (**Figure 10.5.002**). These are:

- Lough Corrib cSAC
- Lough Corrib SPA
- Galway Bay Complex cSAC
- Inner Galway Bay SPA

Ballindooley Lough is identified in **Chapter 8, Biodiversity** as supporting the wintering birds of the Lough Corrib SPA and Inner Galway Bay SPA. On this basis Ballindooley Lough is included in the assessment under the heading of European sites.

Lough Corrib cSAC, Lough Corrib SPA, Galway Bay Complex cSAC and Inner Galway Bay SPA receive groundwater from the Galway Granite Batholith and the Visean Undifferentiated Limestone that the proposed road development traverse. The supporting site, Ballindooley Lough, only receives groundwater from the Visean Undifferentiated Limestone. A breakdown of the contributions from groundwater bodies traversed by the proposed road development to these European sites (including supporting sites) are summarised below in **Table 10.12**.

Table 10.12: Groundwater bodies traversed by the proposed road development and the European sites they potentially contribute to

Groundwater Body	Lough Corrib cSAC	Lough Corrib SPA	Galway Bay Complex cSAC	Inner Galway Bay SPA	Ballindooley Lough
Spiddal GWB	-	-	Contributes	Contributes	-
Maam Clonbur GWB	Contributes	Contributes	Contributes	Contributes	-
Ross Lake GWB	Contributes	Contributes	Contributes	Contributes	-
Lough Corrib Fen 1 (Menlough) GWB and Lough Corrib Fen 1 (Lackagh) GWB	Contributes	-	Contributes	Contributes	-
GWDTE Lough Corrib Fen 2	Contributes	Contributes	Contributes	Contributes	-
Clare-Corrib	Contributes	Contributes	Contributes	Contributes	Contributes
Clarinbridge	-	-	Contributes	Contributes	-

Based on the hydrogeological characterisation (**Section 10.3.3**) the Visean Undifferentiated Limestone contributes a greater component of groundwater to the River Corrib than the Galway Granite Batholith.

The Visean Undifferentiated Limestone includes a number of karst point discharges to the Lough Corrib cSAC, which include the Western Coolagh Spring and Terryland River (during high groundwater flow). These karst point discharges provide significant contribution to habitat in the Lough Corrib cSAC.

Each of these European sites has a ranking of ‘Extremely High’ importance in line with TII Guidelines. Potential impacts to these European sites from the characteristics of the proposed road development are evaluated in **Section 10.5**.

National Heritage Area (NHA)

This section identifies those National sites (both National Heritage Areas and proposed National Heritage Areas) that have the potential to be impacted from a hydrological perspective. All National sites within 30km of the proposed road development have been considered using the precautionary principle. The National sites beyond 15km do not have a groundwater connection from the proposed road development and are not considered further.

The screening of all National sites within 15km of the proposed road development is presented below in **Table 10.13**. Those National sites that are located in separate and distinct groundwater bodies or sub catchments are not considered further as there is no groundwater connection from the proposed road development.

Table 10.13: Screening of National Heritage Areas (NHA) and proposed National Heritage Areas (pNHA) by proximity to the proposed road development

Site Name	Proximity to the proposed road development	Screening	Result
Ross Lake and Woods pNHA	11km	Site lies in separate groundwater body sub catchment	Not considered further
Moycullen Bogs NHA (Lough Inch / Na Foraí Maola Thair, Tonabrocky and Letteragh)	0km	Lough Inch / Na Foraí Maola Thair lies within 250m Tonabrocky lies at 250m Letteragh lies adjacent	Impact assessment required for all three locations
Furbogh Woods pNHA	2km	Site lies beyond 250m but within groundwater body traversed by proposed road development	Impact assessment required
Gortnandarragh Limestone Pavement pNHA	14km	Site lies in separate groundwater body	Not considered further
Drimcong Wood pNHA	8km	Site lie in separate groundwater body	Not considered further
Killarainy Lodge, Moycullen pNHA	8km	Site lies in separate groundwater body	Not considered further
Ballycuirke Lough pNHA	5km	Site lies in separate groundwater body	Not considered further
Lough Corrib pNHA	0km	Site lies adjacent at the Corrib crossing	Impact assessment required
Kiltullagh Turlough pNHA	2km	Site lies within same groundwater body sub catchment	Impact assessment required
Cregganna Marsh NHA	4km	Site lies in separate groundwater body sub catchment	Not considered further

Site Name	**Proximity to the proposed road development**	**Screening**	**Result**
Galway Bay Complex NHA	0.2km	Site lies adjacent to groundwater body traversed by proposed road development	Impact assessment required
East Burren Complex pNHA	14km	Site lies in separate groundwater body	Not considered further
Rahasane Turlough pNHA	14km	Site lies in separate groundwater body sub catchment	Not considered further
Lough Fingal Complex pNHA	11km	Site lies in separate groundwater body	Not considered further
Castletaylor Complex pNHA	14km	Site lies in separate groundwater body sub catchment	Not considered further
Kiltiernan Turlough pNHA	14km	Site lies in separate groundwater body sub catchment	Not considered further
Ballyvaughn Turlough pNHA	15km	Site lies in separate groundwater body	Not considered further
Blackhead Poulsallagh Complex pNHA	11km	Site lies in separate groundwater body	Not considered further

Based on the above regional screening there is one NHA site and four pNHA sites that have the potential to be impacted by the proposed road development. These are:

- Moycullen Bogs NHA
- Furbogh Woods pNHA
- Kiltullagh Turlough pNHA
- Galway Bay Complex pNHA
- Lough Corrib pNHA

The Moycullen Bogs NHA, which are located on the Galway Granite Batholith, occur as one main site encompassing west of Lough Inch and two isolated sites one at Letteragh and one at Tonabrocky. The southern corner of the main site lies within 250m of the proposed road development, whilst the site at Letteragh lies adjacent to the proposed road development. The site at Tonabrocky lies 250m away from the footprint of proposed road development.

The Moycullen Bogs include areas of surface water ponding, which is present at all sites. Based on the conceptual site model for the Galway Granite Batholith (**Section 10.3.3**) the surface water ponding is caused by the low aquifer properties of the underlying granite, which causes water infiltrating through the subsoil to perch above the undulating rock head.

These surface ponds are not dependant on groundwater per se but they are dependent on the site specific hydrogeology, specifically the low aquifer properties, the undulating nature of the rock head and also rainfall. The Moycullen Bogs are ranked as having a 'Very High' importance based on the TII guidance and are assessed in the evaluation of impacts (**Section 10.5**).

Furbogh Woods pNHA area located at the coast within the Spiddal GWB approximately 2km west of the proposed road development. Groundwater flow within the Spiddal GWB follows surface water patterns and may be divided into sub catchments on the basis of surface water streams. On this basis the Furbogh Woods pNHA lies in a separate sub catchment to the proposed road development, and is not considered further in this assessment.

Kiltullagh Turlough pNHA lies near Galway Airport, 2.5km east of the proposed road development. The turlough lies within the Clarinbridge GWB at an elevation of approximately 10m OD. Based on the groundwater levels recorded for the environmental studies for the proposed road development (refer to **Section 10.3.2**) the groundwater flow direction is southwards towards Galway Bay. On this basis, although Kiltullagh Turlough NHA is topographically low, it is located 2.5km upgradient of the proposed road development and is not considered further.

Lough Corrib NHA and Galway Bay Complex NHA receive groundwater from the Galway Granite Batholith and the Visean Undifferentiated Limestone that the proposed road development traverse. Both the Lough Corrib NHA and Galway Bay Complex NHA has a ranking of 'Very High' importance in line with TII Guidelines.

In summary, the following National sites are considered receptors for the proposed road development:

- Moycullen Bogs NHA (Lough Inch/Na Foraí Maola Thair, Tonabrocky and Letteragh)
- Galway Bay Complex pNHA
- Lough Corrib pNHA

A breakdown of the groundwater bodies that contribute to those NHA identified above to be included in the evaluation of impacts are summarised below in **Table 10.14**.

Table 10.14: Summary of groundwater bodies traversed by the proposed road development that contribute to National Heritage Areas (NHA) and proposed National Heritage Areas (pNHA)

Groundwater Body	Lough Corrib pNHA	Galway Bay Complex pNHA	Moycullen Bogs NHA	Moycullen Bogs at Tonabrocky NHA	Moycullen Bogs at Letteragh NHA
Spiddal GWB	-	Contributes	Contributes	Contributes	Contributes
Maam Clonbur GWB	Contributes	Contributes			Contributes
Ross Lake GWB	Contributes	Contributes	-	-	-
Lough Corrib Fen 1 (Menlough) GWB and Lough Corrib Fen 1 (Lackagh) GWB	Contributes	Contributes	-	-	-
GWDTE Lough Corrib Fen 2 GWB	Contributes	Contributes	-	-	-
GWDTE Lough Corrib Fen 3 & 4 GWB	Contributes	Contributes			
Clare-Corrib GWB	Contributes	Contributes	-	-	-
Clarinbridge GWB	-	Contributes	-	-	-

Annex I habitats

In addition to the European sites, **Chapter 8, Biodiversity** details Annex I water dependant habitat that are outside of the European site boundaries. These habitat names are listed in **Table 10.15** below (refer to **Chapter 8, Biodiversity** for further details on the habitat). The locations of Annex I habitat are presented on **Figure 10.5.002**.

Table 10.15: Annex I water dependant habitat

Annex I habitat code	Habitat name
4010	Wet heath
6410	Molinia meadows
6430	Hydrophilous tall herb
*7130/7130	Blanket bog (active*)
7140	Transition mires
7150	Rhynchosporion depressions
*7210	Cladium fen*
*7220	Petrifying Springs*
7230	Alkaline fens
*8240	Limestone pavement*
*91E0	Residual alluvial forests*
*3180	Turloughs*

Notes: Denotes a priority habitat*

On the Galway Granite Batholith, the Annex I habitats outside of European and National sites include wet heath, blanket bog and Molinia Meadows. On the Visean Undifferentiated Limestone the Annex I habitats outside of European and National sites include Turloughs, Limestone pavement, Petrifying springs. Annex I habitats are ranked as having a 'Very High' importance, and unless shown to be beyond the potential zone of contribution, are considered in the evaluation of impacts assessment.

Like the Moycullen Bogs, as described in the section on NHA, the surface water ponding within wetland sites on the Galway Granite Batholith are not derived from groundwater, rather that they are caused by ponding above rock head where the rainfall and runoff is perched and trapped by basins in the bedrock topography. These include the following wetlands:

- Wetland habitats in townlands of Na Foraí Maola Thiar (Ch. 0+650 to Ch. 0+750), Na Foraí Maola Thoir (Ch. 1+250 to Ch. 1+500), Troscaigh Thiar (Ch. 1+850 to Ch. 2+400), Bearna (Ch. 2+600 to Ch. 3+100), Aille (Ch. 3+300 to Ch. 3+900) and Ballyburke (Ch. 4+800 to Ch. 5+900)
- Wetland habitats at National University Galway (Ch. 8+800 to Ch. 8+950 and Ch. 9+150 to Ch. 9+250)

Karst features are considered in this section of the assessment based on the water dependent ecology that they support. Three Turloughs (referenced as K20, K31 K72 in the karst database) were identified during the field surveys and their locations are presented in **Figure 10.5.002**. The Turloughs are all located in different groundwater bodies as follows:

- K31 is located in the Lough Corrib Fen 1 (Menlough) GWB

- K20 is located in the Lough Corrib Fen 2 GWB
- K72 is located in the Clare-Corrib GWB

Turlough K31 is crossed to the proposed road development and in this regard is included as a receptor in the evaluation of impacts.

Turlough K20 is located 425m north of the proposed road development in an adjacent GWB. Although in a separate GWB, the feature lies within 250m of the groundwater divide between Lough Corrib Fen 1 (Menlough) and Lough Corrib Fen 2, and as such is included as a receptor in the evaluation of impacts.

Turlough K72 is located in the same groundwater body as the proposed road development albeit 500m up-gradient of it. Turlough K72 is included as a receptor in the evaluation of impacts.

Limestone pavement is also considered in this section as it is present in the region between Lackagh Quarry and Menlough (**Chapter 8, Biodiversity**). Whilst Limestone pavement habitat is not dependent on groundwater it does require the development of a free draining upper zone in the limestone (referred to as epikarst) that rapidly drains rainfall into the aquifer so as not to cause ponding.

Limestone pavement is considered as a hydrogeological receptor as it is susceptible to groundwater level rise and could be impacted if groundwater were to flood the habitat. Limestone pavement is also described as a receptor in both **Chapter 8, Biodiversity** and **Chapter 9, Soils and Geology**. Limestone pavement ecosystems are included as potential hydrogeological receptors.

Lackagh Quarry includes 27 (No.) seepages points, which are mainly located on the northern quarry faces. **Chapter 8, Biodiversity**, classifies six of these seepages as petrifying springs, which have tufa (calcium carbonate) deposition. Hydrogeological observation of all the seepages concludes that all are seasonal and are generally only active between September and May, but they can also activate following prolonged or heavy summer rainfall. All the seepages including the six identified as petrifying springs occur higher than the regional water table. All the seepages occur where karst flow paths through the unsaturated limestone bedrock have been intercepted by the quarry void.

As the petrifying springs are Annex 1 habitats dependant on recharge along karst pathways they ranked as ‘Very High’ in terms hydrogeology.

Non Annex I habitat

A number of locally important ecological habitat, which are dependent on water or hydrogeological characteristics, have been identified and these are included in the **Chapter 8, Biodiversity**. These include a wetland site on the Galway Granite Batholith and calcareous springs in Lackagh Quarry. These features are described in **Chapter 8, Biodiversity**.

The wetland site at Ch. 7+850 is similar in hydrogeological character to the Moycullen Bogs discussed earlier in this section on NHA. The site is located in a topographic hollow in the Galway Granite Batholith where surface water ponds. Often the Galway Granite Batholith forms basins in the rock topography and surface water ponds in these hollows and is slow to drain away. The wetland at Ch.

7+850 is where a fen is located in a hollow on the highest point in the granite topography.

Of the 27 (No.) seepages identifies in Lackagh Quarry a total of 21 (No.) are classified in **Chapter 8, Biodiversity** as being calcareous springs, which is a non-annex 1 habitat. These seepages are seasonal and typically flow between September and may or following prolonged or heavy summer rainfall.

10.3.4.4 Groundwater Dependent Surface Water Features

As presented in the conceptual site model, the study area includes surface water features that are dependent on groundwater. These include the River Corrib, Ballindooley Lough, Coolagh Lakes, Turlough K20, Turlough K31, Turlough K72 and Terryland River. It is noted that whilst the Eastern Coolagh Spring has the potential for groundwater contribution, Coolagh Lakes is not dependent on this spring. Coolagh Lakes is however dependent on the Western Coolagh Spring.

Of these the River Corrib, Ballindooley Lough, Coolagh Lakes, Turlough K20, Turlough K31 and Turlough K72 are part of a European sites or Annex I habitat outside of European sites and have been described in previous sections.

Groundwater can contribute to the Terryland River and also the River Corrib via the Terryland River but only during times of a high water table. In this regard groundwater can provide a significant baseflow to the Terryland River but, unusually, only during winter. On the basis that groundwater contributes to the River Corrib which is part of the Lough Corrib cSAC is considered to have an ‘extremely high’ importance rating but only when flow in the Terryland River has reversed its normal flow.

10.3.4.5 Summary

This section has identified all hydrogeological receptors within the study area that have the potential of being impacted by the proposed road development. Hydrogeological receptors are divided in three sub categories, ecosystems, surface water and resources. Those sites and features from each of these three subcategories within the study area are summarised below in **Table 10.16**.

