Appendix A.8.2

HD45 Groundwater Protection Response Assessment

A.8.2

Galway County Council

N6 Galway City Ring Road

Groundwater Protection Response for the Use of Permeable Drains Assessment (HD45 Assessment)

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Contents

1 Introduction

Arup has been appointed by Galway County Council (GCC) as designer for the N6 Galway City Ring Road (N6 GCRR) project. As part of this commission, Arup is designing the drainage network for the proposed road. Due to the limited number of surface water bodies to the east of the River Corrib, a high number of discharges to ground at infiltration basins are incorporated into the design. The viability of discharges to ground have been considered as part of the design and this report assesses any potential environmental impacts arising from those discharges.

The Transport Infrastructure Ireland (TII) Design Manual for Roads and Bridges (DMRB) Volume 4, Section 1 includes a methodology for the preliminary screening of risks to groundwater quality (Part 1 HD/45-15 in Appendix A, Method C[1]). This methodology has been followed in this report and where necessary, a more detailed assessment has been undertaken by a qualified hydrogeologist.

1.1 Methodology

The Groundwater Protection Response (GPR) assessment methodology developed by TII is presented in **Annex A**. The GPR is a preliminary screening tool developed to assess the potential risk to groundwater quality from routine runoff from roads. Paragraph 5.29 of DN-DNG-03065 Road Drainage and the Water Environment (including Amendment No. 1 dated June 2015) states:

'The assessment methodology should be considered as a screening tool and be undertaken at the design (Phase 3 of the NRA PMG) and environmental assessment (Phase 4 of the NRA PMG) phases of a project based on the information available at that time. Sufficient information should be available during Phase 3 and 4 to carry out these assessments. The assessment should then be refined during Phases 5 and 6 (NRA PMG) if further information becomes available. Where relevant, a site specific risk assessment undertaken by qualified groundwater professional may supersede the requirements of the GPR. In these cases the assessment methodology followed should be fully outlined, the raw data provided and any interpretation of the data should be clearly explained.'

TII provides guidance on the typical quality of runoff from roads, which it refers to as routine runoff. Water quality of routine runoff is expressed as event mean concentrations (EMC) of significant contaminants (**Table 1**). The groundwater protection response (GPR) provides an assessment on the suitability of discharging routine road runoff to groundwater, without treatment as long as specific hydrogeological criteria. These hydrogeological criteria are listed as five notes and seven requirements, which apply depending on the aquifer classification and groundwater vulnerability. These conditions are set to provide protection to groundwater receptors (aquifers, Groundwater Dependant Terrestrial Ecosystems (GWDTE) and source protection zones for supply wells) and the potential

[1] Transport Infrastructure Ireland (2015). Design Manual for Roads and Bridges. TDN-DNG-03065/NRA HD 45/15/Method C

vulnerability of the groundwater at that location based on the hydrogeological characterisation of the overburden and bedrock aquifer.

Table 1: 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

The TII Groundwater Protection Response is provided below in **Table 2**, with the related Geological Survey of Ireland (GSI) vulnerability assessments provided below in **Table 3**. Based on the vulnerability information, the GPR is used to determine the appropriate 'Response' category depending on the aquifer category and vulnerability rating. Each category has conditions associated with it in the HD45 GPR and these conditions are presented in **Annex A,** which presents the full HD45 GPR guidance.

Table 2: Groundwater Protection Response Matrix for the use of permeable drains in road schemes (Taken from Table A.4, NRA DMRB, Part 1 HD 45/15)

Vulnerability rating	Source protection area	Resource protection area (aquifer category)							
		Regionally Important Aquifer			Locally Important Aquifer			Poor aquifer	
		Rk*	Rf	Rg	Lg	Lm	Ll	Pl	Pu
Extreme: Rock near Surface or karst (X)	R4	R4	R4	R3(2)	R3(2)	R3(1)	R3(1)	R3(1)	R3(1)
Extreme (E)	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.

Table 3: GSI vulnerability classification criteria

Vulnerability Rating	Hydrogeological Conditions				
	Subsoil Permeability (Type) and Thickness			Unsaturated Zone	Karst Features
	High permeability (sand/gravel)	Moderate permeability (e.g. Sandy subsoil)	Low permeability (e.g. Clayey subsoil, clay, peat)	(Sand/gravel aquifers only)	(<30 m 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 1-2 m below ground surface.

The GPR is a screening tool to assess suitability for use of permeable drainage systems along the length of the alignment. Completing the GPR is an iterative process with the assessment being updated as more information becomes available. As an initial GPR the GSI national vulnerability dataset is used, the GPR is then updated as site specific data on the hydrogeology beneath the invert level of the drain is available. As such whilst the first iteration of the GPR will be based on national datasets the assessment must be repeated as site specific data becomes available. This exercise has been completed in this report and all data provided is based on site specific data.

It should be noted that the GPR assessment is a tool to investigate the potential implications of road runoff on groundwater quality. It does not assess the potential for the drainage to cause mounding or flooding beneath the drain e.g. in areas of low permeability.

2 Groundwater Protection Response (GPR)

As outlined above, the GPR HD 45/15 methodology provides guidance for groundwater protection responses for the use of permeable drainage. This assessment comprises of a preliminary screening to determine whether permeable drainage is appropriate. As required, a hydrogeological assessment is undertaken where receptors are present or there is risk to groundwater.

A preliminary GPR is presented below and is followed by a more detailed hydrogeological assessment.

2.1 Preliminary screening

The assessment has undertaken a groundwater protection response (GPR) for use of permeable drainage on all 50 (No.) drainage networks for routine runoff (annotated as an S with a reference number e.g. S19) on the proposed road development. The assessment does not cover those sealed networks that discharge to foul sewer (which are annotated as an F and reference number e.g. F20). The GPR completed in the same format as the worked examples shown in Appendix C of HD 45/15. The results are presented in **Annex B** and are summarised as:

- 22 no. drainage networks on the Galway Granite Batholith, which are categorised as R2(1)
- 28 no. of drainage networks on the Visean Undifferentiated Limestone, which are categorised as R2(3)

Based on the drainage design, the groundwater vulnerability for the proposed road development will range between extreme (E) and moderate (M). The details of the GPR for both the R2(1) and R2(3) responses are presented below.

2.1.1 Galway Granite Batholith

The Galway Granite Aquifer is classified as poor aquifer (Pl) by the GSI. GSI Groundwater vulnerability for the Galway Granite Batholith varies between extreme (X) and moderate (M) in the natural environment. The ground investigation data collected for this project confirms the natural vulnerability range presented by the GSI.

In the built environment the vulnerability of the N6 GCRR will range from extreme (E) to moderate (M). Based on these data then where the proposed road development crosses the Galway Granite Batholith then the R2(1) GPR applies, which stipulates that permeable drainage is acceptable subject to minimum design standards in the DMRB as well as requirements 1, 2 and 3 (refer to Annex A).

Requirement 1. There is a consistent minimum thickness of 1m unsaturated subsoil, or 2m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1).

As the Galway Granite Batholith is classified as a Pl aquifer then 1m unsaturated zone is required.

Requirement 2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum.

There are no karst landforms or features in the Galway Granite Batholith. Springs and seepages may be present in granite but these are not common and do not form by dissolution processes and therefore are not karst features.

Requirement 3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required.

The hydrogeological study has identified receptors within the groundwater bodies that the proposed road development crosses.

2.1.2 Visean Undifferentiated Limestone

The Visean Undifferentiated Limestone is classified as an Rkc aquifer by the GSI. The GSI have mapped the natural groundwater vulnerability for the Visean Undifferentiated Limestone for the study area as ranging from extreme (X) to Moderate (M). The ground investigation data collected for this project generally confirms the natural vulnerability range presented by the GSI with the exception of a number of valley floors such as Coolagh Lakes, Terryland, Ballindooley Lough and Tuam Road where the GI proves the vulnerability to be low. In the built environment the vulnerability of the N6 GCRR will range from extreme (E) to moderate (M). Based on these data then where the proposed road development crosses the Visean Undifferentiated Limestone a R2(3) GPR applies, which stipulates that permeable drainage is acceptable subject to minimum design standards in the DMRB as well as requirements 1, 2, 3, 4, 5, 6 and 7 (refer to **Annex A)**.

The Visean Undifferentiated Limestone is a karst aquifer and the hydrogeological investigations for the GCRR project have shown that groundwater in the aquifer locally supports groundwater dependant terrestrial ecosystems (GWDTE). On this basis, the design strategy is to control runoff using sealed drains so that it can be treated prior to discharge. Where surface water courses are present along the alignment then appropriate discharge locations are selected and all runoff discharge to surface water, after treatment. However, where no surface water courses (or foul sewers) are present then the runoff is discharged to groundwater via infiltration basins, after treatment. As those drainage networks that drain to surface water are lined and do not have input to groundwater the GPR assessment below is only for those networks with infiltration basins (S19a, S19b, S20, S21A, S21B, S22A, S22B, S22C2, S22E, S40).

Requirement 1. There is a consistent minimum thickness of 1m unsaturated subsoil, or 2m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1).

All of the proposed infiltration basins will require excavation into the natural topography. Due to the shallow bedrock at each location, all will require an over excavation into bedrock with backfill of appropriate material. As each location will have a placed, engineered overburden rather than a natural subsoil then requirement No.4 is applied rather than requirement 1.

Requirement 2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum.

A karst survey has been completed as part of this assessment, which details the location and description of all features encountered. As per requirement 2, as the karst survey identifies that karst features are present the groundwater protection response for all infiltration basins on the Rkc aquifer is R2(3).

Requirement 3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required.