Table 10.16: Ranking of Importance of all hydrogeological features within the project study area

Feature	Location relative to proposed road development	Importance Ranking	Justification
Groundwater Resources			
Poor Bedrock Aquifer (Pl)	Section 1 of proposed road development	Low	Poor Bedrock Aquifer
Regionally Important Aquifer (Rkc)	Sections 2, 3 and 4 of the proposed road development	Very High	Regionally Important Aquifer (Rkc)
Groundwater supplies (Wells and springs)			

Feature	Location relative to proposed road development	Importance Ranking	Justification
Knocknacarra GWS (W50-01)	1km	Medium	Group water scheme supplying up to 50 houses
W50-02	2km	Low	Agricultural / Domestic supply
W50-03 04, 05, 06 and 07	2km	Low	Agricultural / Domestic supply
W50-08	1.4km	Low	Agricultural / Domestic supply
W50-09	0.5km	Low	Agricultural / Domestic supply
W50-10	0km	Low	Agricultural / Domestic supply
W50-11	0.5km	Low	Agricultural / Domestic supply
W50-12	0km	High	Commercial supply 250m^3/d
W50-13 and W50-14	0km	Very High	Commercial supply 2,000m^3/d
W50-15	0km	High	Commercial supply 380m^3/d
W100-01 & 02	0.6km	Low	Agricultural / Domestic supply
W100-03, 04, 05 and 06	0.3km	Low	Agricultural / Domestic supply
W500-01	0.8km	Low	Agricultural / Domestic supply
W1000-01	0.5km	Low	Agricultural / Domestic supply
W1000-02	0.2km	Low	Agricultural / Domestic supply
W1000-03	1.1km	Low	Agricultural / Domestic supply
W1000-04	0.5km	Low	Agricultural / Domestic supply
G50-01	0.1km	Low	Geothermal well
Surface Water Features			
Terryland River	0.6km	Extremely High	Contributes to River Corrib during peak groundwater levels
Ecosystems			
Galway Bay Complex cSAC	0.8km	Extremely High	European site

Feature	Location relative to proposed road development	Importance Ranking	Justification
Inner Galway Bay SPA	1km	Extremely High	European site
Lough Corrib SPA	0km	Extremely High	European site
Lough Corrib cSAC	0km	Extremely High	European site
Ballindooley Lough	0.1km	Extremely High	Supporting feature for Lough Corrib SPA
Moycullen Bogs	0.2km	Very High	National site
Moycullen Bogs (Tonabrocky)	0.3km	Very High	National site
Moycullen Bogs (Letteragh)	0km	Very High	National site
Lough Corrib NHA	0km	Very High	National site
Galway Bay NHA	0.2km	Very High	National site
Turlough K20	0.4km	Very High	Annex 1 habitat
Turlough K31	0km	Very High	Annex 1 habitat
Turlough K72	0.5km	Very High	Annex 1 habitat
Petrifying springs (Lackagh Quarry)	0km	Very High	Annex 1 habitat
Calcareous springs (Lackagh Quarry)	0km	Low	Locally important habitat
Fen Ch. 7+850	0km	Low	Locally important habitat

10.4 Characteristics of the Proposed Road Development

A detailed description of the proposed road development and construction work is provided in **Chapter 5, Description of Proposed Road Development** and **Chapter 7, Construction Activities**. This section outlines the characteristics and activities of the proposed road development which will interact with hydrogeology and hydrogeological receptors.

The elements of the proposed road development that will interact with the hydrogeological environment are those activities that have the capacity to change the groundwater regime in terms of recharge groundwater levels and water quality. These activities could be:

- **Construction:** dewatering of the bedrock aquifer for cuts or structures, accidental spillages of potentially polluting materials etc.
- **Operation:** discharge of road drainage; road cuts intercepting groundwater or structures (tunnels, sealed cuttings) acting as a barrier to flow

The profile of the proposed road development presented in **Figure 10.6.101** to **Figure 10.6.112** shows the locations where the proposed road development is in cutting, fill and at grade as well as showing the location of minimum and maximum groundwater levels for comparison.

Lowering of groundwater levels is referred to as water table ‘draw down’. **Table 10.17** summarises the excavations along each section of the proposed road development and identifies those sections of the proposed road development that will incur drawdown. Based on properties for the aquifers (**Table 10.10**) the maximum drawdown from the cutting is calculated, which is included in **Table 10.17** as a measurement from the footprint of the proposed road development.

With respect to the aquifer types discussed in **Section 10.3.3** the location and extent of excavations can be summarised as:

- Galway Granite Batholith: there are seven road cuttings (**Table 10.17**) namely, EW01, EW02 (three cuttings), EW04, EW07 and EW11. There are bridge structures at Troscaigh (S01/01), Aille (S03/01), Rahoon (S06/01), Letteragh (S07/01), N59 Link Road North and South (S07/02) and the N59 Moycullen Road (S08/02).
- Visean Undifferentiated Limestone: includes EW22, EW25, EW27, EW28 and EW34-35 (combined) (five cuttings) (**Table 10.17**). There are two tunnels, Lackagh Tunnel (S11/01) and Galway Racecourse Tunnel (S14/02) both of which have approaches. Bridge structures comprise of one crossing of the River Corrib (S08/04), one viaduct at Menlough (S10/01) to cross limestone pavement and road bridges for Menlo Castle Boithrin (S09/01), Coolagh Road (S10/02), the N84 Headford Road (S12/01), Wildlife Overpass Castlegar (S12/02), School Road (S13/01), N83 Tuam Road (S13/02), Park Road Link (S14/01), Monivea Road (S15/01) and Coolagh Junction (S16/01 and S16/02).

The maximum depth of the proposed finished road level below ground level for each cut section is presented in **Table 10.17**. The excavation depths for foundations and drainage have a maximum cut depth elevation of 3m below the finished road elevation, which is applied to the full length of the proposed road development. This is an over estimation on the maximum potential cut depth for drainage and foundations.

As outlined **Section 10.4**, the construction schedules for Lackagh Tunnel and the Menlough Viaduct shall accommodate the seasonal groundwater fluctuation so that construction works always occurs above the water table and dewatering in the bedrock aquifer is not required. For this reason, there will be no lowering in groundwater levels at these locations and accordingly the drawdown is represented as ‘0m’ in **Table 10.17**.

Table 10.17: Summary of earthwork (EW) locations for the proposed road development

Feature type	Earth works Ref no.	Approx. Chainage	Length (m)	Max depth of finished road level (m BGL)	Max depth of construction excavation (m BGL)	Depth to peak winter groundwater level (m BGL)	Max groundwater drawdown (m)	Max Zone of influence radius (m) from footprint of the proposed road development
Section 1 Galway Granite Batholith – R336 to N59 Moycullen Road								
Road Cutting	EW01	0+000 – 0+500	500	1.3	4.3	1.1	3	15
Road Cutting	EW02	1+150 – 1+350	200	0.9	3.9	1.9	2	9
Road Cutting	EW02	1+600 – 1+950	350	1.0	4.0	1.1	3	14
Road Cutting	EW02	2+230 – 2+640	410	3.1	6.1	3.6	2	12
Road Cutting	EW04	3+100 – 4+080	980	5.9	8.9	1.5	8	35
Road Cutting	EW07	5+250 – 5+580	330	5.3	8.3	3.4	5	23
Road Cutting Letteragh Junction	EW11	7+600 – 8+280	690	14.4	17.4	5.7	12	54
Section 2 & 3 Visean Limestone Undifferentiated - River Corrib to N83 Tuam Road								
River Corrib Structure (S06/04)	EW15	9+300 – 9+500	200	(Above ground)	(Above ground)	(Above ground)	0	0
Menlough Viaduct (S10/01)	EW17	9+500 – 10+100	600	(Above ground)	(Above ground)	(Above ground)	0	0

Feature type	Earth works Ref no.	Approx. Chainage	Length (m)	Max depth of finished road level (m BGL)	Max depth of construction excavation (m BGL)	Depth to peak winter groundwater level (m BGL)	Max groundwater drawdown (m)	Max Zone of influence radius (m) from footprint of the proposed road development
Western Approach to Lackagh Tunnel	EW19	10+810 – 11+140	350	13.5	16.5	12.2	0	0
Lackagh Tunnel (S11/01)	EW20	11+140 – 11+420	270	Bored tunnel	Bored tunnel	Bored tunnel	0	0
Road Cutting	EW22	11+720 – 11+920	200	24.6	27.6	35.5	0	0
Road Cutting	EW25	12+500 – 12+920	370	7.6	10.6	15.6	0	0
Road Cutting	EW27	13+050 – 13+650	600	12.0	15.0	12.1	3	70
Section 4 N83 Visean Limestone Undifferentiated Tuam Road to existing N6								
Road Cutting	EW28	14+150 – 14+450	300	12.3	15.3	18.6	0	0
Western Approach to Galway Racecourse Tunnel	EW30	14+450 – 14+950	500	11.4	14.4	18.5[*5]	2	14
Galway Racecourse Tunnel (S14/02)	EW31	14+950 – 15+190	240	9.2	12.2	8.9	4	35
Eastern Approach to Galway Racecourse Tunnel	EW32	15+190 – 15+500	310	8.7	11.7	7.8	4	35

Feature type	Earth works Ref no.	Approx. Chainage	Length (m)	Max depth of finished road level (m BGL)	Max depth of construction excavation (m BGL)	Depth to peak winter groundwater level (m BGL)	Max groundwater drawdown (m)	Max Zone of influence radius (m) from footprint of the proposed road development
Road Cutting	EW34-35	16+200 – 17+500	740	6.8	9.8	11.9*6	2	12

Notes:

Structure depths are presented to 10cm. Predicted drawdown and radius are rounded up to nearest 1m.
The maximum depth of proposed road level refers to the finished road level.
Max drawdown depth = Max baseline groundwater level - (max finished road level - 3m over excavation for drains)
*Maximum groundwater level uses maximum groundwater levels measured during the project monitoring period 2015 - 2017 (**Section 10.3.2**) for the chainage with the maximum excavation depth*
Winter water table at eastern end of cutting (Ch. 14+950) has seasonal peak 1.6m higher than max excavation depth
Winter water table at western end of cutting (Ch. 16+200) has seasonal peak 1.3m higher than max excavation depth

The drainage design of the proposed road development is presented in **Chapter 5, Description of the Proposed Road Development**, and is summarised below for the four hydrogeological sections:

- Section 1 – R336 to N59 Moycullen Road: Ch. 0+000 to Ch. 8+850
    - Permeable drains where possible on mainline, side roads and service roads
    - Treated road runoff discharged to surface watercourse (refer to **Chapter 11, Hydrology**) or public sewers
    - Permeable sub-surface groundwater interception drains in road cuttings
- Section 2 - N59 Moycullen Road to River Corrib Ch. 8+850 to Ch. 9+400
    - Sealed drains on mainline, side roads and service roads
    - Discharge of road runoff to River Corrib (refer to **Chapter 11, Hydrology**)
- Section 3 - River Corrib to N83 Tuam Road Ch. 9+400 to Ch. 14+000
    - Sealed drains on mainline, side roads and service roads
    - Discharge of treated road runoff to ground via infiltration basins in the absence of surface water (refer to **Chapter 11, Hydrology**) or public sewers
    - Permeable sub-surface groundwater drains in all cuttings
- Section 4 – N83 Tuam Road to existing N6
    - Sealed drains on mainline, side roads and service roads
    - Discharge of treated road runoff to ground via infiltration basins in the absence of surface water features or public sewers
    - Permeable sub-surface drains in all cuttings

The assessment of the potential impacts that these design elements may have on the hydrogeological environment is presented in **Section 10.5**.

10.5 Evaluation of Impacts

10.5.1 Introduction

The potential impacts on hydrogeology receptors from the proposed road development are presented in this section. An assessment of potential impacts for the construction phase is presented in **Section 10.5.3** and during the operation phase in **Section 10.5.4**.

Hydrogeological receptors within the study area are listed and ranked for importance in **Section 10.3.3** for each of the four hydrogeological sections. A summary of these rankings is presented in **Table 10.16**.

This section ranks the Magnitude and Significance of any potential hydrogeological impacts in line with TII Guidelines. Where hydrogeological impacts are predicted then these are also assessed for interaction with other aspects of the environment, most notably Biodiversity, Soils and Geology, Hydrology and Material Assets.

10.5.2 Do-Nothing Scenario

In the absence of the proposed road development then the baseline hydrogeological environment will remain as presented in **Section 10.3**.

10.5.3 Construction Phase

Construction activities can interact with hydrogeological receptors by changing the groundwater regime that a receptor is dependent upon. The potential impacts outlined in this section are pre-mitigation. Mitigation measures are described in **Section 10.6** and residual impacts post mitigation are outlined in **Section 10.7**.

There are a number of ways the hydrogeological environment may potentially be impacted during the construction phase and these include:

- the removal of the aquifer during excavations
- changes in recharge characteristics
- changes in groundwater levels
- changes in water quality

These potential changes to the groundwater regime are considered here and the interaction of these changes on receptors are considered below for groundwater resources (**Section 10.5.1**), groundwater supplies (**Section 10.5.2**), groundwater dependant habitats (**Section 10.5.3**) and groundwater contributions to surface water (**Section 10.5.4**).

Removal of part of the aquifer occurs in cut sections where saturated rock is removed. Those cuttings that intercept groundwater will lead to a reduction in groundwater level, the aquifer saturated thickness and the aquifer unsaturated thickness for the cutting footprint. If groundwater is not intercepted, then there will only be a reduction in the unsaturated thickness.

The concept of recharge is explained in **Section 10.3**. During construction where vegetation is removed then there will be an increase in the quantity of effective rainfall available to recharge to ground or runoff as surface water. Where vegetation is removed then there typically is an increase in the quantity of runoff. Any potential impacts of this on the identified receptors are discussed further below where relevant.

Groundwater levels will be lowered by dewatering of the bedrock aquifer during the construction phase of the proposed development for those elements of the road being constructed below the water table. These include road cuttings and construction phase excavations for drainage (attenuation ponds, infiltration ponds, stream realignment) as well as excavations for structures including bridges, viaducts, tunnels and underpasses. This section of the report outlines how the groundwater levels will change during the construction phase. The potential impacts on specific receptors are discussed below, which also includes potential impact on groundwater levels from the interception of karst pathways during construction.

The drawdown extents are presented in **Figure 10.7.101** to **Figure 10.7.114** for the construction phase for the full dataset (road cuttings and drainage excavations combined). A summary extract of the drawdown extents at individual road cuttings (road cuttings and drainage excavations combined) are presented below in **Table 10.17**. The Zone of Influence (ZoI) of the cutting / dewatering location is the area within which groundwater levels are affected by dewatering of the bedrock aquifer – outside of this area groundwater levels will remain at their natural level. The ZoI is presented as a radius on either side of the proposed road development, which is calculated using the upper range of aquifer properties and the hydraulic gradient of the water table. The detailed calculations are presented in **Appendix A.10.6** and summarised in **Table 10.17**. The assessment of drawdown is conservative as it assumes that drainage excavation extends across the full width of the footprint of the proposed road development, when in reality the excavations only extend part of the way.

In summary, **Table 10.17** identifies that groundwater levels will be lowered during the construction phases at the following sections:

- Section 1 (Galway Granite Batholith): EW01, 02 (three cuttings), 04, 07 and 09. EW11 includes the N59 Link Road North and South
- Sections 2 - 4 (Visean Undifferentiated limestone): EW27 and Galway Racecourse Tunnel and its approaches. The dewatering of the bedrock aquifer in EW27 will only be required seasonally

The quality of groundwater is potentially at risk during construction and activities on site are managed in accordance with guidelines to ensure that this potential risk managed appropriately. Risk to groundwater quality derives from the following main sources:

- storm runoff, which can have high turbidity
- occurrence of karst, which can lead to point recharge input to the aquifer
- Accidental spillages of polluting materials on site
- Vandalism

The above risks are assessed for receptors in the below **Section 10.5.3.1** to **Section 10.5.3.4**. Management of the above risks are dealt with by mitigation measures, which are detailed in **Section 10.6**.

10.5.3.1 Potential Impact to Groundwater Resources

The potential impact assessment on the groundwater resources during the construction phase considers the impact that the changes in the groundwater regime and groundwater quality have on the characteristics of the two aquifers. The potential impacts on each of these aquifers is assessed below.

10.5.3.1.1 Galway Granite Batholith (Section 1)

In line with TII guidance, the magnitude of the impact on the aquifers within the study is based on the portion of the aquifer that will be removed. The Pl Galway

Granite Batholith is 2,378km^2 (2,378,000,000m^2) in size (GSI Groundwater data viewer) and 1,000m thick (Pracht, 2015), giving an aquifer volume of 2,824,800,000,000m^3.

As outlined in **Chapter 9, Soils and Geology**, 905,345m^3 of granite will be excavated for the construction of the proposed road development. This volume is a very small percentage of the aquifer volume and for this reason, in line with TII rating, the Magnitude of the impact on the aquifer is Negligible and the Significance of the impact is Imperceptible.

Section 10.5.3 highlights that changing the recharge characteristics has the potential to impact the aquifer. GSI data indicates that the recharge rate to the Galway Granite Batholith is 100mm/yr (**Table 10.5**) and this will not change during construction. In line with TII rating, the Magnitude of the impact on the aquifer from changing recharge is Negligible and the Significance of the impact is Imperceptible.

Changing groundwater levels during construction activities may affect the aquifer characteristics. Eight locations have been highlighted in **Section 10.5.3** where groundwater levels will be lowered locally during construction.

Table 10.17 presents the Zone of Influence (ZoI) for each of these, which is the area away from the proposed road development within with groundwater levels will be lowered during construction. The largest drawdown ZoI occurs at the N59 Letteragh Junction (EW11). Based upon the assessment undertaken (**Appendix A.10.6**) the drawdown at this junction will extend for up to 54m from the edge of the footprint of the proposed road development.

Owing to the low aquifer properties of the Galway Granite Batholith the expected inflows from the construction are expected to be low. During construction the quantities of water intersected will initially be higher as the groundwater storage in the bedrock is tapped into, when the storage has been drained then the quantities that are intercepted will relate to recharge within the ZoI. Groundwater intercepted during construction will remain within the surface water catchment that they would naturally have been received by.

This, along with the minimal influence of the construction activities on the proposed road level indicates that, in line with TII rating, the Magnitude of the impact on the aquifer from changing groundwater levels is Negligible and the Significance of the impact is Imperceptible.

As outlined in **Section 10.5.3** suspended solids in site runoff is the prime concern with pollution from accidental spillages or vandalism also being a risk. Based on the recharge cap of 100mm more than 90% of the effective rainfall during construction will remain overland flow and will not recharge to ground. Spillages, accidental or by vandalism, the low infiltration rate will promote runoff rather than infiltration.

Pollutants that do infiltrate to ground will have limited mobility and will be limited to the construction footprint. On this basis the risk to the groundwater in the Galway Granite Batholith is limited to the construction footprint and not beyond it. In the unlikely event of significant flow paths (fault or fracture zones) being encountered during construction, then these shall be mitigated against using the same methodology as the Karst Protocol (refer to **Section 10.6**). The ZoI for construction phase pollution risk is presented for the Galway Granite Batholith in **Figure 10.7.101** to **Figure 10.7.105**.

The balance of rock excavated in cuttings and used for embankments and fill calculates a surplus of granite but a deficit of limestone. Due to the chemically inert nature of granite, if it is transported and used on embankments in limestone areas then there is no water quality concerns in terms of hydrogeology.

If any of these unplanned activities which have the potential to impact water quality occur, these have the potential to contaminate groundwater. In line with TII guidance, the magnitude of this potential impact on the aquifer is Moderate Adverse and the significance Significant / Moderate.

10.5.3.1.2 Visean Undifferentiated Limestone (Sections 2, 3 & 4)

In line with TII guidance, the magnitude of the impact on the aquifers within the study is based on the portion of the aquifer that will be removed. The Rkc Visean Undifferentiated Limestone aquifer is 7,062km^2 (7,062,000,000m^2) in size (GSI Groundwater data viewer) and 400m thick (Pracht, 2015), giving an aquifer volume of 2,824,800,000,000m^3.

As outlined in **Chapter 9, Soils and Geology**, 2,096,175m^3 of limestone will be excavated for the construction of the proposed road development. This volume is a very small percentage of the aquifer volume and for this reason, in line with TII rating, the Magnitude of the impact on the aquifer is Negligible and the Significance of the impact is Imperceptible.

Section 10.5.3 highlights that changing the recharge characteristics has the potential to impact the aquifer. The effect of an increased recharge in areas where vegetation has been removed may cause a groundwater rise below the footprint of the proposed road development due to an increase in recharge. Based on the baseline recharge quantities listed in **Table 10.5**, and the increase in recharge/runoff being equal then recharge is estimated to rise to 705- 803mm/yr and runoff to 447-545 mm/yr. Using these estimations there will be a temporary increase in winter groundwater levels of up to 0.1m during the construction period (**Appendix A.10.6**).

Where infiltration basins are used to discharge runoff during the construction period then there will be modest temporary rises in groundwater level at these locations, of up to approximately 0.4m. Calculations for the estimated groundwater level rise are presented in **Appendix A.10.6**).

In conclusion, the removal of vegetation will increase effective rainfall and lead to increases in recharge and runoff in the Visean Undifferentiated Limestone. It is estimated that there will be a temporary rise of up to 0.1m in peak groundwater levels below the construction site.

If karst is intercepted in any of these earthworks or infiltration basin excavations, then there is a risk of point recharge from construction site runoff directly to the aquifer. If karst is encountered during construction then the Karst Protocol will be implemented, which is a project specific procedure that is detailed in the Construction Environmental Management Plan (CEMP) (refer to **Appendix A.7.5**) and also presented in **Section 10.6 Mitigation Measures**.

For those sections of the aquifer which will not be subject to the influence of dewatering, in line with TII rating, the Magnitude of the impact on the aquifer from changing recharge rates is Negligible and the Significance of the impact is Imperceptible as the increases will not lead to groundwater flooding.

Changing groundwater levels during construction activities may affect the aquifer characteristics. Three locations have been highlighted in **Section 10.5.3** where groundwater levels will be lowered locally during construction.

Table 10.17 presents the ZoI for each of these, and this is the area away from the proposed road development within with groundwater levels will be lowered during construction. However, it should be noted that due to the design of the proposed road development, where dewatering of the bedrock aquifer will not be undertaken in the most sensitive areas, the drawdown and zones of influence associated with the construction impacts are relatively small.

For example, the largest ZoI in the Visean Undifferentiated Limestone will be observed in EW27 which lies west of the N83 Tuam Road. The groundwater levels recorded in this part of the Clare-Corrib GWB show a seasonal variation of 9m (ref BH3/34) and based on the design elevations for the cutting (refer to **Figure 10.6.108**) then groundwater has the potential to enter the cutting only during peak winter water levels. The impact from the dewatering of the bedrock aquifer is localised around the cutting and calculated to have a maximum lateral extent of 70m (**Table 10.17**), which is calculated using the upper range of permeabilities measured from testing. In line with TII rating, the Magnitude of the impact on the aquifer from changing groundwater levels is Negligible and the Significance of the impact is Imperceptible.

For a number of the structure excavations concrete is required as part of the foundation construction, which may need to be poured into excavations. There is a risk that poured concrete may enter the aquifer if karst is present in the foundation excavations. If karst is present then the concrete could migrate into the aquifer and potentially block pathways, modifying flow paths to receptors. Of the GWB with karst there are three structures that have a risk to groundwater quality, namely the Corrib Bridge, Menlough Viaduct and Lackagh Tunnel. This risk requires mitigation which is presented in **Section 10.6**. In line with TII rating, the Magnitude of the impact on the aquifer from blocking conduits is High and the Significance of the impact is moderate adverse.

The overburden across the study area consists of glacial till derived from the underlying bedrock. The bedrock changes in Section 2 at the N59 Moycullen Road, from a granite to a limestone bedrock which have different chemical compositions.

If limestone derived material is placed over granite bedrock, surface water run-off or groundwater movements through the material have the potential to impact local areas of peatland habitats by changing the pH of the local groundwater. In line with TII rating, the Magnitude of the impact on the aquifer from placing non-native rock is small and the impact imperceptible. Due to the chemically inert nature of granite, if it is transported and used on embankments on limestone then there are no water quality concerns in terms of hydrogeology.

As outlined in **Section 10.5.3** unplanned discharges such as site runoff with a high proportion of fines / sediment or accidental spillages of fuel, lubricants have the potential to cause groundwater quality to deteriorate.

Unlike the low aquifer properties encountered in the granite, the limestone has a wide range of aquifer properties with zones where conduit flow can occur. Similarly, the Visean Undifferentiated Limestone has a high recharge coefficient when karst is present and in these areas runoff generally recharges to ground rather than becoming overland flow.

These features mean that if potential pollutants enter karst pathways then they can travel significant distances relatively quickly. The groundwater bodies (GWB) that have karst are Ross Lake GWB, Lough Corrib Fen 1 (Menlough) GWB, Lough Corrib Fen 1 (Lackagh) GWB, Lough Corrib Fen 2 GWB and Clare-Corrib GWB.

In the Clarinbridge GWB there are no recorded significant karst features and surface water ponding as well as overland flow occurs during storm events, which is due to the lower recharge rates that are present in this area. Infiltration to ground will diffuse and provide slow pathways to the groundwater table that will naturally promote settlement of fines. In the groundwater there will be significant dilution and some attenuation of any fines.

Earthworks along the proposed road development include areas where the subsoil is removed leaving a reduced thickness of subsoil or exposing the underlying limestone. The removal of subsoil will reduce the natural protection for groundwater and increases the groundwater vulnerability (**Table 10.4**). During construction the excavation of subsoil will increase the risk to groundwater from accidental pollution. The area's most susceptible to pollution are those where the subsoil is already thin, which are the high and extreme areas presented in **Figure 10.7.106** to **Figure 10.7.114**.

Conversely, in the natural environment, recharge to limestone where there is no karst relies in part on storage in the overlying subsoil which provides superficial storage to the fracture flow network in the underlying limestone. In the situation where the subsoil is removed there is an increase in overland flow with recharge significantly reduced. As such, where the limestone bedrock is exposed there will be an increase in runoff except for in zones of weathered limestone or karst (in those GWB with karst). The potential impacts associated with this are discussed in **Chapter 11, Hydrology**.

For the Ross Lake GWB, Lough Corrib Fen 1 (Menlough) GWB, Lough Corrib Fen 1 (Lackagh) GWB, Lough Corrib Fen 2 GWB and the Clare-Corrib GWB where there is a potential for karst and point input of runoff the areas at higher risk of pollution is extended over the full extent downstream of the proposed road development. For the Clarinbridge GWB where aquifer properties are relatively low, this area encompass the full extent of the construction footprint.

Infiltration from construction runoff on the Visean Undifferentiated Limestone will occur both on the construction footprint and from infiltration basins. The infiltration basins will be excavated at the construction stage to allow their use during construction. These may act as a source of point contamination to the karst. In line with TII rating, the Magnitude of the potential impact on the water quality of the aquifer is high and the Significance of the impact is moderate adverse.

Hydrogeological mitigation measures are required to control runoff to limit the potential impacts of accidental discharges to groundwater quality during construction. These are outlined in **Section 10.6**.

10.5.3.2 Potential Impacts to Groundwater supplies

A number of groundwater abstractions which may be impacted by the proposed road development were identified in **Section 10.3.4.3**. If groundwater levels at supply wells were lowered due to construction dewatering of the bedrock aquifer, or the groundwater quality at these wells was impacted, it could render the wells unusable. For the case of geothermal wells, a reduction in groundwater level can reduce the heat supply if the well relies on groundwater for thermal conductance.

The potential impact of construction dewatering of the bedrock aquifer on the wells can be assessed by comparing the well locations to the drawdown zone of influence. If the wells are located within the zone of influence, then by the precautionary principle it is assumed that they will be impacted by dewatering of the bedrock aquifer.

The first consideration for water supply wells is to assess whether the water quality at a well will be impacted by construction activities, which depends on whether a well is up- or down-gradient of the proposed road development. If a well is up-gradient of the proposed road development, it cannot be impacted by any potentially polluting materials at the proposed road development.

If a well is down-gradient, then the travel time of any contamination to that well should be considered. The GSI determine the inner Source Protection Area as the area within which human activities may have an immediate effect on the source and it is defined by the 100-day time of travel (TOT) from any point below the water table to the source.

The 100-day TOT has been calculated for each well down-gradient of the proposed road development to determine if it may potentially be impacted.

There is one well in the granite down-gradient of the proposed road development. Based on maximum locally measured permeability of $4.6x10^{-7}$m/s [4], the distance which defines the 100-day TOT for this well is 80m.

There are 10wells in the limestone down-gradient of the proposed road development. Based on maximum locally measured permeability of $3.1x10^{-5}$m/s[4] for the Menlough and Ballindooley area and maximum locally measured permeability of $1.7x10^{-6}$m/s[4] for the Ballybrit to Briarhill area, then the distance

[4] This has been calculated based on the hydraulic conductivity rather than the average linear velocity. Using hydraulic conductivity to determine 100-TOT is considered to be more conservative.

which defines the 100-day TOT for these is 1,500m and 500m respectively (rounded up).

It should be noted that this is a highly conservative assessment as the 100-day TOT was derived based on the likelihood of microbial contamination. These contaminants are more mobile than those associated with road runoff, however, the resultant distance indicates the maximum travel distance in 100 days and allows an informed decision on whether there is any potential for the well to be impacted.

The assessment of the potential impacts on each individual well has been summarised in **Table 10.18**.

Table 10.18: Impact assessment of wells within the study area (pre-mitigation)

Feature	Location relative to radius of influence	Position relative to proposed road development	Within 100-day TOT of the well?	Potential impact	Magnitude of impact	Significance of impact
Knocknacarra GWS (W50-01)	Outside the zone of influence	Down-gradient	No	None	No Impact	N/A
W50-02	Outside the zone of influence	Down gradient	No	None	No Impact	N/A
W50-03 04, 05, 06 and 07	Outside the zone of influence	Down gradient	No	None	No Impact	N/A
W50-08	Outside the zone of influence	Down gradient	No	None	No Impact	N/A
W50-09	Outside the zone of influence	Up gradient	N/A	None	No Impact	N/A
W50-10	Inside the zone of influence	Below footprint of proposed road development	Yes	Well will be lost	Large adverse	Slight / moderate
W50-11	Outside the zone of influence	Down gradient	No	None	No Impact	N/A
W50-12	Inside the zone of influence	Below footprint of proposed road development	Yes	Well will be lost	Large adverse	Profound / Significant

Feature	Location relative to radius of influence	Position relative to proposed road development	Within 100-day TOT of the well?	Potential impact	Magnitude of impact	Significance of impact
W50-13 & W50-14	Inside the zone of influence	Below footprint of proposed road development	Yes	Both wells will be lost	Large adverse	Profound
W50-15	Inside the zone of influence	Below footprint of proposed road development	Yes	Well will be lost	Large adverse	Profound / Significant
W100-01 & 02	Outside the zone of influence	Down gradient	No	None	No Impact	N/A
W100-03, 04, 05 and 06	Outside the zone of influence	Up gradient	N/A	None	No Impact	N/A
W500-01	Outside the zone of influence	Down gradient	No	None	No Impact	N/A
W1000-01	Outside the zone of influence	Up gradient	N/A	None	No Impact	N/A
W1000-02	Outside the zone of influence	Down gradient	Yes	Potential water quality deteriorati on	Moderate adverse	Slight
W1000-03	Outside the radius of influence	Down gradient	No	None	No Impact	N/A
W1000-04	Outside the radius of influence	Down gradient	No	None	No Impact	N/A
G50-01 (Geothermal well)	Outside the radius of influence	Up gradient	N/A	None	No impact	N/A

This assessment highlights that five wells (W50-10, W50-12, W50-13, W50-14 and W50-15) will be permanently impacted. Accordingly, these will be removed as part of the proposed road development and decommissioned based on IGI (2007) and EPA (2013) guidelines.

One well (W1000-02) has a potential risk for water quality deterioration as it lies down gradient and within the 100-day TOT from the proposed road development.

10.5.3.3 Potential Impacts to Groundwater Dependent Terrestrial Ecosystems (GWDTE)

This section assesses potential impact to groundwater dependent habitats and limestone pavement habitat from the construction phase of the proposed road development. Ecosystems may be potentially impacted through accidental contamination of the groundwater which supports them, the alteration of groundwater levels and/or the reduction in the groundwater contribution to the ecosystem. The characteristics which determine the potential impact are:

- The proximity to the feature
- The level of hydraulic connection between the feature and the section of aquifer at the proposed road development i.e. is the feature in the same aquifer unit as the proposed road development, or is there a hydraulic divide between the feature and the proposed road development
- The groundwater flow direction in the vicinity
- The level of cut of the proposed road development, which may determine the degree of variation in the groundwater level and also the extent of dewatering which may occur
- The water quality of the feature and the groundwater from which it receives its baseflow

Those receptors which need an impact assessment have been identified in **Section 10.3.4.2**. Ecosystem receptors comprise of European sites (cSAC and SPA), National sites (NHAs and pNHAs) and Annex I habitats.

It should be noted that this chapter identifies the potential impacts to the hydrogeology that supports these ecological features and does not assess the Magnitude and Impact Significance of the habitats themselves, which is presented in **Chapter 8, Biodiversity** based on the information provided here.

European Sites

Four European sites have been identified as receiving groundwater from groundwater bodies that are traversed by the proposed road development. These include:

- Lough Corrib cSAC
- Lough Corrib SPA
- Galway Bay Complex cSAC
- Inner Galway Bay SPA

Ballindooley Lough is also included in this assessment as it supports the wintering birds of the Lough Corrib SPA and Galway Bay SPA but also includes Annex 1 habitat on the fringe of the lough. The receiving environment of Ballindooley Lough has been discussed in detail in **Section 10.3.3.2**.

The discussion of the characteristics of the Galway Granite Batholith in **Section 10.5.3.1.1** outlines the zones of influence for dewatering of the bedrock aquifer and the areas vulnerable to contamination. Based on these there will be no impact either from drawdown or water quality impacts from the proposed road development to European sites.

The discussion of the characteristics of the Visean Undifferentiated Limestone in **Section 10.5.3.1.2** outlines the zones of influence for dewatering of the bedrock aquifer and interception of karst pathways as well as the areas vulnerable to contamination.

For the Visean Undifferentiated Limestone, the drawdown zones of influence do not impact on any European sites or Ballindooley Lough. However, this section of the report provides additional detail on the construction in order to relate the conceptual model to any potential impacts that may arise during construction.

The Western Approach to Lackagh Tunnel (EW19) and Lackagh Tunnel (EW20) are discussed in the Lackagh Tunnel Appraisal Report, which is included in **Chapter 7, Construction Activities**. The hydrogeological setting of the Western Approach to Lackagh Tunnel (EW19) and Lackagh Tunnel (EW20) are located at the groundwater divide between Lough Corrib Fen 1 (Menlough) and Clare-Corrib GWBs.