The hydrogeological assessment has identified receptors within the groundwater bodies where that the infiltration basins are located. Those receptors located within groundwater bodies where infiltration basins are proposed are highlighted for additional assessment.

Requirement 4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by *limestone bedrock, there is a consistent minimum thickness of 2m unsaturated subsoil beneath the invert level of the drainage system.*

OR

There is a minimum consistent unsaturated thickness 1m of "appropriate material" either natural or man-made beneath the invert level of the point of discharge.

Based on requirement No. 4 the design will include a minimum of 1m of appropriate material across the full extent of the infiltration basin. For all mainline infiltration basins 2m of appropriate material is used to provide a robust drainage solution to meet HD45 requirements. Using engineered overburden placement that meets the specification of Note 3 by having a minimum of 10% fines and a hydraulic conductivity of between 5 x10^{-5} and 5x10^{-7}m/s then the material will be considered as appropriate. The material will require processing prior to placement to ensure a consistent permeability and for the purposes of design a hydraulic conductivity of 1 x 10^{-5} m/s is used. As per HD45 full details of the proposed material to be used (either sourced from site or imported to site) will be submitted to TII for approval prior to use.

Requirement 5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present.

No gravel aquifers have been identified in any of the groundwater bodies that the infiltration basins will discharge to.

Requirement 6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features)).

The GPR assessment using the project karst survey confirms that there are no surface karst landforms within 15m of the infiltration basins.

Requirement 7. The site investigation shall pay particular attention to the possibility of instability in these karst areas.

The site investigation has included borehole drilling and geophysics to specifically investigate areas along the proposed road development identified during desk study and site walk over stages that may include karst.

2.2 Hydrogeological Assessment

Hydrogeological assessments are presented below for the drainage design on both the Galway Granite Batholith and the Visean Undifferentiated Limestone. For both aquifers the assessment considers how groundwater is recharged, the pathways used through the aquifer and the receptors that are dependent on groundwater.

2.2.1 Galway Granite Batholith

Irrespective of vulnerability of the Galway Granite Batholith, the limit of recharge to the bedrock is a function of the low aquifer properties, which equates to approximately 100mm/yr (Geological Survey of Ireland), which equates to a very low recharge coefficient of less than 10% of effective rainfall. Based on the GSI recharge quantification as well as the GSI classification as a poor aquifer and well testing undertaken for this project (refer to **EIA Report Chapter 10**), then the hydraulic conductivity of the Galway Granite Batholith and the rate of infiltration through the overlying subsoils to it are considered to be very low.

The GSI aquifer classification of the granite as poorly productive (Pl) indicates that there may be localised flow paths where faulting is present but based on the characteristics of the rock these flow paths will be limited in their extent. The GSI describe the Spiddal GWB as typically having a maximum flow path of 100m, which is also supported from the ground investigation undertaken for this project. The GSI state that flow paths in the Maam-Clonbur GWB are short but refer to these being 30-300m in length. Generally, whilst it is conceivable that a 300m long flow path could exist in granite these would only occur where major faults were present. On this basis the length of a pathway in any locally productive zones of the Galway Granite Batholith is considered to be 100m, with the pathway increasing to 300m in a major fault zone.

The hydrogeological investigation has taken into account receptors located within the groundwater bodies along the alignment, with particular focus on those within 250m of the proposed road development fence line. Owing to the poor yield of the Galway Granite Batholith there are very few supply wells installed in this aquifer, and none are located within 250m of the road fence line. The groundwater contribution to surface water baseflow from the Galway Granite Batholith is very low and considered not to be significant. There are a number of ecological habitats within the 250m of the proposed road development fence line, which include those part of the Moycullen Bog NHA as well as a number of locally important water dependant habits. Moycullen Bog NHA is located entirely upgradient of the proposed road development fence line and as such has a hydrogeology significance rating of imperceptible from drainage design. A number of locally important water dependant habitats will be intersected by or lie immediately downgradient of the proposed road development. Where the habitats are intersected by the proposed road development they will be permanently impacted. Where water dependant habitats lie downgradient of the proposed road development then they are only at risk if faulting is present to provide flow paths for groundwater. Major fault zones are not common in granite but if these are encountered during the construction, then these vertical features will be covered by an appropriately constructed seal (of similar design detailed in the karst protocol of the Construction Environmental Management Plan (CEMP)) to prevent connectivity with the drainage system. On this basis those water dependant habitats downgradient of the proposed road development with have an impact rating of imperceptible.

Based on the recharge cap of 100mm/yr then more than 90% of the runoff will remain overland flow and not recharge to ground. Of the runoff that recharges to ground, then these will be limited in the extent that they can migrate by the naturally low aquifer properties and sealing of significant flow zones (if are encountered) from road drainage.

Based on the drainage design and hydrogeological mitigation measures there will be no risk to groundwater quality from permeable drainage on the Galway Granite Batholith.

2.2.2 Visean Undifferentiated Limestone

The recharge rates for the Visean Undifferentiated Limestone are high, with up to 100% of effective rainfall infiltrating to ground. The high recharge rate, frequent fracture flow and presence of karst pathways provide a high degree of connectivity from recharge through the aquifer to receptors. Some groundwater bodies that the proposed road development traverse support water dependant habitats,

Based on the preliminary GPR screening for the GCRR infiltration basins then all locations have an R2(3) response, which is the minimum response for a karst aquifer. Individual hydrogeological assessments for each of the infiltration basins are presented in **Annex C**. The methodology provides an update of the preliminary screening assessment using site specific data, followed by a hydrogeological characterisation of the area where permeable drainage is proposed to determine if it will pose a risk to groundwater receptors.

The infiltration design is standardised for the proposed road development with all infiltration basins on the mainline having a minimum of 2m appropriate material below the invert level. On side roads, the depth of appropriate material will be a minimum of 1m depth. The reduced subsoil thickness for the side roads is a due to reduced spillage risk (refer to **EIA Report Chapter 11 Hydrology**) for the lower traffic count on the side road compared to mainline. The GPR requires a minimum of 1m unsaturated appropriate material below the infiltration basin invert. The 2m minimum provided on the mainline is included as a design measure to provide additional attenuation during the summer when groundwater levels are lower and dilution in the aquifer will be reduced. Where drainage networks on the mainline are discharging to groundwater bodies that support extremely high status GWDTE then the sides of the excavation are lined to ensure that infiltration drains through the full thickness of subsoil as opposed to through the sides.

As per TII HD45/15 the subsoil proposed for the infiltration basins will be appropriate material with a minimum of 10% fines and a hydraulic conductivity of between 5×10^{-5} and 5×10^{-7}m/s. For design purposes the average permeability of the material is set at 1×10^{-5} m/s so that each basin dimensions can be set to ensure that 50% of the flooded area will drain within 24hrs.

The HD45 GPR highlights the importance of groundwater receptors and identifies that where these are present then additional assessment is required.

Infiltration basins on the mainline are designed with a minimum of 2m subsoil that meets TII definition of appropriate material. Infiltration basins on side roads are designed with 1m of subsoil that meets TII definition of appropriate material.

Based on the drainage design and hydrogeological mitigation measures there will be an imperceptible risk to groundwater quality from permeable drainage on the Visean Undifferentiated Limestone.

A summary of the results of the detailed assessment, which are presented in full in **Annex C**, are summarised below in **Table 4**.

Table 4: Summary of groundwater protection responses

Network ref	Basin Invert mOD	Subsoil thickness *1	Min unsaturated zone depth below invert m	HD45 GPR	Meets requirements 1-7?	Impact significance (TII 2009, guidelines[2])
S19A	11.15	2	1.4	R2(3)	Yes	Imperceptible
S19B	10.24	2	0.4	R2(3)	N/C with no.5	Imperceptible
S20	14.74	2	0	R2(3)	N/C with no.5	Imperceptible
S21A	13.75	2	2.6	R2(3)	Yes	Imperceptible
S21B	18.53	2	9.1	R2(3)	Yes	Imperceptible
S22A	14.07	2	3.1	R2(3)	Yes	Imperceptible
S22B	37.93	2	3.9	R2(3)	Yes	Imperceptible
S22C2	38.64	2	15.2	R2(3)	Yes	Imperceptible
S22E	45.71	2	9.9	R2(3)	Yes	Imperceptible
S40	7.61	1	1	R2(3)	Yes	Imperceptible

Note:

*1 All infiltration basins will be constructed using Appropriate material as defined in HD45/15 Method C Note 5[3]

N/C = Non-compliance

The winter groundwater levels used in this assessment were recorded during the winter of 2015/16 which is accepted as being as being the wettest winter on record and considered an extreme event by Walsh, 2016 [4]as well as Nicholson *et al*., 2016[5].

3 Conclusions

The groundwater protection response (GPR) for the proposed road development has concluded that where the alignment crosses the Galway Granite Batholith then the GPR has a R2(1) response, whilst where the road crosses the Visean Undifferentiated Limestone then the GPR has a R2(3) response.

The drainage design across the Galway Granite Batholith incorporates a permeable design with discharge to surface water. The hydrogeological assessment has been undertaken for the Galway Granite Batholith and this confirms that the aquifer properties of the bedrock are low and that groundwater pathways are limited in occurrence as well as width and length. On this basis permeable drainage is acceptable for the proposed road development where it traverses the Galway

[2] Transport Infrastructure Ireland (TII) Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes (TII, 2009)
[3] TII Design Manual for Roads and Bridges. DN-DNG-03065/NRA HD 45/15/Method C.(TII, 2015)
[4] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016
[5] Nicholson, O., Gebre, F., Casey, J and Synott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

Granite Batholith subject to minimum DMRB conditions and GPR requirements 1, 2 and 3. In the event of a vertical flow zone being encountered where a fault crosscuts the proposed road development then the drainage design will be sealed to prevent communication between flow zone and runoff.

The 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 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.

Based on the infiltration basin hydrogeological assessments a number of measures have been proposed and these are detailed below:

1. All infiltration basins have been sited away from known surface karst features. Ground investigations have been undertaken to determine if subsurface karst is present at the proposed sites. However, it is still possible that subsurface karst features may be encountered during the excavation. If karst features are encountered, then these are be mitigated against by following the karst protocol detailed in the CEMP, which includes inspection of potential karst features by a geotechnical engineer and a hydrogeologist.
2. The hydrogeological assessments have identified that groundwater flooding has occurred at Lackagh Quarry during extreme groundwater level conditions, such as that observed during the winter of 2015/16. As a mitigation measure infiltration basin S20 has been oversized in order to provide additional capacity in the case of an extreme event. Under normal winter groundwater levels, flooding does not occur.
3. By incorporating an emergency spillage containment area as well as pre-treatment by hydrocarbon interceptor and wetland prior to the infiltration basin then the water quality at infiltration will be of a higher quality than routine runoff (as listed in HD45/15) and to the same standard as surface water discharges. On this basis, in the event of extreme events where groundwater flooding may occur adjacent to the basin then the discharge will not cause deterioration of groundwater quality.
4. All infiltration basins will be checked by a hydrogeologist on a 5 yearly basis to confirm that there is no unexpected subsidence in the level of the appropriate material. If subsidence is present, then the karst protocol detailed in the CEMP will be used to excavate and examine the location to ensure that no karst flow paths have developed in the basin.

On the basis of this hydrogeological assessment the design and measures of the infiltration basins assessed are considered to meet the criteria for HD45/15 for permeable drainage in the Visean Undifferentiated Limestone.

Incorporating pre-treatment of runoff with the infiltration basin along with the mitigation of the karst protocol, monitoring at receptors for turbidity during construction and long term checks for settlement in the basins then multiple levels of protection will be in place to ensure that the significance rating of impacts to receptors from infiltration basins will be imperceptible in the Visean Undifferentiated Limestone.

Annex A

Assessment Method C

f) chloride; and

g) alkalinity.

As with the simple assessment, at least five water samples spread over a six month period will be required. It is advised that all parameters are included in the original analyses so that the sampling procedure does not need to be repeated if a detailed assessment is required.

B.5 Following the procedure in Figure A.4, if the bioavailability tests show that no ecological impact is expected then no further action need be taken with respect to annual average concentrations. If an impact is predicted then mitigation should be considered. Mitigation can be included in HAWRAT at Step 3 (refer to paragraphs A.19 to A.21 for further information). The post-mitigation annual average concentrations of copper and zinc can then be re-run through the procedure shown in Figure A.4. Once both Method A and Method B assessments have been completed, Table 5.2 should be consulted for advice on how to proceed.

METHOD C – GROUNDWATER PROTECTION RESPONSE FOR THE USE OF PERMEABLE DRAIN SYSTEMS ON ROAD SCHEMES

Background

C.1 Groundwater in Ireland is protected under European Union and national legislation. Local authorities and the Environmental Protection Agency (EPA) have responsibility for enforcing this legislation. The Geological Survey of Ireland (GSI) in conjunction with the Department of Environment, Community and Local Government (DECLG) (formerly the Deparment of Environment and Local Government, DELG) and the EPA have developed a methodology for the preparation of groundwater protection schemes to assist the statutory authorities and others to meet their responsibility to protect groundwater (DELG/EPA/GSI, 1999). This methodology incorporates land surface zoning and groundwater protection responses.

These groundwater protection responses are concerned with routine runoff from roads and do not deal with spillages.

The risk to groundwater from road runoff is mainly influenced by:

a) Hydraulic and contaminant load. This will be a function of the rainfall, traffic count and contaminants expected.

b) The infiltration capacity of the subsoil. This will determine whether, and how fast, the soil will drain or whether ponding will occur.

c) The thickness, permeability and moisture content of the unsaturated zone. The thickness of the unsaturated zone will be a function of the depth to the water table and whether the drainage is at grade, in a cut or in fill. The vertical permeability of the unsaturated zone will influence the infiltration capacity.

d) The thickness and porosity of the saturated subsoil.

e) The presence or lack of weathered bedrock.

f) The attenuation capacity of the subsoil.

g) Groundwater flow mechanisms i.e. whether horizontal flow is intergranular or fracture flow.

C.2 The topsoil and subsoil, depending on their type, permeability and thickness, play a critical role in preventing groundwater contamination and mitigating the impact of many potential pollutants. They act as a protecting filtering layer over groundwater. The vulnerability of the groundwater is the most important factor in deciding on the control measures for any area. It should be noted however, that in areas classed as 'Low Vulnerability' (thick deposits of low permeability subsoils) there may be an increased risk to surface waters due to run-off, which should be addressed in the drainage design.

C.3 In general the pollution risk is greater near groundwater abstraction sources, in particular within the Inner Protection Area.

C.4 Guidance presented in this document is based on the precautionary principle. This guidance should be used to assist in the design of road drainage and the decision as to whether impermeable drainage systems are required to protect groundwater. Each road design will be unique and should take local site specific factors into account in applying the responses.

C.5 If the assessment is undertaken and determines that permeable drainage is not suitable, mitigation measures can be designed and incorporated into the proposed design. The GPR assessment should be undertaken again at this stage, this time considering the proposed mitigation measures. The stages of the assessment, including any iterations of the assessment to include mitigation measures, should be fully documented.

C.6 These groundwater protection responses should be read in conjunction with Groundwater Protection Schemes (DELG/EPA/GSI, 1999).

Routine runoff from roads: a Potential Hazard for Groundwater

C.6 A broad range of potential pollutants is associated with routine runoff from operational roads. These are combustion products of hydrocarbons, fuel and fuel additives, catalytic converter materials, metal from friction and corrosion of vehicle parts, lubricants, and materials spread during gritting and de-icing. Particulate contaminants originating from vehicles and vehicle related activities include carbon, rubber, plastics, grit, rust and metal filings.

C.7 Most organic compounds have very low solubility in water. Such compounds can occur in routine runoff and include a wide range of polycyclic aromatic hydrocarbons (PAHs). Other materials may be deposited on road surfaces such as wind blown soils from adjacent land.

C.8 Studies referenced by the UK Highways Agency (HA) show that routine road runoff contains both dissolved and particulate contaminants. A large number of studies have investigated the concentrations of contaminants in road runoff. These studies have investigated a variety of road types in a number of countries. Research into the concentrations of contaminants in road runoff shows a large variation in concentrations of those contaminants detected. Applied road salt may also enhance the release of toxic metals from silts and sludge.

C.9 The UK HA has undertaken collaborative research in England with the Environment Agency (EA) to significantly improve the reliability and extent of existing data for pollutants and their concentrations found in road runoff from non-urban trunk roads and motorways. The results were used to identify a list of significant pollutants that are routinely found in road runoff and which pose a risk of short-term acute impacts (from soluble pollutants) and/or long-term chronic impacts (from sediment-bound pollutants) on ecosystems. The study also identified those site characteristics that influence pollutant concentrations.

Table A.3: Summary of EMCs and Loads from in road runoff for Significant Pollutants (UK HD 45/09)

Determinand	Runoff Concentration						Runoff Load	
	Units	LOD	Min. EMC	Mean EMC	Median EMC	Max. EMC	Mean/ 1000m²	Units
Total Copper	µg/l	0.3	4.00	91.22	42.99	876.80	0.66	g
Dissolved Copper	µg/l	0.3	2.15	31.31	23.30	304.00	0.16	g
Total Zinc	µg/l	0.6	9.73	352.63	140.00	3510.00	2.44	g
Dissolved Zinc	µg/l	0.6	4.99	111.09	58.27	1360.00	0.50	g
Total Cadmium	µg/l	0.01	<0.01	0.63	0.29	5.40	0.00	g
Total Fluoranthene	µg/l	0.01	<0.01	1.02	0.30	12.50	0.01	g
Total Pyrene	µg/l	0.01	<0.01	1.03	0.31	12.50	0.01	g
Total PAHs (Total)	µg/l	0.01	<0.01	7.52	3.33	62.18	0.04	g

LOD = Analytical limit of detection

Groundwater Protection Response Matrix for the use of permeable drain systems on Road schemes

C.10 The reader is referred to the full text in Groundwater Protection Schemes (DELG/EPA/GSI, 1999) for an explanation of the role of groundwater protection responses in a groundwater protection scheme.

C.11 The role of the groundwater response matrix is to provide an initial evaluation of the general suitability of a permeable drainage system for National Road schemes. This should be carried out for each drainage catchment to determine the requirements for impermeable drainage systems. It takes account of the resource protection area, the Source Protection Area (SPA) and the vulnerability of the groundwater.

C.12 A permeable drainage system, for the purposes of this assessment, is one that allows infiltration of surface water runoff to ground.

C.13 A risk assessment approach is taken in the development of this response matrix. A precautionary approach is taken because of the variability of Irish subsoils and bedrock.

C.14 Prior to proceeding to the response matrix, if a permeable drainage system is being considered the following points should be investigated to confirm they won't preclude the use of a permeable system:

a) Is the ground capable of accepting infiltration? This should be confirmed through site specific testing.

b) Is there a risk of groundwater flooding?

c) Is there the risk of karst reactivation through discharges to ground?