Due to the dependency of Coolagh Lake (part of the Lough Corrib cSAC) on Western Coolagh Spring the design excludes dewatering of the bedrock aquifer within this spring's catchment. Based on the mapping of groundwater levels (refer to **Figure 10.6.008**) this catchment encompasses the area Ch. 9+700 and Ch. 11+500.

Dewatering of the bedrock aquifer will not be permitted during construction so there is no reduction in groundwater flow transmitted by these pathways through the aquifer to the Western Coolagh Spring. By not dewatering, the boundary between Clare-Corrib GWB and Lough Corrib Fen 1 (Menlough) will not be impacted. All construction works will remain above the groundwater table for the duration of the works to ensure the groundwater table is not intercepted and dewatering of the bedrock aquifer is not required.

On this basis there will be no drawdown in the Western Approach to Lackagh Tunnel (EW19) and Lackagh Tunnel (EW20) and therefore no impact to the groundwater divide between the Lough Corrib Fen 1 (Menlough) GWB and the Clare-Corrib GWB or to the Lough Corrib cSAC.

In addition, as detailed in the Karst Protocol (refer to CEMP **Appendix A.7.5**), if karst conduits are encountered during the excavation of structure foundations, concrete poured in these may block the conduits. This may affect the hydrogeological regime of the groundwater body feeding the ecological receptors. Mitigation measures for this are presented in **Section 10.6**.

The bridge over the River Corrib (EW15) requires excavations on the east and west shore to install piers. These excavations will extend below the groundwater table and will require dewatering to enable dry working conditions. As the eastern excavations occur on the margins of the Lough Corrib Fen 1 (Menlough) GWB with the River Corrib, there is no potential for impact to Western Coolagh Spring, which is up-gradient of the location.

There are European sites that receive groundwater from GWB with karst pathways that the proposed road development traverses. These GWB and the European sites they contribute to are listed below:

- Lough Corrib Fen 1 (Menlough) GWB, from groundwater flowing westwards to Western Coolagh Spring and the River Corrib (Lough Corrib cSAC). Water emergent from Western Coolagh Spring is the main contribution to Coolagh Lakes.
- Clare Corrib GWB, from groundwater flowing southwards to Galway Bay. This also includes emergent groundwater to the Terryland River during times of high groundwater levels, which flows to the River Corrib (Lough Corrib cSAC). Groundwater contribution from Clare-Corrib GWB provides a minor component of flow to Galway Bay or River Corrib.

The extent of the area where contamination may extend to is caused by the potential presence of karst which could allow pathways to carry pollutants from the construction site or infiltration basins to receptors. Mitigation has been developed to accommodate potential karst and these are detailed in **Section 10.6**.

Ballindooley Lough is up gradient of the proposed road development and as such not considered to be at risk from pollution.

National Heritage Areas

Three National Heritage Areas have been identified as receiving groundwater from groundwater bodies that are traversed by the proposed road development. These include:

- Moycullen Bogs NHA (including Tonabrocky and Letteragh)
- Galway Bay Complex pNHA
- Lough Corrib pNHA

The hydrogeological assessment undertaken in **Section 10.5.3** identified a zone of influence for drawdown and an area more prone to potential pollution.

Based on the zones of influence extent for the Galway Granite Batholith, there will be no impact either from drawdown or water quality impacts from the proposed road development to NHA receptors. The Moycullen Bog at Letteragh is close to the proposed road development however, the calculated drawdown does not extend as far as the habitat. Moycullen Bog at Letteragh lies upgradient of the proposed road development and as such there is no risk of pollution.

For the Visean Undifferentiated Limestone the drawdown zones of influence do not impact on any NHA receptors. The zone of influence for water quality at the Clarinbridge GWB shows no impact to NHA receptors. However, the areas which may be prone to potential pollution shows a potential groundwater impact for:

- Lough Corrib Fen 1 (Menlough) westwards to Western Coolagh Spring and the River Corrib (Lough Corrib NHA)
- Clare Corrib GWB southwards to Terryland River, which flows to the River Corrib (Lough Corrib NHA) during times of high groundwater levels

The extent of the area where contamination may extend to is caused by the potential presence of karst which could allow pathways to carry pollutants from the construction site to receptors. Mitigation has been developed to accommodate potential karst and these are detailed in **Section 10.6**.

Annex I habitats

A number of Annex I habitats have been identified as water dependant and are located on groundwater bodies that are traversed by the proposed road development and are listed below:

- Wetland habitats in townlands of Na Foraí Maola Thiar (Ch. 0+650 to Ch. 0+750), Na Foraí Maola Thoir (Ch. 1+250 to Ch. 1+500), Troscaigh Thiar (Ch. 1+850 to Ch. 2+400), Bearna (Ch. 2+600 to Ch. 3+100), Aille (Ch. 3+300 to Ch. 3+900) and Ballyburke (Ch. 4+800 to Ch. 5+900)
- Wetland habitats at National University Galway (Ch. 8+800 to Ch. 8+950 and Ch. 9+150 to Ch. 9+250)
- Turlough K31 is located in the Lough Corrib Fen 1 (Menlough) GWB
- Turlough K20 is located in the Lough Corrib Fen 2 GWB
- Turlough K72 is located in the Clare-Corrib GWB
- Petrifying springs, located on the northern face of Lackagh Quarry
- Wetland habitats at Terryland River

The zone of influence for drawdown shows that impacts from groundwater lowering will occur to the Annex I habitats within the townlands of Na Foraí Maola Thiar (Ch. 0+650 to Ch. 0+750), Na Foraí Maola Thoir (Ch. 1+250 to Ch. 1+500), Troscaigh Thiar (Ch. 1+850 to Ch. 2+400), Bearna (Ch. 2+600 to Ch. 3+100), Aille (Ch. 3+300 to Ch. 3+900) and Ballyburke (Ch. 4+800 to Ch. 5+900).

Wetland habitats at NUIG Sporting Campus lie downgradient and upgradient of the proposed road development. Neither habitat at NUIG Sporting Campus lies within the drawdown ZOI, however, the habitat to the south, which lies downgradient, has the potential to be impacted from pollution.

Turlough K31 also lies within the footprint of the proposed road development but as it is traversed as part of the Menlough Viaduct. As the viaduct can be constructed without dewatering of the bedrock aquifer there will be no impact from groundwater lowering at turlough K31.

The extent of the area identified as being prone to potential pollution shows that Turlough K31 lies within this area but that Turloughs K20 and K72 lie beyond it. The potential impacts to Turlough K31 derive from the potential of karst being encountered during construction and as such pollution from the site draining to ground, and the turlough.

Petrifying springs have been included in **Chapter 8, Biodiversity** as occurring on the western face of the inactive Lackagh Quarry. The Petrifying springs occur as seepages that are located above the regional groundwater table, which occur from small pathways in the limestone bedrock that are fed by recharge. The source area for the seepages is the limestone pavement immediately north and west of Lackagh Quarry. These seepages have developed from the excavation of the quarry. Rock bolting is proposed to stabilise the quarry face at the eastern portal of Lackagh Tunnel in Lackagh Quarry. Rock bolting will have an insignificant impact on recharge pathways through the unsaturated zone. Concreting will not be part of the face stabilisation works.

Wetland habitats associated with the Terryland River are located on thick low permeability subsoils. The water dependence of these habitats is derived from water ponding on the surface rather and are therefore not groundwater dependant.

Local Ecosystems

A number of local ecosystems are identified in the **Chapter 8, Biodiversity** that are water dependant and these include a wetland site on the Galway Granite Batholith at Ch. 8+850 and quarry wall seepages in the Visean Undifferentiated Limestone in Lackagh Quarry that have calcareous springs.

Based on the zone of influence for draw down, the wetland site at Ch. 8+850 will be impacted by the drawdown and its southern margin where the groundwater level will lower during construction.

The calcareous spring locations identified in Lackagh Quarry are all located above the groundwater table and mainly in the western quarry face. All seepages occur above the water table and occur from recharge within the unsaturated zone. The proposed road development will not impact on water quality.

Summary

The hydrogeology of ecological receptors with dependence on groundwater have been assessed (in the absence of mitigation measures) for the construction phase of the proposed road development. The assessment takes into account receptors within the study area for both the drawdown zone of influence and areas which are potentially vulnerable to pollution. **Table 10.19** below provides a summary of the ecological receptors and identifies those that lie within the drawdown zone of influence and those areas that lie down gradient of the proposed road development and are at risk from pollution.

The magnitude and significance of hydrogeological impacts refer to potential changes in groundwater quantity and/or quality at the European or National site or groundwater dependent Annex I habitat. The assessment in accordance with TII Guidelines. For assessment on ecological impacts as a consequence of these potential hydrogeological impacts, please refer to **Chapter 8, Biodiversity**.

Table 10.19: Summary of potential hydrogeological impacts at GWDTE during construction phase (pre-mitigation)

Feature	Potential Impact to Groundwater Level	Potential Impact to Groundwater Quality	Magnitude of Hydrogeology Impact	Significance of Hydrogeology Impact
European Union sites				
Galway Bay Complex cSAC	Potential temporary quantity deterioration of groundwater in karst pathways to Galway Bay. The groundwater contribution from GWB is of insufficient magnitude to affect integrity	Potential temporary quality deterioration of groundwater in karst pathways to Galway Bay. The groundwater contribution from GWB is of insufficient magnitude to affect integrity	Negligible	Insignificant
Inner Galway Bay SPA	Potential temporary quantity deterioration of groundwater in karst pathways to Galway Bay. The groundwater contribution from GWB is of insufficient magnitude to affect integrity	Potential temporary quality deterioration of groundwater in karst pathways to Galway Bay. The groundwater contribution from GWB is of insufficient magnitude to affect integrity	negligible	Insignificant
Lough Corrib cSAC	Potential temporary quantity deterioration of groundwater in karst pathways within contributing GWB would lead to impact at Western Coolagh Spring, which is the main water contribution for Coolagh Lakes	Potential temporary quality deterioration of groundwater in karst pathways within contributing GWB would lead to impact at Western Coolagh Spring, which is the main water contribution for Coolagh Lakes	Large Adverse	Profound
	The groundwater contribution from GWB to River Corrib is of insufficient magnitude to affect integrity	The groundwater contribution from GWB to River Corrib is of insufficient magnitude to affect integrity	Negligible	Insignificant

Feature	Potential Impact to Groundwater Level	Potential Impact to Groundwater Quality	Magnitude of Hydrogeology Impact	Significance of Hydrogeology Impact
Lough Corrib SPA	No (upgradient of the proposed road development)	No (upgradient of the proposed road development)	N/A	N/A
Ballindooley Lough	No (upgradient of the proposed road development)	No (upgradient of the proposed road development)	N/A	N/A
National Heritage Sites				
Moycullen Bogs (Lough Inch/Na Foraí Maola Thair)	No (upgradient of the proposed road development)	No (upgradient of the proposed road development)	N/A	N/A
Moycullen Bogs (Tonabrocky)	No (upgradient of the proposed road development)	No (upgradient of the proposed road development)	N/A	N/A
Moycullen Bogs (Letteragh)	No (upgradient of the proposed road development)	No (upgradient of the proposed road development)	N/A	N/A
Lough Corrib NHA	Potential temporary quantity deterioration of groundwater in karst pathways within contributing GWB would lead to impact at Western Coolagh Spring, which is the main water contribution for Coolagh Lakes	Potential temporary quality deterioration of groundwater in karst pathways within contributing GWB would lead to impact at Western Coolagh Spring, which is the main water contribution for Coolagh Lakes	Large Adverse	Significant
	The groundwater contribution from GWB to River Corrib is of insufficient magnitude to affect integrity	The groundwater contribution from GWB to River Corrib is of insufficient magnitude to affect integrity	Negligible	Insignificant
Galway Bay NHA	Potential temporary quantity deterioration of groundwater in karst pathways to Galway Bay. The	Potential temporary quality deterioration of groundwater in karst pathways to Galway Bay. The groundwater contribution from	Negligible	Insignificant

Feature	Potential Impact to Groundwater Level	Potential Impact to Groundwater Quality	Magnitude of Hydrogeology Impact	Significance of Hydrogeology Impact
	groundwater contribution from GWB is of insufficient magnitude to affect integrity	GWB is of insufficient magnitude to affect integrity		
Annex I habitats (outside of European sites)				
Na Foraí Maola Thiar Ch. 0+650 to Ch. 0+750	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Na Foraí Maola Thoir Ch. 1+250 to Ch. 1+500	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Troscaigh Thiar (Ch. 1+850 to Ch. 2+400)	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Bearna (Ch. 2+600 to Ch. 3+100)	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Aille (Ch. 3+300 to Ch. 3+900)	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Ballyburke (Ch. 4+800 to Ch. 5+900)	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
NUI Galway (Ch. 8+800 to Ch. 8+950	No (upgradient of the proposed road development)	No (upgradient of the proposed road development)	N/A	N/A
NUI Galway (Ch. 9+150 to Ch. 9+250	No Outside of drawdown zone of influence	Within area liable to contamination	Moderate Adverse	Profound / Significant
Turlough K20 (Menlough North East)	No Outside of drawdown zone of influence	No (upgradient of proposed road)	N/A	N/A
Turlough K31 (Menlough East)	No Outside of drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound

Feature	Potential Impact to Groundwater Level	Potential Impact to Groundwater Quality	Magnitude of Hydrogeology Impact	Significance of Hydrogeology Impact
Turlough K72 (Coolagh North)	No Outside of drawdown zone of influence	No (upgradient of proposed road)	N/A	N/A
Petrifying Springs (Lackagh Quarry)	Rock bolts may intersect recharge pathways	No Located above the groundwater table	Negligible	Insignificant
Local habitats				
Fen Ch. 7+850	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Slight / Moderate
Calcareous springs (Lackagh Quarry)	Rock bolts may intersect recharge pathways	No Located above the groundwater table	Negligible	Insignificant

On the basis of the above assessment impacts to groundwater dependant habitat are assessed based on the importance of the hydrogeology attribute and the magnitude of impact. Those features that lie beyond the zone of influence to hydrogeological impacts and away from the area vulnerable to contamination are assessed to have no impact.

10.5.3.4 Hydrogeological Impacts to Groundwater Dependent Surface Water Features

Groundwater contributes to surface water in the study area. In the area of the Galway Granite Batholith, the groundwater contribution is minimal, as evidenced by low baseflow. However, groundwater provides more significant contribution to baseflow in the area of the Visean Undifferentiated Limestone (refer to **Chapter 11, Hydrology**). Whilst, the River Corrib receives most of its contribution from upstream of the study area, surface water features such as Ballindooley Lough, Coolagh Lakes, turlough K20, Turlough K31, Turlough K72 and the Terryland River (during high groundwater levels), are dependent on groundwater. It is noted that whilst the Eastern Coolagh Spring has the potential for groundwater contribution, Coolagh Lakes is not dependent on this spring. Coolagh Lakes is however dependent on the Western Coolagh Spring.

Based on the ZoI for drawdown there will be no reduction in groundwater flow from the Galway Granite Batholith or the Visean Undifferentiated Limestone. Furthermore, for the Galway Granite Batholith those areas highlighted as being vulnerable to potential pollution do not extend to surface water features.

For the Visean Undifferentiated Limestone the areas which have been described as having karst or being highlighted as potentially vulnerable to pollution include surface water features dependant on groundwater. Of these features listed above Ballindooley Lough, Turlough K20, Turlough K72 have been described in **Section**

10.5.3.3 (Potential Impacts to GWDTE). As such, only the Terryland River is described under the heading of hydrogeological impacts to surface water.

The hydrogeology of the Terryland River is described in **Section 10.3.3**, which explains the importance of two estavelles at the eastern end of the river. Although the Terryland River sinks at the estavelles for most of the year, these reverse during peak groundwater levels and become resurgences. On these occasions groundwater from the Clare-Corrib GWB contributes to the River Corrib and the Lough Corrib cSAC. On this basis the Clare-Corrib GWB contributes Galway Bay during normal conditions but Galway Bay and the River Corrib during high groundwater levels.

The potential impact magnitude to the Terryland River during high groundwater is quantified as ‘Small Adverse’. As during these times the Terryland River is entirely groundwater fed, then the rating significance is ‘Significant’. The hydrological impacts are described in **Chapter 11, Hydrology**.

The magnitude and significance of hydrogeological impacts refer to potential changes in groundwater quantity and/or quality at receiving surface water from the proposed road development. The assessment is made in accordance with TII Guidelines. For assessment on surface water impacts as a consequence of these potential hydrogeological impacts, please refer to **Chapter 11, Hydrology**.

10.5.3.5 Summary

This section has provided a detailed assessment of the potential impacts to receptors for the proposed road development prior to implementation of mitigation measures. Based on the conceptual site model (**Section 10.3.3**) a zone of impact has been delineated for groundwater level drawdown. Areas that lie downgradient of the proposed road development have also been identified as being at risk from pollution, with the extent downgradient being dependant on the aquifer properties.