C.15 The appropriate response to the risk of groundwater contamination is given by the assigned response category (R) appropriate to each protection area (Refer to Table A.4). Individual design responses are assigned based on the risk to groundwater resources. The risk to groundwater resources is determined based on the following criteria:

a) **Aquifer category:** subdivides areas according to the value of the groundwater resources or aquifer category. This can be used to identify karst or high resource value aquifers. The GSI aquifer maps (bedrock and gravel) should be used to determine the resource protection area. If a gravel aquifer is present, the requirements for the protection of this aquifer will supersede those for the protection of the bedrock aquifer beneath it.

b) **Groundwater vulnerability**: subdivides the entire land surface according to the vulnerability of the underlying groundwater to contamination and is based on the thickness and permeability of the overburden above the aquifer. The groundwater vulnerability should be determined on a site specific basis based on the ground investigation information available. The appropriate vulnerability should be calculated based on the criteria for a bedrock or gravel aquifer outlined in Groundwater Protection Schemes (DELG/EPA/GSI, 1999). The invert level of the drain is the point of discharge and this should be used as the criteria to determine the vulnerability, not the existing ground level.

c) **Source Protection Areas:** delineates areas contributing to public groundwater supplies and will identify the location of important resources such as public and group supply sources. Source Protection Areas (SPA) are divided into the Inner Protection Area (SI) and Outer Protection Area (SO) based on the travel time for any potential contamination, however this assessment considers the SPA as a whole, with the same protection criteria applied to the SO and SI. The GSI and EPA mapping tools define 'Drinking Water Protection Areas' and these should be consulted to determine the extents of the Inner and Outer Protection Areas.

C.16 A series of notes have been developed to accompany the matrix in Table A.4 which apply in all situations. These are as follows:

Note 1: The assessment methodology should considered as a Screening tool and be undertaken at the Design (Phase 3 of the NRA PMG) and environmental assessment (Phase 4 of the NRA PMG) phases of a project based on the information available at that time. It should be refined during Phases 5 and 6 (NRA PMG) if more information becomes available. Where relevant, a site specific risk assessment undertaken by qualified groundwater professional may superceed the requirements of this assessment. In these cases the assessment methodology followed should be fully outlined, the raw data provided and any interpretation of the data should be clearly explained.

Note 2: The vulnerability rating should be determined on a site specific basis based on the material below the invert level of the point of discharge to ground. Information on this material should be obtained from ground investigations and may be reassessed as more information becomes available.

Note 3: The matrix responses refer to "Appropriate material": This material may be natural in-situ material which should be unsorted, have a minimum of 10% total fines and less than 13% clay content, have a post compaction infiltration rate ranging from $5x10^{-5}$ to $5x10^{-7}$ m/s and be classed (using BS5930) as either; silty SAND, sandy SILT or SILT/CLAY. If the designer/contractor proposes to use reworked or process material to fulfil the requirements of the unsaturated zone, full details must be submitted to the NRA for approval prior to use.

Note 4: Cuts into rock will require impermeable drainage systems OR the placement of material in line with Note 3 beneath the invert level of the drain. Where the drainage system in a rock cut is being used to lower the water table to prevent groundwater discharging into the cut (the road), a separate impermeable or closed system must be designed to deal with the surface runoff.

Note 5: Where over the edge drainage is being used on permeable embankments over 1m high, the GPR assessment based on the invert level of the discharge point, is a conservative assessment. In these scenarios, if the designer wishes to use a permeable system where the response from the GPR is recommending an impermeable system, the designer must demonstrate that there is no risk to groundwater at that location.

Table A.4: Groundwater Protection Response Matrix for the use of permeable drains in road schemes

Vulnerability rating	Source protection area	Resource protection area (aquifer category)							
		Regionally Important Aquifer			Locally Important Aquifer			Poor aquifer	
		Rk*	Rf	Rg	Lg	Lm	Ll	Pl	Pu
Extreme: Rock near Surface or karst (X)	R4	R4	R4	R3(2)	R3(2)	R3(1)	R3(1)	R3(1)	R3(1)
Extreme (E)	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.

<table>
<tr><td>R1</td><td>Acceptable subject to minimum design standards in the NRA DMRB and Notes 1 and 2.</td></tr>
<tr><td colspan="2">R2</td></tr>
<tr><td>R2(1)</td><td>Acceptable subject to minimum design standards in the NRA DMRB and to meeting the following requirements :

1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1).

2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum.

3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required.</td></tr>
</table>

R2(2)	Acceptable subject to minimum design standards in the NRA DMRB, meeting requirements 1, 2 and 3 of above and the following additional requirements: 4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system. OR There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the point of discharge. 5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present.
R2(3)	Acceptable subject to minimum design standards in NRA DMRB, meeting requirements 1, 2, 3, 4 and 5 above and the following additional requirements: 6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features)). 7. The site investigation shall pay particular attention to the possibility of instability in these karst areas.
R3	
R3(1)	Not generally acceptable, unless requirements 1, 2, 3 and 4 and the following additional requirements are met: 8. If discharge to surface water is not possible then additional assessments by an appropriately qualified groundwater specialist are required to determine the risk to groundwater resources (the aquifer).

R3(2)	Not generally acceptable, unless requirements 1, 2, 3, 4, 5 (in karst areas), 6 (in karst areas), 7 and 8 and the following additional requirements are met: 9. A risk assessment undertaken by a qualified hydrogeologist demonstrates that there will be no significant impact to groundwater or receptors. AND 10. A treatment system which treats pollutants through filtration, sedimentation, absorption etc should be incorporated into the system prior to discharge.
R4	Not acceptable.

METHOD D – ASSESSMENT OF POLLUTION IMPACTS FROM SPILLAGES

D.1 This method provides an indication of the risk of a spillage causing a pollution impact on receiving water bodies.

D.2 This risk is defined as the probability that there will be a spillage of pollutant and that the pollutant will reach and impact the water body to such an extent that either a Category 1 or 2 incident – a serious pollution incident – occurs. Table A.5 defines these categories. The probability is the product of two separate risks:

a) the probability that there will be a spillage with the potential to cause a serious pollution incident; and

b) the probability, assuming such a spillage has occurred, that the pollutant will cause a serious pollution incident.

D.3 The risk is expressed as the probability of an incident in any one year. It is initially assessed without any mitigation measures. If mitigation measures are needed, the risk is reduced by the pollution risk reduction factor for each measure given in Table 8.1.

D.4 In most circumstances, the acceptable risk of a serious pollution incident occurring will be where the annual probability is predicted to be less than 1%. In cases where, for example, road runoff discharges within close proximity to (i.e. within 1km) a natural wetland or designated wetlands, such as SACs and SPAs, or it could affect important drinking water supplies or other important abstractions, a higher standard of protection will be required such that the risk of a serious pollution incident has an annual probability of less than 0.5%. In such cases, advice is to be sought from the EPA, IFI and NPWS.

D.5 To determine the risk, the following data are required for each reach or section of aquifer into which runoff is to be discharged:

a) the length of road in each of the categories in Table A.5;

b) the AADT two way flow for each section of road, other than slip roads, identified above (for new roads, use the design year traffic flow); and

c) the percentage of the AADT flow that comprises Heavy Goods Vehicles (HGVs) (where roads are known to carry an unusually high proportion of hazardous materials, for example to an oil refinery or creamery, a higher factor may be appropriate).

Annex B

Groundwater Protection Response
Summary of Preliminary Screening

Network	Aquifer Type	Vulnerability rating	Groundwater Protection Response (GPR)	Use of permeable drains based on GPR
S1	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S2	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S3	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S4A	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S4B	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S5A	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S5B	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S7A	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB

Network	Aquifer Type	Vulnerability rating	Groundwater Protection Response (GPR)	Use of permeable drains based on GPR
				standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S7B	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S8	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S9	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S10	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S11	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S12	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S13	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2

Network	Aquifer Type	Vulnerability rating	Groundwater Protection Response (GPR)	Use of permeable drains based on GPR
				and requirements 1, 2 &3)
S14A	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S14B	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S15	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S16A	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S16B	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S17A	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)
S17B	Pl	Extreme (E)	R2(1)	Acceptable (subject to minimum DMRB standards and GPR Note 1 & 2 and requirements 1, 2 &3)

Network	**Aquifer Type**	**Vulnerability rating**	**Groundwater Protection Response (GPR)**	**Use of permeable drains based on GPR**
S18A	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S18B	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S19A	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S19B	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S20	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S21A - Attn	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S21A - Inflt	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 &

Network	Aquifer Type	Vulnerability rating	Groundwater Protection Response (GPR)	Use of permeable drains based on GPR
				3and requirements 1, 2, 3, 4, 5, 6 & 7)
S21B	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S22A	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S22B	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S22C1	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S22C2	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S22E	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)

Network	**Aquifer Type**	**Vulnerability rating**	**Groundwater Protection Response (GPR)**	**Use of permeable drains based on GPR**
S26	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S27	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S29	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S30	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S31A	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S31B	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S31C	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 &

Network	Aquifer Type	Vulnerability rating	Groundwater Protection Response (GPR)	Use of permeable drains based on GPR
				3and requirements 1, 2, 3, 4, 5, 6 & 7)
S32	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S33	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1,2, 3, 4, 5, 6 & 7)
S36A	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S36B	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S37	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S38	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S39	Rkc	Extreme (E)	R2(3)	Acceptable (subject to

Network	Aquifer Type	Vulnerability rating	Groundwater Protection Response (GPR)	Use of permeable drains based on GPR
				minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S40	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)
S41	Rkc	Extreme (E)	R2(3)	Acceptable (subject to minimum DMRB standards and GPR Note 1, 2 & 3and requirements 1, 2, 3, 4, 5, 6 & 7)

Annex C

Detailed Assessment – GPR Infiltration Basins

Annex C

This annex presents the ground water protection response hydrogeological assessment for each location where an infiltration basin is proposed. The hydrogeological assessments presented in this annex make reference throughout to text and figures in the Volume 3 of the EIAR.

For each assessment the following format is used:

- The Groundwater Protection Response is updated using site information
- A Hydrogeological Assessment based on groundwater levels, karst and receptors at the location.

Each hydrogeological assessment is written as an individual report. For extents of drainage networks and locations of infiltration basins please refer to Drainage Design Report.

1 Drainage Network 19A

Network S19A of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

1.1 Groundwater Protection Response

A hydrogeological summary for this drainage network is presented below in **Table 1**.

Table 1: Hydrogeology summary for S19A

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	11.15m OD
Subsoil thickness	2m
Summer groundwater level (m below invert level)	3.6m (7.6m OD)
Winter groundwater level (m below invert level):	1.4m (9.8m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an ‘Extreme’ (E) vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 2**.

Table 2: Groundwater protection response for S19A

<table>
<tr><th>Relevant requirements from matrix (Note ref)</th><th colspan="2">Site specific answers</th></tr>
<tr><td>1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)</td><td colspan="2">2m subsoil
Summer groundwater level 3.6m below invert
Winter groundwater level 1.4m below invert
*see note 1</td></tr>
<tr><td>2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum</td><td colspan="2">The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics
No karst features recorded within 15m</td></tr>
<tr><td>3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required</td><td><u>Receptors</u>
Turlough (K20)
Turlough (K31)
Eastern Coolagh Spring (K45)
Western Coolagh Spring (K25)</td><td><u>Distance</u>
850m W
300m NW
250m SE
800 SW</td></tr>
<tr><td>4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system
OR
There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system</td><td colspan="2">The basin will be sufficiently over excavated so that a minimum of 2m appropriate material (HD45/15) can be placed below the infiltration invert</td></tr>
<tr><td>5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present</td><td colspan="2">Not relevant.</td></tr>
</table>

Relevant requirements from matrix (Note ref)	Site specific answers
6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))	There are no surface karst features within 15m
7. The site investigation shall pay particular attention to the possibility of instability in these karst areas	The infiltration basin is located on limestone bedrock. GI undertaken includes: • geophysics (GP3/8) • borehole (BH3/29) • trial pits (TP3/24, TP3/36) • soakaway test (SW3/01)

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[1] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[2] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

On the basis of there being a minimum consistent thickness of 1m of appropriate material beneath the invert level of the infiltration basin then drainage network S19A meets HD45/15 requirements.

Survey of all karst landforms was completed as part of the karst survey (refer to EIA Report **Chapter 10, Hydrogeology**). The karst survey confirms that surface karst is not present within 15m of the infiltration basin location. Ground investigation undertaken at and near the infiltration basin did not encounter subsurface karst below the infiltration basin. Groundwater receptors are located downgradient of the infiltration basin and these are presented in the detailed hydrogeological assessment below.

[1] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.

[2] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

1.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst
- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)
- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations.

1.2.1 Groundwater levels

The hydrogeological assessment for the infiltration basin at network S19A is based on groundwater levels recorded in BH3/29, BH972 and RC133, which are in the immediate vicinity of S19A, as well as BH04, LQ MW4, RC1104 and RP-2-03 which are located to the east of S19A at Lackagh Tunnel, Lackagh quarry and Ballindooley. The assessment takes into account trial pits and soakaway tests undertaken near the site of the infiltration basin. A schematic section of groundwater levels is shown in **Plate 1** and **Table 3**. Groundwater monitoring locations are shown in Hydrogeology HD45 Assessment **Figure 10.6.001** to **Figure 10.6.012**.

Plate 1: Groundwater levels in the vicinity of S19A

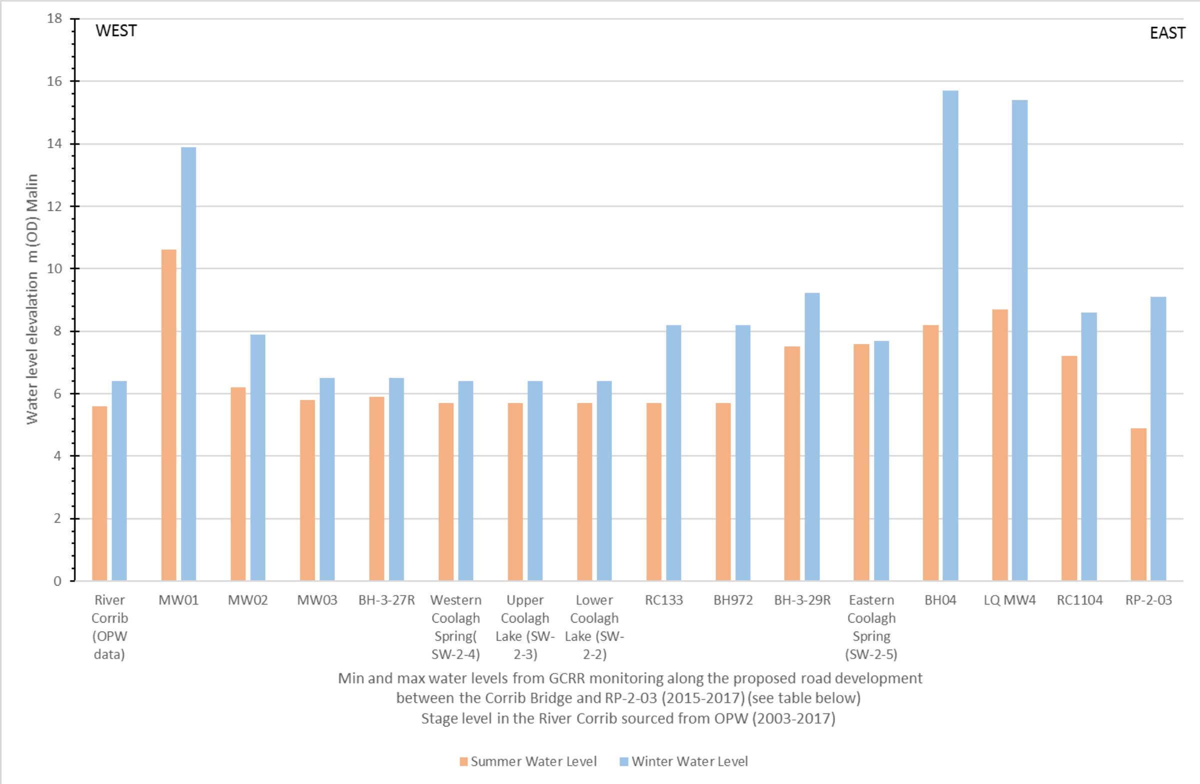


Table 3: Groundwater levels in the area of infiltration basin S19A

Monitoring Location	Ground Elevation	Summer Water Level	Winter Water Level	Seasonal Change
	(mOD)	(mOD)	(mOD)	(m)
River Corrib (OPW data)	-	5.6	6.4	0.8
MW01	16.1	10.6	13.9	3.3
MW02	13.4	6.2	7.9	1.7
MW03	6.7	5.8	6.5	0.7
BH-3-27R*	9.1	5.9	6.5	0.6
Western Coolagh Spring (K25)	5.4	5.7	6.4	0.7
Upper Coolagh Lake (K45) (SW-2-	-	5.7	6.4	0.7
Lower Coolagh Lake (SW-2-2)	-	5.7	6.4	0.7
RC133	11.7	5.7	8.2	2.5
BH972	12.3	5.7	8.2	2.5

Monitoring Location	Ground Elevation	Summer Water Level	Winter Water Level	Seasonal Change
	(mOD)	(mOD)	(mOD)	(m)
BH-3-29R*	13.7	7.5	9.2	1.7
Eastern Coolagh Spring (SW-2-5)	7.4	7.6	7.7	0.1
BH04	32.2	8.2	15.7	7.5
LQ MW4	16.8	8.7	15.4	6.7
RC1104	9.4	7.2	8.6	1.4
RP-2-03	22.4	4.9	9.1	4.2

*Monitoring from Spring 2016-Winter 2016 only.

The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**. On the basis of these data there is a groundwater ridge east of S19A in the vicinity of BH04 and a groundwater ridge west of S19A near MW01. These groundwater ridges divide the aquifer into groundwater bodies. The groundwater ridge near BH04 divides the aquifer in the Lough Corrib Fen 1 (Menlough) GWB in west and the Clare-Corrib GWB in the east.

The groundwater levels in the Lough Corrib Fen 1 (Menlough) GWB identify that the groundwater level at infiltration basin 19A drains westwards towards turlough K31 and Western Coolagh Spring (K25 and monitoring location SW-2-4).

Water level monitoring at Eastern Coolagh Spring indicates that the ponding does not have a significant seasonal response. Bedrock does not outcrop at Eastern Coolagh Spring and GSI subsoil mapping as well as the GI undertaken for N6 GCRR shows significant increase of thickness at the Coolagh Lakes and K45. On this basis of its location and its geological setting, Eastern Coolagh Spring (K45) is not considered to be a receptor for infiltration basin 19A.

Based on this conceptual model, the groundwater level in the Lough Corrib Fen 1 (Menlough) GWB, only overflows to Upper Coolagh Lake where groundwater can rise over the thickness of subsoil deposits, which only occurs at Western Coolagh Spring and not Eastern Coolagh Spring. The conceptual model for the groundwater inflow to Upper Coolagh Lake during high and low groundwater levels is presented in **Plate 2** and **Plate 3** below.