The design of the proposed road development is cognisant of the hydrogeological existing environment and specifically groundwater receptors. Below is a summary of the design measures incorporated into the design of the proposed road development for the construction phase:

- The design of the construction minimises areas of land stripping so as to reduce the increase in runoff from where vegetation (and evapotranspiration) is removed
- In the area of the Galway Granite Batholith the aquifer properties are poor and recharge is very low. In these areas runoff is managed on site and discharged to surface water (refer to **Chapter 11, Hydrology**). There is no reliance on groundwater infiltration where the road traverses the Galway Granite Batholith
- Groundwater inflows will occur in road cuttings due to the high water table in the Galway Granite Batholith. Where groundwater inflows occur these are likely to be minimal owing to the low aquifer properties. In the case of local zones of higher inflow, for example at a fault zone, then mitigation measures will be employed to control the inflow and isolate the pathway from the construction site

- The assessment has identified a risk specific to the Visean Undifferentiated Limestone where karst is present within the groundwater bodies that the proposed road development traverses. Karst has been identified in Lough Corrib Fen 1 (Menlough) GWB and Lough Corrib Fen 1 (Lackagh) GWB, GWDTE Lough Corrib Fen 2 GWB and the Clare-Corrib GWB. If karst was encountered in these groundwater bodies then there is a risk that runoff and accidental spills could impact on groundwater quantity and quality. These potential impacts require mitigation using the karst protocol, which is detailed in **Section 10.6** mitigation measures
- During construction of the proposed tunnel at Lackagh Quarry there is a risk of groundwater impacts if dewatering of the bedrock aquifer occurs, which could have hydrogeological impacts at Western Coolagh Spring which in turn could impact Coolagh Lakes which are part of Lough Corrib cSAC. Detail of the assessment of Lackagh Tunnel and its approaches are presented in **Appendix A.7.3**. For the tunnel section the eastern section of the western portal and approach the construction works will be restricted to above the groundwater table at all times
- At the eastern approach to Lackagh Tunnel support system of rock bolts will be used to stabilise the quarry face rather than concrete. Rock bolts will prevent impact to the petrifying springs and calcareous identified in the faces of Lackagh Quarry
- To facilitate groundwater flow around the completed tunnel the construction design includes a drainage blanket up to the winter groundwater level (+16.7mOD). It is envisaged that this will take the form of a drainage layer, drainage pipes or similar placed outside the permanent cast in-situ reinforced concrete tunnel lining and waterproof membrane
- The proposed finished level of the proposed road development at Lackagh Quarry will lie above the groundwater table, however, the embankment starter layer at the eastern approach would, in part, be submerged during peak winter groundwater high. In this regard the starter layer will be constructed so as not to dam groundwater in parts of the quarry floor. Similarly, the drainage network will not be installed during the seasonal groundwater high so as to avoid the need for dewatering of the bedrock aquifer and groundwater lowering
- A watertight seal will be installed on the road base of Lackagh Tunnel and its western approach and the cutting sides to protect against groundwater inflow. This area will be sealed during construction (and permanently) to +17.7mOD; which is derived from the groundwater high (+15.7mOD) plus 2m free board. Slope or retaining structures will be utilised from +17.7mOD to existing ground level where required

Based on the design measures above each of the receptors have been assessed. **Table 10.20** below provides a summary of impact magnitude and impact significance for those hydrogeological receptors considered at risk during the construction phase. The assessment of ecological and surface water receptors refers only to the hydrogeology of each location (refer to **Chapter 8, Biodiversity** and **Chapter 11, Hydrology**).

Table 10.20: Summary of impact magnitude and significance for hydrogeological aspects of receptors at risk during the construction phase of the proposed road development

Feature	Importance of Hydrogeology Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude	Hydrogeology Impact Significance
Groundwater Resources				
Galway Granite Batholith (Pl)	Low	Permanent groundwater quality and quantity impacts	Negligible	Imperceptible
Visean Undifferentiated Limestone (Rkc)	Very High	Permanent groundwater quality and quantity impacts	Negligible	Imperceptible
Groundwater Supplies				
W50-10	Low	Well will be lost	Large adverse	Slight / moderate
W50-12	High	Well will be lost	Large adverse	Profound / significant
W50-13 & W50-14	Very High	Well will be lost	Large adverse	Profound
W50-15	High	Well will be lost	Large adverse	Profound / significant
W1000-02	Low	Potential risk to water quality	Moderate adverse	Slight
Ecological Receptors				
Lough Corrib cSAC	Extremely High	Potential temporary quantity and quality deterioration of groundwater in karst pathways within contributing GWB would lead to impacts at Western Coolagh Spring, which is the main water contribution for Coolagh Lakes	Large Adverse	Profound
		The groundwater contribution from GWB to River Corrib is of insufficient	Negligible	Insignificant

Feature	Importance of Hydrogeology Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude	Hydrogeology Impact Significance
		magnitude to affect integrity		
Galway Bay Complex cSAC	Extremely High	Potential temporary quantity and quality deterioration of groundwater in karst pathways to Galway Bay. The groundwater contribution from GWB is of insufficient magnitude to affect integrity	Negligible	Insignificant
Inner Galway Bay SPA	Extremely High	Potential temporary quantity and quality deterioration of groundwater in karst pathways to Galway Bay. The groundwater contribution from GWB is of insufficient magnitude to affect integrity	Negligible	Insignificant
Lough Corrib pNHA	Very High	Potential temporary quantity and quality deterioration of groundwater in karst pathways within contributing GWB would lead to impacts at Western Coolagh Spring, which is the main water contribution for Coolagh Lakes	Large Adverse	Profound
		The groundwater contribution from GWB to	Negligible	Insignificant

Feature	Importance of Hydrogeology Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude	Hydrogeology Impact Significance
		River Corrib is of insufficient magnitude to affect integrity		
Na Foraí Maola Thiar (Annex I) Ch. 0+650 to Ch. 0:750	Very High	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Profound
Na Foraí Maola Thoir (Annex I) Ch. 1+250 to Ch. 1+500	Very High	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Profound
Troscaigh Thiar (Annex I) (Ch. 1+850 to Ch. 2+400)	Very High	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Profound
Aille (Annex I) (Ch. 3+300 to Ch. 3+900)	Very High	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Profound
Ballyburke (Annex I) (Ch. 4+800 to Ch. 5+900)	Very High	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater	Large Adverse	Profound

Feature	Importance of Hydrogeology Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude	Hydrogeology Impact Significance
		levels below the habitat		
NUI Galway (Annex I) (Ch. 9+150 to Ch. 9+250)	Very High	Potential contamination impact	Moderate Adverse	Profound
Turlough K31 (Annex I) Menlough East	Very High	Proposed road development traverses the habitat Potential temporary groundwater contamination impact	Large Adverse	Profound
Petrifying springs	Very High	Rock bolting to stabilise eastern portal of Lackagh Tunnel	Negligible	Insignificant
Unnamed Fen (Locally important) Ch. 7+850	Low	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Slight / moderate
Calcareous springs	Low	Rock bolting to stabilise eastern portal of Lackagh Tunnel	Negligible	Insignificant
Surface water				
Terryland River	Extremely High	Potential temporary water quantity and quality impact to Terryland estavelles (K87 & K96) during high groundwater levels when these outflows contribute to the River Corrib	Small Adverse	Significant

10.5.4 Operational Phase Impacts

There are a number of operation phase activities or features of the proposed road development that have the potential to cause hydrogeological impacts. The potential impacts of these on the hydrogeological receptors identified in **Section 10.3.4** are discussed in this section of the chapter. The potential impact outlined in this section are pre-mitigation. Residual impacts are outlined in **Section 10.7**.

As with construction activities, the main impacts to groundwater from operation arises from the potential to impact on groundwater level and groundwater quality. Operation can alter the groundwater regime by:

- Lowering of groundwater level from operational dewatering
- Raising groundwater levels by impeding or impounding groundwater
- Discharge of road runoff to ground

The quantification of these potential operational impacts are presented in this section of the chapter, while the impacts on receptors identified in **Section 10.3.4** are presented in **Section 10.5.4.4**. Many of these impacts are similar to the impacts quantified in the construction phase of this assessment e.g. the operation of road cuttings in the Galway Granite Batholith, and should be cross referenced to **Section 10.5.3** where necessary.

There will be no active dewatering of the bedrock aquifer required during the operation phase but passive dewatering will occur at a number of cutting locations and the drainage associated with the proposed road development will cause the groundwater levels to adjust locally.

The drawdown and ZoI for road cuttings was presented in **Table 10.17** of the construction impacts and should also be referred to when considering the impacts from the operation phase. It should be noted that all tunnels and associated approaches will be sealed as part of their construction where below the winter water table and so, for example, the Galway Racecourse Tunnel and approaches will require dewatering of the bedrock aquifer during construction but they will not require dewatering during operation. Dewatering of the bedrock aquifer either during construction or operation at Lackagh tunnel and its approaches is not permitted.

The potential impacts from interception of karst conduits was highlighted during the construction phase as having a potential impact on the hydrogeological regime by either modifying pathways (reactivating sediment filled karst or blocking active karst) or from point input recharge for contaminants. Mitigation measures to prevent these impacts from occurring are presented in **Section 10.6**. If implemented during the construction phase, these impacts will not occur during the operation phase.

During operation, potential groundwater quality impacts occur from the discharge of road runoff or from accidental spillages. Potential impacts of the discharge of routine road runoff is assessed in line with HD45/15 ‘Road Drainage and the water Environment’ Method C, while the assessment of accidental spillages is undertaken in **Chapter 10, Hydrology** line with HD45/15 'Road Drainage and the water Environment' Method D.

Within HD45/15, a Groundwater Protection Response (GPR) is presented which is a risk assessment methodology based on the vulnerability and aquifer classification of the aquifer where the discharge will occur. A matrix of these elements, presented below in **Table 10.21**, is used to determine the potential risk and sets out a series of 'Responses' that the drainage design of the proposed road development should comply with to minimise the risk to the groundwater environment. The assessment is considered a screening tool which can be superseded by a site specific hydrogeological risk assessment.

Table 10.21: Groundwater response matrix for the use of permeable drains in road schemes (TII, HD45/15, 2015)

Vulnerability rating	Source protection area	Resource protection area (Aquifer category)							
		Regionally Important Aquifer			Locally Important Aquifer			Poor aquifer	
		Rk*	Rf	Rg	Lg	Lm	LI	PI	Pu
Extreme: Rock near Surface or karst (X)	R4	R4	R4	R3(2)	R3(2)	R3(1)	R3(1)	R3(1)	R3(1)
Extreme €	R4	R2(3)	R2(2)	R3(2)	R3(2)	R2(2)	R2(2)	R2(1)	R2(1)
High (H)	R3(2)	R2(2)	R2(2)	R2(2)	R2(2)	R2(2)	R2(2)	R2(1)	R2(1)
Moderate (M)	R3(1)	R2(1)	R2(1)			R2(1)	R2(1)	R1	R1
Low (L)	R3(1)	R1	R1			R1	R1	R1	R1

*A small proportion of the country (~0.6%) is underlain by locally important karstic aquifers (Lk); in these areas, the groundwater protection responses for the Rk groundwater protection zone shall apply.

The Geological Survey of Ireland (GSI) provides mapped classifications of the aquifer and vulnerability criteria across the country, however it is recommended that the vulnerability criteria is updated based on site specific information.

Groundwater vulnerability assesses the geological and hydrogeological characteristics of the subsoil overlying the aquifer and provides a rating response using the TII HD45/15 GPR (**Table 10.21**). The GSI make a distinction between extreme vulnerability with bedrock at surface (X) and extreme vulnerability with subsoil being 0-3m thick (E). Where extreme (X) vulnerability refers to rock outcrop at surface or the location of a karst feature.

The groundwater protection response for the proposed road development is presented in **Appendix A.10.7** and concludes the following:

- Significant areas of the Galway Granite Batholith are identified by the GSI as being rock at or near surface. However, as most of the proposed road development is on embankment the groundwater vulnerability is mainly extreme (E). Those areas where groundwater vulnerability is extreme (X) are areas where the proposed road development is in cutting. In these areas the drainage design includes verges and swales that maintain a 1m constructed subsoil above bedrock. As the granite is of a low permeability infiltration to the bedrock is very low

- Drainage design for the Visean Undifferentiated Limestone is sealed up to the point of discharge, where to surface water or infiltration basin. Where discharge is proposed by infiltration basins then all locations have a GPR response of R2(3)
- Permeable drainage is acceptable for both R2(1) and R2(3) responses subject to subject to minimum Design Manual for Roads and Bridges (DMRB) standards and GPR Notes
- Permeable drainage is acceptable for the proposed road development where it traverses the Galway Granite Batholith subject to minimum DMRB conditions and GPR requirements 1,2 and 3. The design takes into account those ground receptors identified in **Section 10.3.4**. In the event of a vertical fault crosscutting the proposed road development then the drainage design will locally be sealed to prevent communication between flow zone and runoff
- Permeable drainage is acceptable for the proposed road development where it traverses the Visean Undifferentiated Limestone subject to minimum DMRB conditions and GPR requirements 1, 2, 3, 4, 5, 6 and 7. The drainage design takes into account karst primarily by avoidance but also by incorporating pre-treatment prior to discharge. Drainage design for the Visean Undifferentiated Limestone employs a sealed design with discharge either to surface water courses or infiltration basins. Where runoff discharges to surface water then there is no discharge to groundwater and a detailed hydrogeological assessment is not required. For those networks with discharge by infiltration basin then a hydrogeological assessment has been undertaken for each networks to assess the potential risks to groundwater. The individual assessments are included into **Appendix A.10.7**

On the basis of this hydrogeological assessment the design and measures of the infiltration basins assessed meet the criteria for HD45/15 for permeable drainage.

The potential impacts from accidental spillages have been assessed in line with TII Guidelines HD45/15 Method D. The potential risk of a serious pollution incident occurring has been calculated >1% and the calculations to confirm this are presented in **Chapter 10, Hydrology**.

The potential zone of influence for operation drawdown and water pollution impacts are presented in **Figure 10.8.101** to **Figure 10.8.114**.

10.5.4.1 Potential Impacts to groundwater resources

The potential impact assessment on the groundwater resources during the operation phase considers the impact that the changes in the groundwater regime and groundwater quality have on the aquifer.

In line with TII guidance, the magnitude of the impact on the aquifers within the study area is based on the portion of the aquifer that will be removed. This has been presented for the construction phase in **Section 10.5.3**, however it also applies here.

In summary, the volume of the aquifer is a very small percentage of the aquifer volume and for this reason, in line with TII rating, the Magnitude of the impact on the aquifers is 'Negligible' and the Significance of the impact is 'Imperceptible'.

The presence of the proposed road development itself can affect the aquifer by changing the recharge pattern to it. Details of the drainage design for the proposed road development are provided in **Chapter 5, Description of the Proposed Road Development**, which includes the surface areas of the proposed road development where recharge to the aquifer will not occur. Using this data, the surface area of the proposed road development is negligible when compared to the surface area of the land providing recharge to the aquifer. The Magnitude of the impact on the aquifer is 'Negligible' and the Significance of the impact is 'Imperceptible'.

Other impacts that have the potential to impact groundwater resources changing groundwater levels and changing water quality. The magnitude and significance of other impacts on the two aquifer types along the proposed road development is outlined in **Sections 10.5.4.1.1** and **10.5.4.1.2**.

10.5.4.1.1 Galway Granite Batholith (Section 1)

Based on the results presented in **Table 10.17** there are seven cuttings in the Galway Granite Batholith which have the potential to intersect the groundwater table locally. These road cuttings are EW01, EW02 (three cuttings), EW04, EW07 and EW11. As outlined in **Section 10.4**, EW11 has the largest ZoI with drawdown extending up to 54m from the edge of the footprint of the proposed road development.

The installation of drainage both for the proposed road development runoff and for pre-earthworks drainage will locally intercept drainage and for this reason, the conservative assumption is that the operational ZoI will mimic the construction ZoI for these excavations.

Other excavations which are included in the construction ZoI such as excavation for structures and attenuation ponds are relevant for construction only and hence the ZoI for operation will locally be reduced from the ZoI for construction.

Using the reported aquifer properties, the operation ZoI within the Galway Granite aquifer will yield relatively small volumes of groundwater, which will be managed on site and discharged to those nearby watercourses that the groundwater would contribute too indicating that there will be no net change to the volume of water in the aquifer. On this basis, in line with TII rating, the Magnitude of the impact of lowering the groundwater level on the aquifer is Negligible and the Significance of the impact is 'Imperceptible'.

Potential impacts to groundwater quality during operation occur from infiltration to ground from the proposed road runoff. The assessment of the infiltration of proposed road runoff for the Galway Granite Batholith is detailed in **Appendix A.10.7** and a summary is provided below.

The assessment of the operational discharges to ground is based on the TII HD45/15 GPR assessment which is based on the groundwater vulnerability and the aquifer type. For the Galway Granite Batholith, the GSI Groundwater vulnerability varies between extreme (X) and high (H) and the aquifer characterisation is poor (Pl). Based upon the design of the proposed road development with the mainline of the proposed road development on embankment or where in cutting verges and swales for over the edge drainage are proposed, the GPR returns a R2(1) response and meets TII HD45/15 guidelines. Due to the low hydraulic conductivity of the granite bedrock the potential impact to groundwater quality is local to the proposed road development. In line with TII guidance, the Magnitude of this potential impact on the aquifer is Moderate Adverse and the Significance of this impact is Significant / Moderate respectively. The duration of the impact is permanent.

If accidental spillages occur during the operation of the proposed road development, they have the potential to impact water quality. In line with TII guidance, the Magnitude of this potential impact is ‘Moderate Adverse’ and the Significance of this impact ‘Significant / Moderate’ respectively. The duration of such impacts will be brief, lasting less than one day.

10.5.4.1.2 Visean Undifferentiated Limestone (Section 2, 3 & 4)

During the operation phase of the proposed road development, there are thirteen sections in the Visean Undifferentiated Limestone Aquifer that remain in an open cutting or tunnel (see **Table 10.17**). This is two less than during construction as the River Corrib Bridge and Menlough Viaduct do not have excavations during operation.

The potential for impact is assessed on the basis of the depth of the cutting, including drainage, and the maximum groundwater levels monitored during the project specific ground investigation (2015-2017). Of these thirteen cuttings, six remain above the water table at all times and will not impact on groundwater levels. Seven cuttings do have the potential to intersect and impact on the water table locally during operation.

The seven cuttings/tunnel that have the potential to intersect the water table include three cuttings (EW27, EW34 and EW35), three tunnel approaches (EW19, EW30 and EW32) and two tunnels (EW20 Lackagh Tunnel and EW31 Galway Racecourse Tunnel). Both the Lackagh Tunnel and its western approach and the Galway Racecourse with its eastern approach will be sealed.

Based on the water level data collected for the proposed road development and the sealed design of the tunnels and their approaches the only excavations that have the potential to require operational dewatering of the bedrock aquifer are EW27, (Clare-Corrib GWB) EW34 and EW35 (Clarinbridge GWB).

The installation of drainage both for proposed road runoff and for pre-earthworks drainage will locally intercept drainage and for this reason, the conservative assumption is that the operational ZoI will mimic the construction ZoI for these three excavations. Based on the different aquifer properties for the various groundwater bodies outlined in the **Section 10.3.2**, the ZoI for drainage will be larger for the cuttings in the Clare-Corrib GWB than in the Clarinbridge GWB.

EW27 lies immediately west of the N83 Tuam Road and is a cutting where the proposed finished road level lies 10m above the summer groundwater level and 0.5m above the peak recorded winter groundwater level. As part of the design permanent drains will be installed to control the groundwater level 2m below the finished road level.

All groundwater intercepted by drains during the peak groundwater rise will be carried eastwards by unlined 150mm perforated pipes either side of the proposed road development with discharge along the pipe length and overflow to an infiltration basin. All groundwater intercepted by these drains will be discharged back into the groundwater body further east where groundwater levels are <5m below the proposed road level.

Within the Clarinbridge GWB the aquifer properties are relatively low and on this basis the volumes of groundwater to be generated during excavations are relatively small. Any groundwater lowering required will be kept within the same GWB so that groundwater volumes are maintained.

In the area of the Visean Undifferentiated Limestone there are few surface water features present. Where there is no option for discharge via surface water or storm water sewers the proposed road development will discharge to ground. As outlined in **Section 10.5.4** a hydrogeological assessment, in line with TII HD45/15 guidelines, was undertaken for the drainage design for discharges to ground. The full assessment is presented in **Appendix A.10.7** and is summarised below.

The design of the infiltration basin includes a 2m over excavation from the invert to place a 2m thick subsoil that will meet the TII definition of being an appropriate material (TII HD45/15). All of the infiltration basins are more than 15m from surface karst mapped during the karst survey (refer to **Figure 10.1.002**) and will be sealed up to the point of discharge. Additionally, all infiltration basins are designed to include the following features as standard design:

- A containment area
- A hydrocarbon interceptor
- A wetland

There is also a containment area in each drainage network that can manually be activated to contain spillage on the proposed carriageway.

Groundwater levels have been monitored along the route of the proposed road development between February 2015 and January 2017 in order to determine the seasonal variation in the groundwater level. On the basis of these measurements the minimum thicknesses of the saturated zone have been calculated for the infiltration basins and are presented in **Table 10.22**.

Table 10.22: Summary the unsaturated thicknesses below invert level for all infiltration basins

Network Ref	S19A	S19B	S20	S21A	S21B	S22A	S22B	S22C2	S22E	S40
Minimum unsaturated zone (m)	1.4	0.3	0	2.6	9.1	2.0	3.9	15.2	9.9	1.0

The groundwater level data shows significant seasonal variation locally and whilst all infiltration basins meet the requirement of 2m unsaturated zone during the groundwater low, infiltration basins S19a, S19b, S20 and S40 have less than 2m unsaturated zone during winter peaks. On this basis, infiltration basins at networks S21A, S21B, S22A, S22B, S22C2 and S22E meet and exceed the TII HD45/15 GPR criteria for R2(3) due to the pre-treatment.

Networks S19a, S19b, S20 and S40, however, do not meet the R2(3) criteria during the winter period when groundwater levels are elevated and there is less than 2m unsaturated zone (**Table 10.22**). However, as the standard design for infiltration basins for the proposed road development includes containment, a hydrocarbon interceptor and a wetland, then each infiltration basin includes significant pre-treatment of runoff prior to infiltration.

HD45/15 provides data on the event mean concentrations (EMC) of significant contaminants in routine runoff. The potential contaminants and their EMC are reproduced below in **Table 10.23**. The EMC data presented in TII HD45/15 is indicative of runoff water pre- treatment.

Table 10.23: Significant pollutants and their EMC

Determinand	Routine runoff Mean EMC µg/l
Total Copper	91.22
Dissolved Copper	31.31
Total Zinc	352.63
Dissolved Zinc	111.09
Total Cadmium	0.63
Total Fluoranthene	1.02
Total Pyrene	1.03
Total PAHs	7.52

As the pre-treatment aspect exceeds the requirements of HD45/15 for all infiltration basins then the treated run-off at infiltration basins S19a, S19b, S20 and S40 is of a higher quality than that listed in **Table 10.23**.

In addition to this, as noted in **Section 10.3.3** the maximum water levels were recorded during a period of unusually elevated groundwater levels following sustained rainfall events in the winter 2015/2016. Outside of these events, the minimum thickness requirement for the unsaturated zone will be present.

On this basis, the use of infiltration basins is assessed as being appropriate if no karst is encountered during construction of the excavation. Mitigation measures will be employed if karst is encountered during construction (refer to **Section 10.6**).

The presence of karst has been accommodated in the placement of the infiltration basins and no known active surface karst is present within 15m of any infiltration basin. However, there is a potential for karst to be encountered during the construction of infiltration basins and this is dealt with in the evaluation of construction impacts in **Section 10.5.3**.

The potential impact of karst is recognised as a significant aspect of the infiltration basins and is included in the mitigation measures of **Section 10.6**, which includes inspections to ensure that the infiltration basins remain in good working order for the operational life of the proposed road development.

Based on the TII HD45/15 Method C for groundwater protection response for routine runoff and site specific hydrogeological assessments the drainage design for operation of the proposed road development is considered to have an impact of negligible magnitude and imperceptible significance for all networks.

The potential accidental spillages to occur during the operation of the proposed road development, has the potential to impact on groundwater quality and has been assessed in line with TII HD45/15 Method C risk assessment. Based on the spillage risk assessment (refer to **Chapter 11, Hydrology**) the risk of a serious spillage occurring has an annual probability of less than 0.5% and is considered as acceptable based on TII guidelines.

In line with TII guidance, the Magnitude of this potential impact on the aquifer is negligible. The Significance of this impact on the Regionally Important is insignificant.

10.5.4.2 Potential Impacts to Groundwater supplies

An impact assessment on abstraction wells was completed for the construction phase and is presented in **Section 10.5.3.1**. The same assessment is valid for the operation phase. It highlights that five wells (W50-10, W50-11, W50-12, W50-13 and W12-14) will be removed by the proposed road development at the construction phase. One well (W1000-02) has been identified as lying downgradient and within the 100-day TOT from the proposed road development.

Mitigation measures for wells impacted outside of the proposed development boundary are proposed in **Section 10.6** and the residual impacts are summarised in **Section 10.7**.

10.5.4.3 Potential Impacts to Groundwater Dependent Terrestrial Ecosystems (GWDTE)

Potential impacts to GWDTE during operation derive from the interception of groundwater in cuttings and the deterioration of water quality from discharges and accidental spillages. A description of the specific locations where groundwater will be intercepted and where discharges will occur during operation of the proposed road development are detailed in **Section 10.5.4.1** for both the Galway Granite Batholith and the Visean Undifferentiated Limestone.

Based on the characteristics of the proposed road development **Section 10.4**. the zone of influence has been calculated for the operational passive dewatering of the bedrock aquifer. The zone of influence has been considered for those GWDTE listed in **Section 10.3.4.3** and the proximity for the operation ZoI to these GWDTE are presented in **Table 10.24**.

The water quality assessment of discharges from the proposed road development has been undertaken as part of TII HD45/15 groundwater protection response and individual hydrogeological assessments. The HD45/15 assessments conclude that the magnitude of the impact is 'Negligible' and the significance 'Imperceptible' for groundwater receptors (refer to **Section 10.5.4.1**). It should be noted that operational impacts are assessed on the basis of construction with guidance of the project karst protocol. In this regard, if karst was encountered during the construction of infiltration basins then these features would have been mitigated against at the construction phase.

Table 10.24: Summary of potential hydrogeological impacts at GWDTE during operation phase (pre-mitigation)

Feature	Impact to Groundwater Quantity	Impact to Groundwater Quality	Magnitude of Hydrogeology Impact	Significance of Hydrogeology Impact
European sites				
Galway Bay Complex cSAC	Localised rise in groundwater table below infiltration basins. Imperceptible net change to groundwater contribution	All discharges to groundwater are treated prior to infiltration	Negligible	Imperceptible
Inner Galway Bay SPA	Localised rise in groundwater table below infiltration basins. Imperceptible net change to groundwater contribution	All discharges to groundwater are treated prior to infiltration	Negligible	Imperceptible
Lough Corrib SPA	No European site lies upgradient	No European site lies upgradient	N/A	N/A
Lough Corrib cSAC	Localised rise in groundwater table below infiltration basin. Imperceptible net change to groundwater contribution	All discharges to groundwater are treated prior to infiltration	Negligible	Imperceptible

Feature	Impact to Groundwater Quantity	Impact to Groundwater Quality	Magnitude of Hydrogeology Impact	Significance of Hydrogeology Impact
Ballindooley Lough	No European site lies upgradient	No European site lies upgradient	N/A	N/A
National Heritage Sites				
Moycullen Bogs	No European site lies upgradient	No European site lies upgradient	N/A	N/A
Moycullen Bogs (Tonabrocky)	No European site lies upgradient	No European site lies upgradient	N/A	N/A
Moycullen Bogs (Letteragh)	No European site lies upgradient	No European site lies upgradient	N/A	N/A
Lough Corrib NHA	Localised rise in groundwater table below infiltration basin. Imperceptible net change to groundwater contribution	All discharges to groundwater are treated prior to infiltration	Negligible	Imperceptible
Galway Bay NHA	Localised rise in groundwater table below infiltration basin. Imperceptible net change to groundwater contribution	All discharges to groundwater are treated prior to infiltration	Negligible	Imperceptible
Annex I habitats (outside of SAC)				
Na Foraí Maola Thiar Ch. 0+650 to Ch. 0+750	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Na Foraí Maola Thoir Ch. 1+250 to Ch. 1+500	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Troscaigh Thiar (Ch. 1+850 to Ch. 2+400)	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Bearna (Ch. 2+600 to Ch. 3+100)	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
Aille	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound

Feature	Impact to Groundwater Quantity	Impact to Groundwater Quality	Magnitude of Hydrogeology Impact	Significance of Hydrogeology Impact
(Ch. 3+300 to Ch. 3+900)				
Ballyburke (Ch. 4+800 to Ch. 5+900)	Within drawdown zone of influence	Within area liable to contamination	Large Adverse	Profound
NUI Galway (Ch. 8+800 to Ch. 8+950	No Outside of drawdown zone of influence	No discharges from road to ground	N/A	N/A
NUI Galway (Ch. 9+150 to Ch. 9+250	No Outside of drawdown zone of influence	No discharges from road to ground	N/A	N/A
Turlough K20 (Menlough North East)	No Outside of drawdown zone of influence	No (upgradient of proposed road)	N/A	N/A
Turlough K31 (Menlough East)	Localised rise in groundwater table below infiltration basin. Imperceptible net change to groundwater contribution	All discharges to groundwater are treated prior to infiltration	Negligible	Imperceptible
Turlough K72 (Coolagh North)	No Outside of drawdown zone of influence	No (upgradient of proposed road)	N/A	N/A
Petrifying Springs (Lackagh Quarry)	No Located above the groundwater table	No Located above the groundwater table	N/A	N/A
Local habitats				
Fen Ch. 7+850	Within ZoI	Drawdown will lower groundwater levels below the habitat	Large Adverse	Slight / Moderate
Calcareous springs (Lackagh Quarry)	No Located above the groundwater table	No Located above the groundwater table	N/A	N/A

Operation specific mitigation measures are presented in **Section 10.6**.

10.5.4.4 Potential Impacts to Groundwater Dependent Surface Water Features

Groundwater contributes to surface water at River Corrib, Ballindooley Lough, Coolagh Lakes, Turlough K20, Turlough K31, Turlough K72, Ballinfoyle Lough and Terryland River. It is noted that whilst the Eastern Coolagh Spring has the potential for groundwater contribution, Coolagh Lakes is not dependent on this spring. Coolagh Lakes is however dependent on the Western Coolagh Spring.

A zone of influence for drawdown has been calculated for both the Galway Granite Batholith and the Visean Undifferentiated Limestone. The design of the cutting carries any groundwater intercepted in cuttings and infiltrates back to ground within the same GWB. On this basis there is no net reduction to groundwater flow in each GWB. There are no operational groundwater impacts to surface water contribution.

10.5.4.5 Summary

The design of the proposed road development is cognisant of the hydrogeological existing environment and specifically groundwater receptors. Below is a summary of the design measures incorporated in the operation phase:

- Passive operational dewatering of the bedrock aquifer will be required within cuttings in the Galway Granite Batholith. Any intercepted groundwater will remain within its natural receiving catchment
- The drainage design in the Galway Granite Batholith is not sealed. Discharge of treated runoff will be to surface water. There will be small (<10%) losses of runoff (treated and untreated) to ground and these have no impact on groundwater quality beyond the footprint of the proposed road development
- Dewatering of the bedrock aquifer will not be undertaken in the catchment for Coolagh Lakes. This area of the proposed road development includes Menlough Viaduct and Lackagh Tunnel (including its approaches)
- Passive operational dewatering of the bedrock aquifer will be required in cutting EW27 but will only be operational during the seasonal groundwater peak. Any intercepted groundwater will remain within the GWB by being carried down gradient and recharged back to ground in an infiltration basin
- The design of the Galway Racecourse Tunnel and its eastern approach includes waterproofing to seal from groundwater ingress. The western approach includes groundwater interception (during peak winter only) which will drain westwards down gradient to an infiltration basin
- The drainage design of the proposed road development in the Undifferentiated Visean Limestone includes a sealed system and uses infiltration basins (operational phase) to discharge of treated runoff

Based on the design measures above each of the receptors have been assessed.

Table 10.25 below provides a summary of impact magnitude and impact significance for those hydrogeological receptors considered at risk during the operation phase. The assessment of ecological and surface water receptors refers only to the hydrogeology of each location (refer to **Chapter 8, Biodiversity** and **Chapter 11, Hydrology**).

Table 10.25: Summary of impact magnitude and significance for hydrogeological aspects of receptors at risk during the operation phase of the proposed road development

Feature	Importance of Hydrogeology Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude	Hydrogeology Impact Significance
Groundwater resources				
Galway Granite Batholith (Pl)	Low	Permanent groundwater quality and quantity impacts	Negligible	Imperceptible
Visean Undifferentiated Limestone (Rkc)	Very High	Permanent groundwater quality and quantity impacts	Negligible	Imperceptible
Groundwater Supplies				
W50-10 (closed loop geothermal)	Low	Well will be lost	Large adverse	Slight/ moderate
W50-12	High	Well will be lost	Large adverse	Profound/ significant
W50-13 & W50-14	Very High	Well will be lost	Large adverse	Profound
W50-15	High	Well will be lost	Large adverse	Profound/ significant
W1000-2	Low	Well located downgradient from road	Large adverse	Slight/ moderate
Ecological Receptors				
Na Foraí Maola Thiar (Annex I habitat) Ch. 0+650 to Ch. 0+750	Proposed road development traverses the habitat	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Profound
Na Foraí Maola Thoir (Annex I habitat) Ch. 1+250 to Ch. 1+500	Proposed road development traverses the habitat	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater	Large Adverse	Profound

Feature	Importance of Hydrogeology Attribute	Hydrogeology Impact Summary	Hydrogeology Impact Magnitude	Hydrogeology Impact Significance
		levels below the habitat		
Troscaigh Thiar (Annex I habitat) (Ch. 1+850 to Ch. 2+400)	Proposed road development traverses the habitat	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Profound
Aille (Annex I habitat) (Ch. 3+300 to Ch. 3+900)	Proposed road development traverses the habitat	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Profound
Ballyburke (Annex I habitat) (Ch. 4+800 to Ch. 5+900)	Proposed road development traverses the habitat	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Profound
Unnamed Fen (Locally important) Ch. 7+850	Unnamed Fen (Locally important) Ch. 7+850	Within calculated drawdown zone of influence Drawdown will permanently lower groundwater levels below the habitat	Large Adverse	Slight / moderate
Surface water				
(No operational impacts)				

10.6 Mitigation Measures

10.6.1 Introduction

This section describes the measures to mitigate the potential impacts for both the construction (**Section 10.6.2**) and operational phases (**Section 10.6.3**) of the proposed road development.