Plate 2: Schematic north south cross-section through Coolagh Lakes (groundwater high)

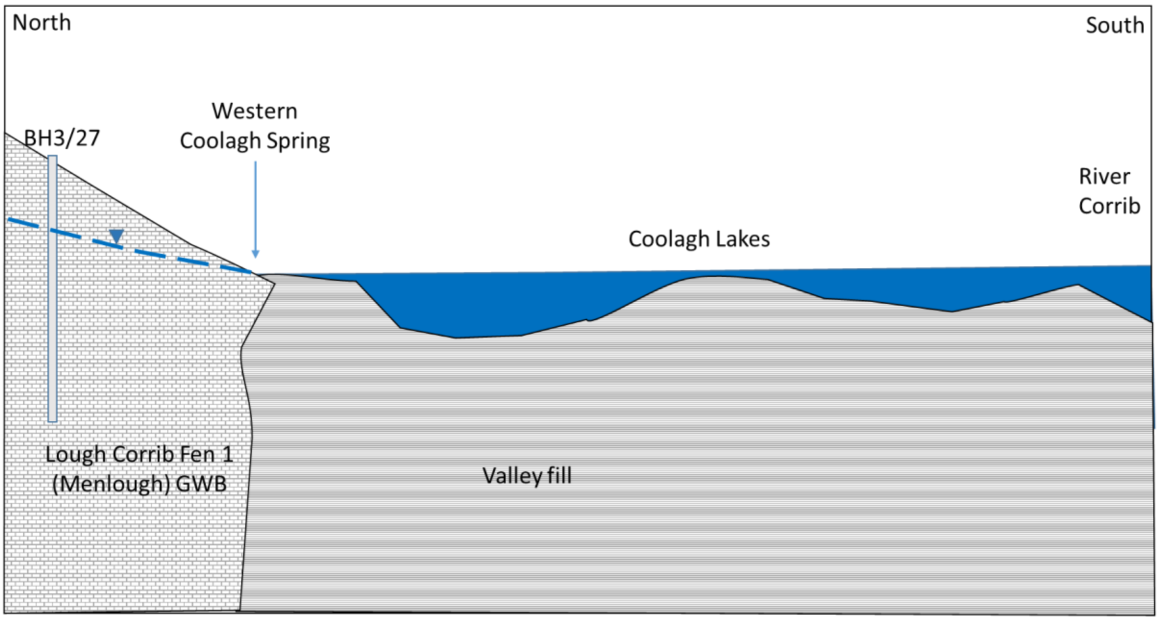
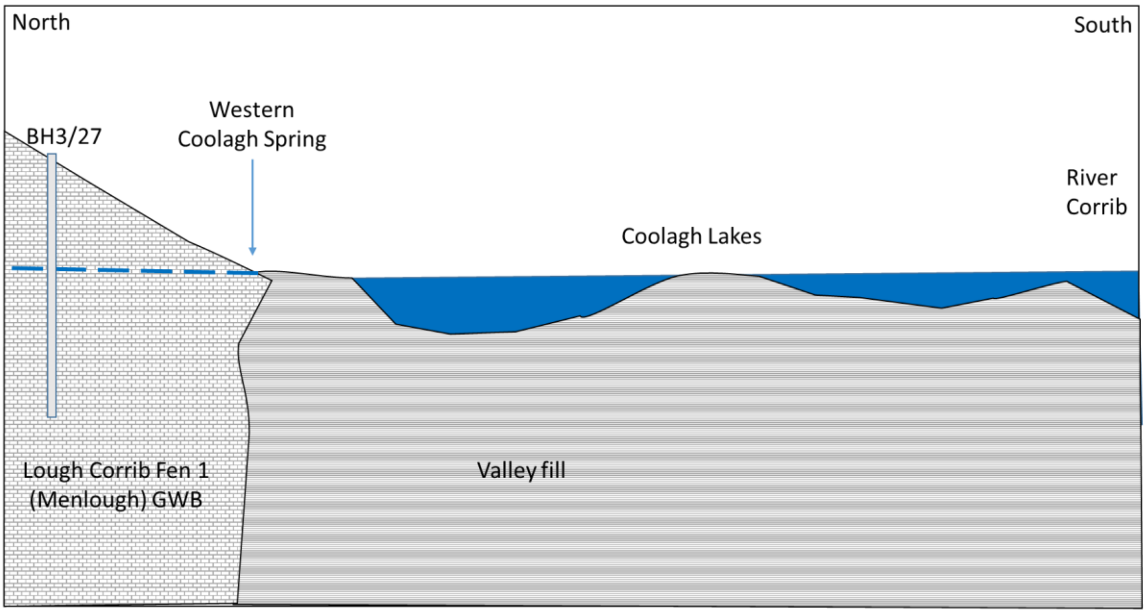


Plate 3: Schematic north south cross-section through Coolagh Lakes (groundwater low)



During the summer groundwater levels in BH972 and RC133 lower to the elevation of the Western Coolagh Spring (K25). Further to the west, there is a small groundwater ridge between Western Coolagh Spring (K25) and the River Corrib (as shown in monitoring wells MW01 and MW02). As such, downgradient of infiltration basin S19A will only extend as far as Upper Coolagh Lake at Western Coolagh Spring (K25). On this basis Western Coolagh Spring and Upper Coolagh Lake is a likely receptor for infiltration S19A.

1.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report (refer to EIA Report **Chapter 10, Hydrogeology**).

There are three active karst features downgradient of network S19A infiltration basin, these are two turloughs (K20 and K31) and Western Coolagh Spring (K25). Eastern Coolagh Spring (K45) is not a karst feature being located on thick subsoil deposits. Other karst features in the vicinity include the sediment filled palaeokarst feature at the Lackagh Tunnel western portal (refer to N6 GCRR Lackagh Tunnel Report), which extends for 200m east of, and upgradient of, infiltration basin S19A. A second palaeokarst feature (or potentially a buried valley feature) is located south of infiltration basin S19A. These features, both active karst and palaeokarst, are described below in relation to infiltration basin S19A.

Turlough K20 lies 850m northwest of infiltration basin S19A. It lies outside of the catchment to S19A in the Lough Corrib Fen 2 groundwater body. Based on the water level data provided and the groundwater bodies delineated by GSI and reinterpreted as part of the N6 GCRR assessment, turlough K20 lies outside of the catchment for infiltration basin S19A and is not hydraulically connected to it.

Based upon the groundwater level data, turlough K31 lies 300m downgradient of infiltration basin S19A. The turlough floods seasonally, between October and March. Water level spot measurements were made in K31, which all matched the groundwater level recorded in nearby borehole RC133. During the winter period when the turlough is flooded it will be a receiving water for the treated road runoff.

Western Coolagh Spring (K25) is a perennial karst spring, which discharges into Upper Coolagh Lake. The estimated flow rate varies though out the year from an estimated 35l/s to less than 1ls. The water level at the spring was recorded by logger from summer 2015 to spring 2016 but due to vegetation in the stream it was not possible to measure the flow velocity accurately and measure the exact flow rate. Based on the conceptual model for the Lough Corrib Fen 1 (Menlough) GWB, the catchment for the spring extends upgradient from the spring towards BH04. Western Coolagh Spring (K25) lies 800m south west from S19A and is a receiving water for the infiltration basin. The Lough Corrib Fen 1 (Menlough) GWB does not include point recharge in the form of dolines or shake holes, instead all recharge is diffuse across the GWB catchment. Other than Coolagh Western Spring (K25) there is no evidence indicative of conduit flow in the GWB.

The palaeokarst feature identified in the Lackagh Tunnel Report is a deep (104.95m) conical shaped karst feature that has been infilled with well consolidated silt and clay. The feature is non active and is located upgradient of infiltration basin S19A. As the hydraulic gradient is away from this palaeokarst feature there is no risk of reactivation or washout in the karst pathways. The well consolidated silt and clay infilling the feature are of low permeability, there will be no flow through this palaeokarst or the similar buried feature that lies to the south of infiltration basin S19a. Features such as that identified in at Lackagh Tunnel western approach are inert and act as barriers to groundwater flow. They compartmentalise the limestone aquifer into discrete groundwater bodies and restrict groundwater flow direction.

As part of the ground investigation for S19A drilling, trial pitting and geophysics was undertaken in the vicinity of infiltration basin S19A. The trial pit at the location of infiltration basin (SW3/01) encountered slightly sandy gravelly Clay with occasional cobbles and occasional boulders from ground level (13.3m OD) to 1.5m (11.8m OD) where probable limestone bedrock was encountered. As the basin invert lies at 11.15m OD the over excavation will be entirely in bedrock. The resistivity surveying (GP3/8) identifies that competent bedrock underlies S19A but that there is a possibility of a weathered zone being encountered.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

1.2.3 Receptors

The hydraulic gradient within the Lough Corrib Fen 1 (Menlough) GWB is westwards. Hydrogeological receptors that could receive recharge from the infiltration basin include the groundwater itself and any abstraction wells and groundwater dependant terrestrial ecosystems (GWDTE) that lie downgradient from the infiltration basin.

There are no groundwater abstraction wells in the Lough Corrib Fen 1 (Menlough) GWB.

GWDTE downgradient of infiltration basin 19A include the Coolagh Lakes (fed from K25 Western Coolagh Spring) and turlough K31. As described above in the section on karst, both the Coolagh Lakes and turlough K31 are groundwater fed. On this basis, the groundwater below and downgradient of the infiltration basin and GWDTE turlough K31 and Coolagh Lakes are potential receptors.

Western Coolagh Spring supplies the sole significant groundwater inflow to Upper Coolagh Lake, with the only other supply coming from a component of runoff and seepage from the thick subsoils around the periphery of the lakes, including the surface water ponding at Eastern Coolagh Spring (K45).

1.3 Summary

Drainage network S19A comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 2m over excavation in bedrock with backfill of 2m appropriate material. Based on the groundwater monitoring data collected over the monitoring period the infiltration basin will provide 1.4m unsaturated zone during an extreme winter event and 1.7m unsaturated zone during a typical winter. The infiltration basin does not meet the minimum 2m unsaturated subsoil design requirement (Note 1) but it does meet the minimum 1m appropriate material requirement (Note 4). The invert level of the infiltration basin has been raised to as high an elevation as possible whilst maintaining the necessary fall on the drainage system.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin. The assessment has identified that turlough K31 lies 300m downgradient and Western Coolagh Spring (K25) lies 800m downgradient. Both K31 and K25 are potential receptors for the treated runoff from the proposed road development at S19A. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during excavations and following the karst protocol as detailed in the CEMP.

Turlough K31, Western Coolagh Spring (K25) and the Lough Corrib cSAC are potential receptors for the infiltration basin at drainage network S19A. By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15. Furthermore, to ensure that the infiltrating water flows through the full 2m of the infiltration basin the sides of the over excavation will be lined to ensure that no lateral flow can take place. On this basis the size of the basin has also been oversized to accommodate flow only through the footprint of the over excavation.

On percolating through the 2m thick infiltration basin the treated runoff will enter the aquifer and be diluted by groundwater. Greater dilution with groundwater will occur in the winter when the water table is higher. Whilst in the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

All infiltration basins will be checked by a hydrogeologist on a 5 yearly basis to confirm that there is no unexpected subsidence in the level of the appropriate material below the infiltration basin invert. If subsidence is present, then the karst protocol will be triggered and the location of subsidence examined to ensure that no karst flow paths have developed in the basin.

On the basis of this hydrogeological assessment, the design and mitigation measures for infiltration basin S19A are considered to meet and exceed the HD45/15 specification for use of permeable drainage. With the mitigation measures of the karst protocol, as well as monitoring at both turlough K31 and Western Coolagh Spring K21 for turbidity and maintenance of infiltration basins by regular surveys then multiple levels of protection will be in place to ensure that there will be no impact to receptors.

2 Drainage Network 19B

Network S19B of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

2.1 Groundwater Protection Response

A hydrogeological summary for this drainage network is presented below in **Table 4**.

Table 4: Hydrogeology summary for S19B

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	10.24m OD
Subsoil thickness	2m
Summer groundwater level (m below invert level)	2.6m (7.6m OD)
Winter groundwater level (m below invert level):	0.4m (9.8m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an ‘Extreme’ (E) vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 5**.

Table 5: Groundwater protection response for S19B

<table>
<tr><th>Relevant requirements from matrix (Note ref)</th><th colspan="2">Site specific answers</th></tr>
<tr><td>1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)</td><td colspan="2">2m subsoil
Summer groundwater level 3.6m below invert
Winter groundwater level 1.4m below invert
*see note 1</td></tr>
<tr><td>2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum</td><td colspan="2">The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics
No karst features recorded within 15m.</td></tr>
<tr><td>3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required</td><td><u>Receptors</u>
Turlough (K20)
Turlough (K31)
Eastern Coolagh Spring (K45)
Western Coolagh Spring (K25)</td><td><u>Distance</u>
850m W
300m NW
250 SE
700m SW</td></tr>
<tr><td>4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system
OR
There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system</td><td colspan="2">2m of appropriate material (HD45/15) will be placed below the invert bedrock</td></tr>
<tr><td>5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present</td><td colspan="2">Not relevant</td></tr>
</table>

Relevant requirements from matrix (Note ref)	Site specific answers
6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))	There are no surface karst features within 15m
7. The site investigation shall pay particular attention to the possibility of instability in these karst areas	The infiltration basin is located on limestone bedrock. GI undertaken includes: • geophysics (GP3/8) • borehole (BH3/29) • trial pits (TP3/24, TP3/36) soakaway test (SW3/01)

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[3] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[4] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S19B meets HD45/15 requirements, with the exception of 2m subsoil an 1m appropriate material having 0.7m of unsaturated zone during peak groundwater events. Based on the assessment presented in Note 1 in **Table 5**, the measurement of 0.7m was undertaken during the winter of 2015/16 when groundwater levels were at their likely highest since 1850. A hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

2.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR

[3] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.
[4] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst
- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)
- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations.

2.2.1 Groundwater levels

The hydrogeological assessment for the infiltration basin at network S19B is based on groundwater levels recorded in BH3/29, BH972 and RC133, which are in the immediate vicinity of S19B, as well as BH04, LQ MW4, RC1104 and RP-2-03 which are located to the east of S19B at Lackagh Tunnel, Lackagh quarry and Ballindooley. A schematic section of groundwater levels is shown in **Plate 4** and **Table 6**. The assessment takes into account trial pits and soakaway tests undertaken near the site of the infiltration basin. Groundwater monitoring locations are shown in Hydrogeology HD45 Assessment **Figure 10.6.001** to **Figure 10.6.012**.

Plate 4: Groundwater levels in the vicinity of S19B

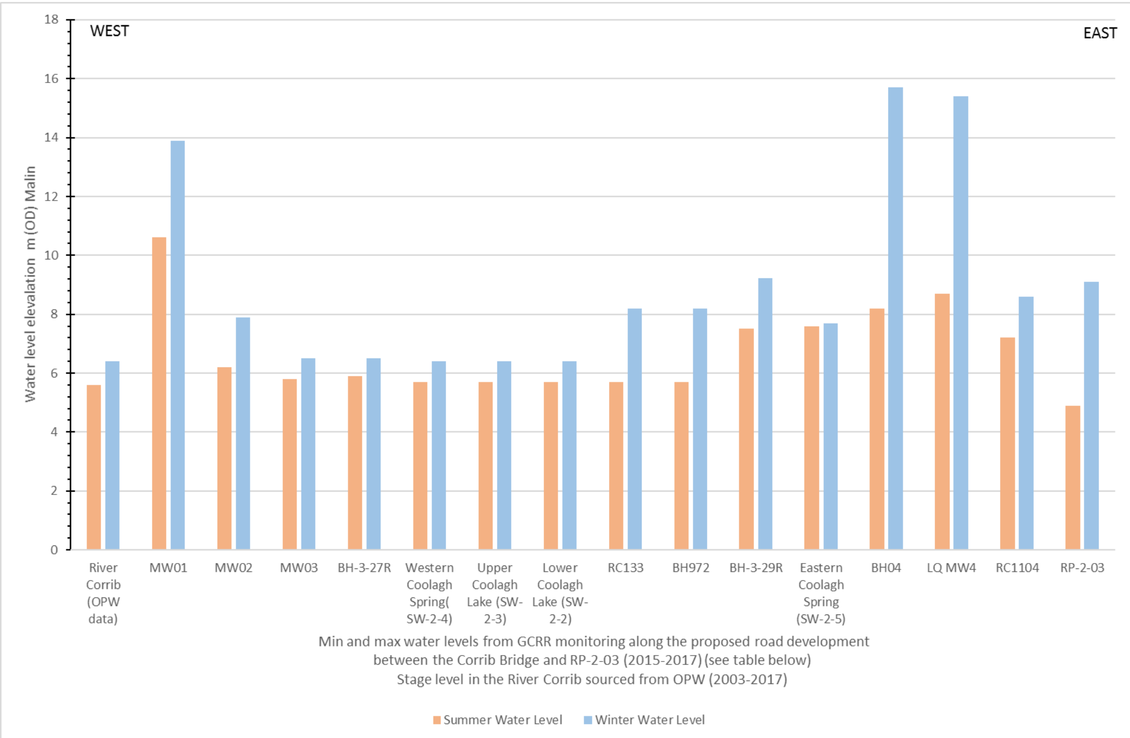


Table 6: Groundwater levels in the area of infiltration basin S19B

Monitoring Location	Ground Elevation	Summer Water Level	Winter Water Level	Seasonal Change
	(mOD)	(mOD)	(mOD)	(m)
River Corrib (OPW data)	-	5.6	6.4	0.8
MW01	16.1	10.6	13.9	3.3
MW02	13.4	6.2	7.9	1.7
MW03	6.7	5.8	6.5	0.7
BH-3-27R*	9.1	5.9	6.5	0.6
Western Coolagh Spring (K25) (SW-2-4)	5.4	5.7	6.4	0.7
Upper Coolagh Lake (K45) (SW-2-3)	-	5.7	6.4	0.7
Lower Coolagh Lake (SW-2-2)	-	5.7	6.4	0.7
RC133	11.7	5.7	8.2	2.5
BH972	12.3	5.7	8.2	2.5
BH-3-29R*	13.7	7.5	9.2	1.7
Eastern Coolagh Spring (SW-2-5)	7.4	7.6	7.7	0.1
BH04	32.2	8.2	15.7	7.5
LQ MW4	16.8	8.7	15.4	6.7
RC1104	9.4	7.2	8.6	1.4
RP-2-03	22.4	4.9	9.1	4.2

*Monitoring from Spring 2016-Winter 2016 only.

The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**. On the basis of these data there is a groundwater ridge in the vicinity of BH04, with separate groundwater catchments to west and east. The groundwater body to the west is named Lough Corrib Fen 1 (Menlough) and to the east Clare-Corrib.