In order to protect receptors identified in **Section 10.3.4**, both in terms of groundwater resources and water quality, mitigation measures will be put in place during the construction and operational phases of the proposed road development.

Through the evolution of the design of the proposed road development measures were included in the design to reduce or avoid specific impacts where possible. Following the evaluation of potential impacts as a result of the design, specific mitigation measures have been developed to avoid, prevent, reduce and, if possible, remedy any significant adverse impacts on hydrogeology. These are described below.

10.6.2 Construction Phase

The measures listed below will be adopted during the construction phase of the proposed road development.

The following measures were incorporated into the design (refer to **Section 10.5**) of the proposed road development:

- No dewatering of the bedrock aquifer will occur during construction at Menlough Viaduct or Lackagh Tunnel (or its approaches). Furthermore, the construction sequence will take into account the seasonal groundwater fluctuation. During the winter groundwater high it may be necessary to limit the depth of works so that dewatering of the bedrock aquifer is not required
- Galway Granite Batholith EW01, 02 (three cuttings), 04, 07 and 09: Groundwater intercepted will be collected and piped to the surface water receptor it would naturally have drained to
- Limestone: Construction dewatering of the bedrock aquifer may seasonally be required in EW27 during peak groundwater levels. Any dewatering will be discharged to the same GWB.
- Construction of the Galway Racecourse Tunnel and its approaches will require dewatering of the bedrock aquifer. All groundwater intercepted will be managed and discharged within the same GWB
- EW27: Groundwater will be controlled within the excavation by collection in drains or sumps. If groundwater is intercepted, it will be piped and discharged at an infiltration basin within the same GWB. Intercepted groundwater is controlled and infiltrates back to the same groundwater body
- Where infiltration basins are used for discharge of site runoff during construction the runoff will be managed on site, collected and treated as per the

Sediment Erosion and Pollution Control Plan (Refer to Section 8 of the CEMP in **Appendix A.7.5**).

The design of the proposed road development includes dewatering of the bedrock aquifer in cuttings in the Galway Granite Batholith and in cuttings in the Visean Undifferentiated Limestone. The drawdown from these cuttings has been assessed. Drawdown impacts are limited in extent and do not impact on European sites or National Heritage Areas. No hydrogeological mitigation is proposed with regard to the design of construction dewatering.

For the Visean Undifferentiated Limestone due to the risk of karst features being intercepted in excavations for earthworks (including viaducts, bridges and tunnels) and infiltration basins, mitigation measures have been developed to preserve the hydraulic connectivity of the feature and then seal it from the excavation. The Karst Protocol mitigation measure will ensure that there is no impact on groundwater flow paths to water dependant receptors. The Karst mitigation plan is detailed in the Construction Environmental Management Plan (CEMP) (**Appendix A.7.5**) and is summarised below in **Section 10.6.2.2.1** Aquifer Specific Mitigation Measures.

Those infiltration basins in the Lough Corrib Fen 1 (Menlough) GWB (S19a and S19b) shall have additional measures incorporated into their construction to provide further protection to the groundwater body. Infiltration basin S19a and S19b include lining the sides of the excavation to ensure vertical groundwater infiltration so that all discharges drain through the placed subsoil for the full thickness of the unsaturated zone.

10.6.2.1 Standard Mitigation Measures

Mitigation of potential construction impacts will be achieved through the stringent implementation of good construction practice procedures and environmental controls so as minimise the opportunity for contaminated releases of construction runoff as set out in the CEMP (**Appendix A.7.5**). Such practices will include adequate bunding for oil containers, wheel washers and dust suppression on site roads, and regular plant maintenance.

The following measures included in the CEMP will be implemented to control the potential for pollution from accidental spillages on site:

- Stockpiling of contaminated material is not permitted
- Good housekeeping (daily site clean-ups, use of disposal bins, etc.) on the site during construction, and the proper use, storage and disposal of these substances and their containers will prevent groundwater contamination
- For all activities involving the use of potential pollutants or hazardous materials, under the CEMP, the contractor will be required to ensure that material such as concrete, fuels, lubricants and hydraulic fluids will be carefully handled and stored to avoid spillages. Potential pollutants shall also be adequately secured against vandalism and will be provided with proper containment according to codes of practice. Any spillages will be immediately contained and contaminated soil removed from the site and properly disposed of

- The contractor will finalise the Incident Response Plan in the CEMP in **Appendix A.7.5** prior to work commencing and regularly update it for pollution emergencies which will be developed by the appointed contractor. The plan identified the actions to be taken in the event of a pollution incident. As recommended in the CIRIA document, the contingency plan for pollution emergencies includes the following:
    - Containment measures
    - Emergency discharge routes
    - List of appropriate equipment and clean-up materials
    - Maintenance schedule for equipment
    - Details of trained staff, location and provision for 24-hour cover
    - Details of staff responsibilities
    - Notification procedures to inform the Environmental Protection Agency (EPA) or environmental department of the Galway County Council
    - Audit and review schedule
    - Telephone numbers of statutory water consultees
    - List of specialist pollution clean-up companies and their telephone numbers
    - No direct untreated point discharge of construction runoff to groundwater will be permitted
    - Where a pollution incident is detected, construction works will be stopped until the source of the construction pollution has been identified and remedied
    - Pollution control facilities and procedures set out in the Sediment, Erosion and Pollution Control Construction Management Plan included in the CEMP will be implemented if required
    - The pollution control and treatment facilities will be installed and the monitoring network including instrumentation and procedures established prior to construction activities taking place on the ground in the vicinity of watercourses and sensitive surface and groundwater receptors. It is envisaged that the pollution control facilities will be monitored daily to ensure their continued function

10.6.2.2 Receptor specific mitigation measures

A number of mitigation measures have been developed specifically for groundwater dependent receptors. These are detailed below for aquifer, supply wells and habitats.

10.6.2.2.1 Aquifer Specific Mitigation Measures

Aquifer specific mitigation measures are implemented where karst or high permeability zones are encountered during the construction programme.

In the event of karst being encountered the Karst Protocol shall be implemented, which is documented in the CEMP (**Appendix A.7.5**). Application of the Karst Protocol are summarised below to detail where they will be implemented:

- Where karst features are encountered during construction works these will be assessed by a hydrogeologist and an engineering geologist. These features will require their extent across the proposed road development to be delineated. In the case of excavations (road cuttings, tunnels, bridge pier excavations) then the karst feature shall be excavated and backfilled with course fill and sealed. This will prevent runoff draining into the feature and therefore protect against accidental spillage. On this basis, construction runoff will not discharge to a karst pathway and will receive natural attenuation and dilution in the aquifer

- With regard to karst features being intercepted in excavations for earthworks (including viaducts, bridges and tunnels) and infiltration basins. The Karst Protocol preserves the hydraulic connectivity of the feature using granular material to fill but then seals the karst from the excavation using a liner (geotextile and or concrete depending on the site specifics) that will prevent linkage between excavation and the karst
- Where dewatering of the bedrock aquifer is proposed, groundwater level monitoring will be installed before construction, during the construction phase and 12 months following construction to enable potential effects from dewatering to be identified. In the shallow cuts of the proposed road development there will be minimal dewatering of the bedrock aquifer required; nonetheless, a monitoring programme will be in place. If the monitoring indicates there is a measureable impact beyond that stated in this EIAR, then work with the potential to increase drawdown will be made safe and cease until the hydrogeological assessment is revised based on the site conditions and mitigation employed if appropriate
- In order to reduce potential contamination impacts, stockpiling of contaminated material and leachate generation will be prohibited. In the situation that potential contaminated material is encountered it will be tested and disposed of in an appropriate manner and in line with current water management legislation. If it is not possible to immediately remove contaminated material, then it will be stored on, and covered by, polythene sheeting to prevent rain water infiltrating through the material. The time frame between excavation and removal will be kept to an absolute minimum

10.6.2.2.2 Mitigation measures specific for supply wells

The mitigation measures listed below will be adopted during the construction phase of the proposed road development:

- Five wells (W50-10, W50-12, W50-13, W50-14 and W50-15) will be lost during the construction of the proposed road development. These will each be mitigated by providing a replacement well, connecting to mains supply where available or by financial compensation. Where wells have to be abandoned as part of the proposed road development they will be sealed and abandoned in general accordance with Well Drilling Guidelines produced by the Institute of Geologists of Ireland (IGI 2007)
- Replacement wells, storage tank, associated pumping equipment and pipework for Wells W50-13 and W50-14 will be commissioned and tested to ensure adequate yield rates in advance of wells W50-13 and W50-14 being decommissioned.

- Wells outside of the proposed development boundary but within the drawdown zone of influence may be impacted by reduced groundwater levels during construction. All wells within 150m of the proposed development 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 12 months after construction. If the monitoring indicates that the proposed road development has impacted on a supply or geothermal well then mitigation will be applied
- Standard mitigation measures and aquifer specific mitigation measures are employed for protection of groundwater. To ensure the protection of quality of groundwater potable supplies, all wells within 150m of the proposed development boundary will be monitored for water quality on a monthly basis. All wells will be monitored for standard drinking water quality parameters on a monthly basis for 12 months before construction, during construction and for 12 months after construction. If the monitoring indicates that the proposed road development has impacted on a supply, then mitigation will be applied

10.6.2.2.3 Specific Mitigation measures for GWDTE

As presented in **Section 10.3.4** the proposed road development traverses groundwater bodies that supply a number of GWDTE. Those GWDTE that have been flagged as being at risk are all in areas where the groundwater pathways are karstic. In this regard the Karst Protocol, as detailed above in **Section 10.6.2.2.1**, forms part of mitigation to prevent groundwater quality or quantity being impacted. Additional mitigation is also employed to ensure that European sites are not impacted.

Construction activities represent a potential source of impact on the water quality of the Coolagh Lakes, which form part of the Lough Corrib cSAC, from uncontrolled construction site runoff and potential contamination of the groundwater from construction spillages. There will be no surface water discharges to the Coolagh lakes and all runoff will be treated before being discharged to ground at infiltration basins. Infiltration basins are designed to include settlement to remove sediment and have an appropriate thickness of subsoil below invert level.

Pouring of the concrete in excavations (River Corrib Bridge, Menlough Viaduct and Lackagh Tunnel) will only be undertaken when the excavation has been inspected by a qualified hydrogeologist. Inspection of the full depth and extent of each excavation will be undertaken to identify if any significant flow paths, such as the karst enhancement of the bedrock permeability, are present. If no significant flow paths are present, then the hydrogeologist will document accordingly and confirm that there is no risk to groundwater from concrete leakage. If significant pathways are present then impacts which may arise from flow along these pathways shall be designed by the hydrogeologist based on the karst mitigation plan, these may comprise of installing a high permeability zone to replace the groundwater pathways which would be removed by the foundations and / or sealing the linkage from excavation to protect the karst. The design of the mitigation measures shall be approved by a qualified hydrogeologist to confirm that there will be no negative impacts to groundwater.

These above measures will ensure that the risk of pollution of groundwater bodies is controlled. These mitigation measures are employed during construction, the impacts on groundwater quality beneath the site will be of Negligible Magnitude and Imperceptible Significance.

10.6.3 Operational Phase

During the operational phase of the proposed road development inspection and maintenance will occur to ensure that the infiltration basins continue to operate as intended for the design life of the proposed road development. A number of measures were incorporated into the design of the proposed road development to minimise their impact. These have been included in **Section 10.5.4** above and are repeated here for clarity.

In the drainage design, the infiltration basin design uses over excavation below the design invert to place subsoil of an appropriate thickness and material that meets TII Guidelines (TII HD45/15). All of the infiltration basins are more than 15m from surface karst mapped during the karst survey (refer to **Figure 10.1.002**) and will have sealed drainage up to the point of infiltration. All infiltration basins are designed to include the following features:

- A containment area
- A hydrocarbon interceptor
- A wetland

There is also a containment area in each drainage network that can manually be activated to contain spillage on the carriageway.

Networks S19a, S19b and S41 are located on the Lough Corrib Fen 1 (Menlough) GWB, which supports groundwater dependant terrestrial ecosystems (GWDTE) at Coolagh lakes. Due to the sensitivity of the Lough Corrib Fen 1 (Menlough) GWB those drainage networks that drain the carriageway above the GWB, which include S19a and S19b, also have a liner installed to ensure that the treated run-off percolates through the full thickness of the subsoil. S41 is located on a side road with a lower risk of accidental spillage and as such does not include this mitigation measure.

Infiltration basins require regular inspection to confirm that no observable subsidence in the infiltration has occurred due to karst. There are no guidelines on the inspection frequency for infiltration basins, however, based on the mitigation measures implemented the risk of subsidence occurring is considered to be low and inspection is recommended on 5-year frequency.

If karst features and potential pathways are found to be present during inspection, then the Karst Protocol developed for the construction phase will be implemented to ensure that no preferential pathways have formed within the infiltration basin.

10.7 Residual Impacts

The residual impacts are those that will occur after the proposed mitigation measures have taken effect and are shown in **Table 10.26** and **Table 10.27** below. There are no residual hydrogeological impacts to European sites.

Residual hydrogeological impacts remain for groundwater level drawdown impacts below the location of five Annex I habitats on the Galway Granite Batholith.

Table 26: Summary of hydrogeological residual impacts to receptors during the construction phase

Constraint	Importance		Construction Phase					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
Groundwater resources and supplies								
Poor Bedrock Aquifer	Low	Poor Bedrock Aquifer	Negligible	A small proportion of the aquifer is being removed	Imperceptible	N/A	Negligible	Imperceptible
Regionally Important Aquifer	Very High	Regionally Important Aquifer	Negligible	A small proportion of the aquifer is being removed	Imperceptible	N/A	Negligible	Imperceptible
Knocknacarra GWS (W50-01)	Medium	Group water scheme supplying approximately 50 houses	No Impact	NA	N/A	N/A	N/A	N/A
W50-02	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W50-03 04, 05, 06 and 07	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W50-08	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A

Constraint	**Importance**		**Construction Phase**					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
W50-09	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W50-10	Low	Domestic geothermal well	Large adverse	Will be decommissioned as part of works	Profound/ Significant	Replace / compensate	N/A	N/A
W50-11	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W50-12	Low	Commercial supply	Large adverse	Will be decommissioned as part of works	Profound/ Significant	Replace / compensate	N/A	N/A
W50-13 & 14	Low	Commercial supply	Large adverse	Will be decommissioned as part of works	Profound	Replace	N/A	N/A
W50-15	Low	Commercial supply	Large adverse	Will be decommissioned as part of works	Profound/ Significant	Replace / compensate	N/A	N/A

Constraint	**Importance**		**Construction Phase**					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
W100-01 & 02	Low	Agricultural supply and / or Domestic supply	No Impact	N/A	N/A	N/A	N/A	N/A
W100-03, 04, 05 and 06	Low	Agricultural supply and / or Domestic supply	No Impact	N/A	N/A	N/A	N/A	N/A
W500-01	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W1000-01	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W1000-02	Low	Agricultural supply and / or Domestic supply	Moderate adverse	Within ZoI for areas of potential pollution	Slight	Well will be monitored for water level and quality as within 150m of fence line	N/A	N/A
W1000-03	Low	Agricultural supply and / or Domestic supply	No Impact	N/A	N/A	N/A	N/A	N/A
W1000-04	Low	Agricultural supply and / or Domestic supply	No Impact	N/A	N/A	N/A	N/A	N/A

Constraint	Importance		Construction Phase					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
G50-01	Low	Closed loop geothermal well	No impact	N/A	N/A	Well will be monitored for water level as within 150m of fence line	N/A	N/A
Groundwater dependent habitats								
Galway Bay Complex cSAC	Extremely High	European site	Negligible	GWB with risk of impact is very small contributor to receiving water	Insignificant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Inner Galway Bay SPA	Extremely High	European site	Negligible	GWB with risk of impact is very small contributor to receiving water	Insignificant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Lough Corrib cSAC	Extremely High	European site	Large adverse	GWB with risk of impact is main contributor to receiving	Profound	CEMP inc. karst protocol, runoff management	Negligible	Insignificant

Constraint	Importance		Construction Phase					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
				water at Coolagh Lakes		and pollution control		
Lough Corrib SPA	Extremely High	European site	No impact	N/A	N/A	N/A	N/A	N/A
Ballindooley Lough	Very High	Support to European site	No Impact	N/A	N/A	N/A	N/A	N/A
Moycullen Bogs	Very High	Site of national importance	No Impact	N/A	N/A	N/A	N/A	N/A
Lough Corrib NHA	Very High	Site of national importance	Large adverse	GWB with risk of impact is main contributor to receiving water at Coolagh Lakes	Significant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Galway Bay NHA	Very High	Site of national importance	Negligible	GWB with risk of impact is very small contributor to receiving water	Insignificant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant

Constraint	**Importance**		**Construction Phase**					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
Na Foraí Maola Thiar (Ch. 0+650 to Ch. 0+750)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound
Na Foraí Maola Thoir (Ch. 1+250 to Ch. 1+500)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound
Troscaigh Thiar (Ch. 1+850 to Ch. 2+400)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound
Aille (Ch. 3+300 to Ch. 3+900)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound

Constraint	**Importance**		**Construction Phase**					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
Ballyburke (Ch. 4+800 to Ch. 5+900)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound
NUI Galway (Ch. 8+800 to Ch. 8+950	Very High	Annex 1 Habitat	None	Upgradient	N/A	N/A	N/A	N/A
NUI Galway (Ch. 9+150 to Ch. 9+250	Very High	Annex 1 Habitat	Moderate adverse	Downgradient of site	Moderate / adverse	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Turlough K20 (Menlough North East)	Very High	Annex 1 Habitat	None	N/A	N/A	N/A	N/A	N/A
Turlough K31 (Menlough East)	Very High	Annex 1 Habitat	Large adverse	Downgradient of site	Profound	CEMP inc. karst protocol, runoff management	Negligible	Insignificant

Constraint	Importance		Construction Phase					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
						and pollution control		
Turlough K72 (Coolagh North)	Very High	Annex 1 Habitat	None	N/A	N/A	N/A	N/A	N/A
Petrifying Springs (Lackagh Quarry)	Very High	Annex 1 Habitat	Negligible	Located above groundwater table	Insignificant	Rock bolting used but no concreting	Negligible	Insignificant
Fen Ch. 7+850	Low	Site of local importance	Large adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Slight / Moderate	CEMP	Large adverse	Slight/ Moderate
Calcareous springs (Lackagh Quarry)	Low	Site of local importance	Negligible	Located above groundwater table	Insignificant	Rock bolting used but no concreting	Negligible	Insignificant
Groundwater dependent surface water features								
Terryland River	Extremely High	Supporting feature for Lough Corrib cSAC	Small adverse	GWB with risk of impact is small contributor to receiving water	Significant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant

Table 27: Summary of hydrogeological residual impacts to receptors during the operational phase

Constraint	Importance		Operational Phase					
Name	**Ranking**	**Justification**	**Magnitude of Hydrogeology Impact**	**Criteria for Hydrogeology Impact Assessment**	**Significance of Hydrogeology Impact**	**Mitigation Measure**	**Residual Hydrogeology Impact Magnitude**	**Residual significance of Hydrogeology impact**
Groundwater resources and supplies								
Poor Bedrock Aquifer	Low	Poor Bedrock Aquifer	Negligible	A small proportion of the aquifer is being removed	Imperceptible	None	Negligible	Imperceptible
Regionally Important Aquifer	Very High	Regionally Important Aquifer	Negligible	A small proportion of the aquifer is being removed	Imperceptible	None	Negligible	Imperceptible
Knocknacarra GWS (W50-01)	Medium	Group water scheme supplying approximately 50 houses	No Impact	NA	N/A	N/A	N/A	N/A
W50-02	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W50-03 04, 05, 06 and 07	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W50-08	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A

Constraint	**Importance**		**Operational Phase**					
W50-09	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W50-10	Low	Domestic geothermal well	Large adverse	Will be decommissioned as part of works	Profound / Significant	Replace / compensate	N/A	N/A
W50-11	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W50-12	Low	Commercial supply	Large adverse	Will be decommissioned as part of development	Profound / Significant	Replace / compensate	N/A	N/A
W50-13 & 14	Low	Commercial supply	Large adverse	Will be decommissioned as part of development	Profound	Replace	N/A	N/A
W50-15	Low	Commercial supply	Large adverse	Will be decommissioned as part of development	Profound/ Significant	Replace / compensate	N/A	N/A
W100-01 & 02	Low	Agricultural supply and / or Domestic supply	No Impact	N/A	N/A	N/A	N/A	N/A
W100-03, 04, 05 and 06	Low	Agricultural supply and / or Domestic supply	No Impact	N/A	N/A	N/A	N/A	N/A

Constraint	Importance		Operational Phase					
W500-01	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W1000-01	Low	Agricultural supply and / or Domestic supply	No Impact	NA	N/A	N/A	N/A	N/A
W1000-02	Low	Agricultural supply and / or Domestic supply	Moderate adverse	Within 150m of fence line	Slight	Well will be monitored for water level and quality as within 150m of fence line	Moderate adverse	Slight
W1000-03	Low	Agricultural supply and / or Domestic supply	No Impact	N/A	N/A	N/A	N/A	N/A
W1000-04	Low	Agricultural supply and / or Domestic supply	No Impact	N/A	N/A	N/A	N/A	N/A
G50-01	Low	Closed loop geothermal well	No impact	N/A	N/A	Well will be monitored for water level as within 150m of fence line	N/A	N/A
Groundwater dependent habitats								
Galway Bay Complex cSAC	Extremely High	European site	Negligible	Meets HD45/15	Insignificant	CEMP inc. karst	Negligible	Insignificant

Constraint	Importance		Operational Phase					
						protocol, runoff management and pollution control		
Inner Galway Bay SPA	Extremely High	European site	Negligible	Meets HD45/15	Insignificant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Lough Corrib cSAC	Extremely High	European site	Negligible	Meets HD45/15	Insignificant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Lough Corrib SPA	Extremely High	European site	No impact	N/A	N/A	N/A	N/A	N/A
Ballindooley Lough	Very High	Support to European site	No Impact	N/A	N/A	N/A	N/A	N/A
Moycullen Bogs	Very High	Site of national importance	No Impact	N/A	N/A	N/A	N/A	N/A

Constraint	Importance		Operational Phase					
Lough Corrib NHA	Very High	Site of national importance	Negligible	Meets HD45/15	Insignificant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Galway Bay NHA	Very High	Site of national importance	Negligible	Road runoff is treated prior to infiltration	Insignificant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Na Foraí Maola Thiar (Ch. 0+650 to Ch. 0+750)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound
Na Foraí Maola Thoir (Ch. 1+250 to Ch. 1+500	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound

Constraint	**Importance**		**Operational Phase**					
Troscaigh Thiar (Ch. 1+850 to Ch. 2+400)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering and downgradient of the bedrock aquifer of site	Profound	CEMP	Large adverse	Profound
Aille (Ch. 3+300 to Ch. 3+900)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound
Ballyburke (Ch. 4+800 to Ch. 5+900)	Very High	Annex 1 Habitat	Large Adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Profound	CEMP	Large adverse	Profound
NUI Galway (Ch. 8+800 to Ch. 8+950	Very High	Annex 1 Habitat	None	Upgradient	N/A	N/A	N/A	N/A
NUI Galway (Ch. 9+150 to Ch. 9+250	Very High	Annex 1 Habitat	Moderate adverse	Downgradient of site	Moderate / adverse	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant

Constraint	Importance		Operational Phase					
Turlough K20 (Menlough North East)	Very High	Annex 1 Habitat	None	N/A	N/A	N/A	N/A	N/A
Turlough K31 (Menlough East)	Very High	Annex 1 Habitat	Large adverse	Downgradient of site	Profound	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant
Turlough K72 (Coolagh North)	Very High	Annex 1 Habitat	None	N/A	N/A	N/A	N/A	N/A
Petrifying Springs (Lackagh Quarry)	Very High	Annex 1 Habitat	Negligible	Located above groundwater table	Insignificant	Rock bolting used but no concreting	Negligible	Insignificant
Fen Ch. 7+850	Low	Site of local importance	Large adverse	Within ZoI for dewatering of the bedrock aquifer and downgradient of site	Slight/ Moderate	CEMP	Large adverse	Slight/ Moderate
Calcareous springs (Lackagh Quarry)	Low	Site of local importance	Negligible	Located above groundwater table	Insignificant	Rock bolting used but no concreting	Negligible	Insignificant

Constraint	Importance		Operational Phase					
Groundwater dependent surface water features								
Terryland River	Extremely High	Supporting feature for Lough Corrib cSAC	Small adverse	GWB with risk of impact is small contributor to receiving water	Significant	CEMP inc. karst protocol, runoff management and pollution control	Negligible	Insignificant

10.7.1 Cumulative Impacts

Cumulative impacts are defined as the combination of many minor impacts creating one, larger, more significant impact (NRA, 2009 and EPA 2017). Cumulative impacts consider existing stresses on the natural environment as well as developments that are underway and in planning.

The baseline hydrogeology has identified that the groundwater bodies in the study area have a number of existing stresses in the form of discharges from wastewater treatment systems, septic tanks, road runoff, quarrying and agriculture. These potential pollutant sources have the potential to impact the groundwater environment in the form of reducing water quality by increased contaminants. On the basis of the design and mitigation measures employed for the proposed road development accommodate and maintain the existing GWB sub-catchments then there will be no alteration of groundwater pathways that could modify the impacts from existing pollutant sources.

The following developments being constructed or in planning are considered in terms of the cumulative hydrogeological impact with the proposed road development.

- N59 Maam Cross to Oughterard Road Project (consented and pre-construction)
- M17 Galway to Tuam Road Project (operational)
- N18 Oranmore to Gort Road Project (operational)
- N17 Tuam Bypass (operational)
- Galway Harbour Port Extension (planning stage)
- Galway Transport Strategy (GTS)

The zone of influence from the N59 Maam Cross to Oughterard Road Project and N17/N18 projects occurs within separate groundwater sub catchments to those identified for the proposed road development and as such any impacts from these projects will not impact on the groundwater systems that the proposed road development straddles.

The proposed Galway Harbour Port Extension is located within the same GWB sub-catchment as the proposed road development but is located significantly downgradient of the proposed road development in transition coastal waters.

The Galway Transport Strategy includes some realignment of local roads but these do not incorporate cuttings or structures that could impact on groundwater.

The cumulative impact of the proposed road development with existing stresses on the hydrogeological environment and those in development or in planning has been considered. On the basis of the design and mitigation measures employed for the proposed road development there will be no alteration of groundwater pathways and hence no enhanced impact from existing pollutant sources within groundwater bodies. Furthermore, those new developments being constructed or proposed are located in different GWB sub catchments or located significantly downgradient so as not to cumulate impacts.

On this basis the cumulative impacts of the above developments with the proposed road development is negligible.

10.8 Summary

The hydrogeological study area is divided into two main areas on the basis of the contrasting aquifer properties for the two main geological rock types in the region; the Galway Granite Batholith in the west and the Visean Undifferentiated Limestone in the east.

In the western section underlain by granite is a poor aquifer that is only productive in local zones. The combination of poor aquifer and blanket bog cover, where rock is not exposed, limits the quantity of recharge that can infiltrate to ground. The groundwater table remains close to the surface and generally follows topography. The area is divided into two groundwater bodies the Spiddal GWB, which drains to Galway Bay and the Maam-Clonbur GWB which drains to the River Corrib. Groundwater flow in the Galway Granite Batholith is isolated to weathered zones and fracture zones and pathways generally tend to be up to 100m.

In the eastern section the Visean Undifferentiated Limestone is a regionally important karstified aquifer, which is dominated by conduit flow. The aquifer is capable of supplying regionally important abstractions and is associated with the presence of karst landforms and features but also the relatively low abundance of surface water features and man-made drainage. The Visean Undifferentiated Limestone is subdivided into groundwater bodies; Lough Corrib Fen 1 (Menlough), Lough Corrib Fen 3 & 4, Clarinbridge, Clare-Corrib and Ross Lake. Features within the groundwater bodies, including Coolagh Lakes, Ballindooley Lough and the Terryland River are located on valley fill which cause the features to become perched during low groundwater levels.

Groundwater receptors have been identified in both sections and include groundwater resources, groundwater abstractions, groundwater dependent habitat and groundwater dependent surface water features.

The potential impacts of the proposed road development on the hydrogeological receptors including groundwater resources, groundwater supplies, groundwater dependant terrestrial ecosystems and groundwater contributions to surface water have been assessed.

Groundwater Resources and Supplies

Where road cuttings are proposed then part of the aquifer will be removed, however, this amounts to a very small part of the aquifers and will have no perceptible impact on groundwater quantity. The water quality of the aquifers will not deteriorate due to the proposed road development and as such the proposed road development meets the requirements of the European Water Framework directive. The assessment highlights that five wells will be removed by the proposed road development. These wells will be decommissioned based on IGI guidelines.

All wells within 150m of the proposed development boundary (or within 150m of the drawdown zone of influence, whichever is the greater) will be monitored for 12 months before construction, during the duration of construction and for 12 months following completion.

Groundwater Dependant Terrestrial Ecosystems

Potential impacts from the proposed road development have been assessed for the hydrogeological setting of ecological habitats within the study area. The assessment has identified that karst is present in the Visean Undifferentiated Limestone and accordingly a karst protocol has been developed between geotechnical and hydrogeological specialists to mitigate against karst and to remove the risk of impact from the proposed road development encountering karst. There are no significant negative residual hydrogeological impacts to European sites due to the proposed road development.

Groundwater Contributions to Surface Water

Groundwater contributions to surface water have been assessed as part of this study, which has included identification of the surface water that groundwater bodies contribute to. The study has identified that there will be no significant negative impact in the groundwater contribution to surface water.

10.9 References

Central Statistics Office. Statistical Release 25th April 2017. Domestic Metered Public Water Consumption.

Department of the Environment and Local Government. (DELG), the Environmental Protection Agency. (EPA) and the Geological Survey of Ireland. (GSI). (1999) *Protection Schemes Guidelines*, available; http://www.gsi.ie/Programmes/Groundwater/Projects/Protection+Schemes+Guidelines.htm#summary

Environmental Protection Agency. (EPA) (2002) *Guidelines on Information to be contained in Environmental Impact Statements.*

Environmental Protection Agency. (EPA) (2003) *Advice Notes on Current Practice in the Preparation of Environmental Impact Statements.*

Environmental Protection Agency. (EPA) (11 September 2013) *Advice Note No.14. Borehole Construction and Wellhead Protection.*

Environmental Protection Agency. (EPA) (2015) *Draft Revised Guidelines on Information to be contained in Environmental Impact Statements.*

Environmental Protection Agency. (EPA) (2015) *Draft Advice Notes for Preparing Environmental Impact Statements*.

Transport Infrastructure Ireland. (2015) *Design Manual for Roads and Bridges.*

Environmental Protection Agency. (Draft August 2017) *Guidelines on the Information to be contained in Environmental Impact Assessment Reports*.

OSI. (2015) Current and historical maps available.

GSI. (2004a) Spiddal Groundwater Body: *Summary of Initial Characterisation (1st Draft, June 2004).*

GSI. (2004b) *Maam-Clonbur Groundwater Body: Summary of Initial Characterisation (1st Draft, July 2004).*

GSI. (2014) *Bedrock Geology 1:100,000, Bedrock Boreholes, Karst Features, Groundwater Aquifers, National Draft Generalised Bedrock map (Groundwater Rock units), National Vulnerability and National Groundwater Recharge maps. available*; www.dcenr.gov.ie

Institute of Geologists of Ireland. (IGI) (2007) *Guidelines for the Water Well Construction*.

Institute of Geologists of Ireland. (IGI) (2013) *Guidelines for the Preparation of Soils, Geology and Hydrogeology Chapters of Environmental Impact Statements*.

Pracht, M. and Somerville I.D., (2015) *A Revised Mississippian lithostratigraphy of County Galway (western Ireland) with analyses of Carbonate lithofacies, biostratigraphy, depositional environments and paleogeography reconstructions utilising new borehole data. Journal of palaeogeography. Volume 4, Issue 1, January 2015, Pages 1-26.*

Transport Infrastructure Ireland. (TII) (2015) *Design Manual for Roads and Bridges* DN-DNG-03065/NRA HD 45/15/Method C.

Transport Infrastructure Ireland. (TII) (NRA, 2008) *Environmental Impact Assessment of National Road Schemes – A Practical Guide.*

Transport Infrastructure Ireland. (TII) (NRA, 2009) Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes.

Waltham, A.C. and Fookes, P. G., (2003) *Engineering classification of karst ground conditions. Quarterly Journal of Engineering Geology and Hydrogeology. Vol.36, pp. 101-118.*