The groundwater levels in the Lough Corrib Fen 1 (Menlough) GWB identify that the groundwater level at infiltration basin 19B drains westwards towards turlough K31 and Western Coolagh Spring (K25 and monitoring location SW-2-4).

Water level monitoring at Eastern Coolagh Spring indicates that the ponding does not have a significant seasonal response. Bedrock does not outcrop at Eastern Coolagh Spring and GSI subsoil mapping as well as the GI undertaken for N6

GCRR shows significant increase of thickness at the Coolagh Lakes and K45. On this basis of its location and its geological setting, Eastern Coolagh Spring (K45) is not considered to be a receptor for infiltration basin 19B.

Based on this conceptual model, the groundwater level in the Lough Corrib Fen 1 (Menlough) GWB, only overflows to Upper Coolagh Lake where groundwater can rise over the thickness of subsoil deposits, which only occurs at Western Coolagh Spring and not Eastern Coolagh Spring. The conceptual model for the groundwater inflow to Upper Coolagh Lake during high and low groundwater levels is presented in **Plate 5** and **Plate 6** below.

Plate 5: Schematic north south cross-section through Coolagh Lakes (groundwater high)

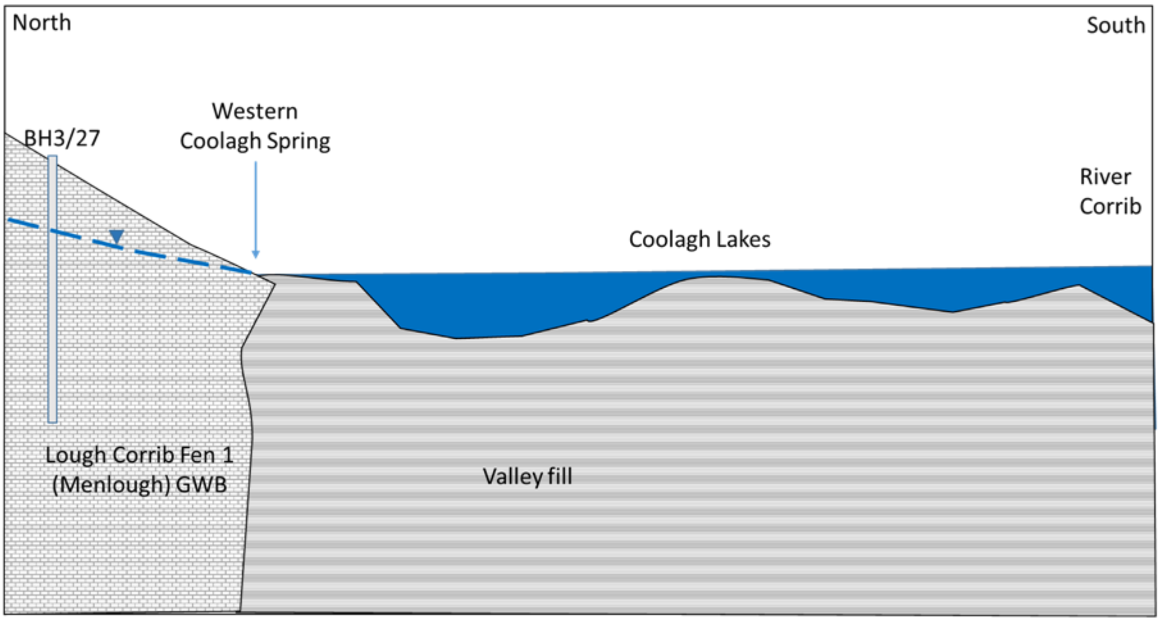
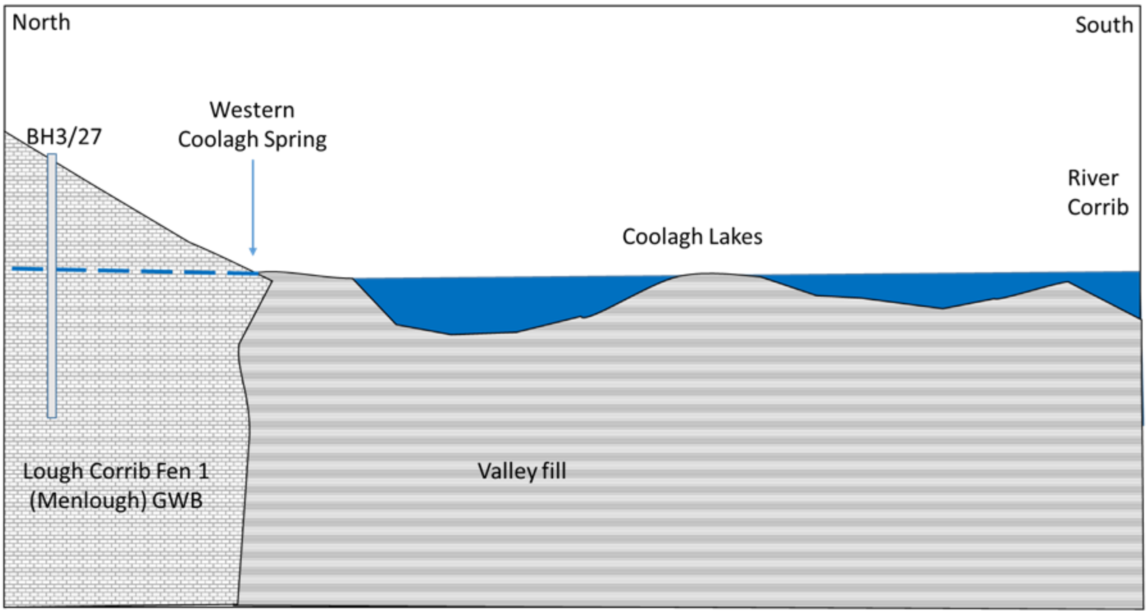


Plate 6: Schematic north south cross-section through Coolagh Lakes (groundwater low)



During the summer groundwater levels in BH972 and RC133 lower to the elevation of the Western Coolagh Spring (K25). Further to the west, there is a small groundwater ridge between Western Coolagh Spring (K25) and the River Corrib (as shown in monitoring wells MW01 and MW02). As such, downgradient of infiltration basin S19B will only extend as far as Upper Coolagh Lake at Western Coolagh Spring (K25). On this basis Western Coolagh Spring and Upper Coolagh Lake is the receptor for infiltration S19B.

The minimum groundwater levels recorded are representative of typical summer groundwater levels. However, the maximum groundwater levels recorded are for extreme groundwater conditions (as discussed in Note 1 in **Table 5**) and are not representative of normal groundwater levels, which will be lower. Based upon the seasonal fluctuation recorded over the monitoring period and information on historical groundwater levels, then an estimate can be made on a typical winter groundwater peak. Historical information is available from Lackagh Quarry (Topographical and Hydrogeological Report, Tobin Consulting Engineers, 2006[5]) and this indicates that the groundwater levels in Lackagh Quarry are below 15m OD, or 0.7m less than that recorded in the winter 2015/16, which represents an 11% reduction in the seasonal range. Given the recorded seasonal range of groundwater during N6 GCRR project 2015 to 2017 monitoring period was 6.7m, then the normal fluctuation would be 6m. By this reasoning a normal winter groundwater range at infiltration basin S19B would have a peak of 9.5m OD, giving 0.7m unsaturated zone rather than the groundwater level of 9.8m indicated by the 2015-2017 monitoring.

2.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.001** to **Figure 10.1.014**.

There are three active karst features downgradient of network S19B infiltration basin, these are two turloughs (K20 and K31) and Western Coolagh Spring (K25). Eastern Coolagh Spring (K45) is not a karst feature being located on thick subsoil deposits. Other karst features in the vicinity include the sediment filled palaeokarst feature at the Lackagh Tunnel western portal (refer to N6 GCRR Lackagh Tunnel Report), which extends for 200m east of, and upgradient of, infiltration basin S19B. A second palaeokarst feature (or potentially a buried valley feature) is located south of infiltration basin S19B. These features, both active karst and palaeokarst, are described below in relation to infiltration basin S19B.

Turlough K20 lies 850m northwest of infiltration basin S19B. It lies outside of the catchment to S19B in the Lough Corrib Fen 2 groundwater body. Based on the water level data provided and the groundwater bodies delineated by GSI and

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[5] Tobin Consulting Engineers, (2006) *Topographical and Hydrogeological Assessment at Coolagh Quarry, Menlough, Galway*.

reinterpreted as part of the N6 GCRR assessment, turlough K20 lies outside of the catchment for S19B and is not hydraulically connected to it.

Based upon the groundwater level data, turlough K31 lies 300m downgradient of infiltration basin S19B. The turlough floods seasonally, between October and March. Water level spot measurements were made in K31, which all matched the groundwater level recorded in nearby borehole RC133. During the winter period when the turlough is flooded it will be a receiving water for the treated road runoff.

Western Coolagh Spring (K25) is a perennial karst spring, which discharges into Upper Coolagh Lake. The estimated flow rate varies though out the year from an estimated 35l/s to less than 1ls. The water level at the spring was recorded by logger from summer 2015 to spring 2016 but due to vegetation in the stream it was not possible to measure the flow velocity accurately and measure the exact flow rate. Based on the conceptual model for the Lough Corrib Fen 1 (Menlough) GWB, the catchment for the spring extends upgradient from the spring towards BH04. Western Coolagh Spring (K25) lies 800m south west from S19B and is a receiving water for the infiltration basin.

The palaeokarst feature identified in the Lackagh Tunnel Report is a deep (104.95m) conical shaped karst feature that has been infilled with well consolidated silt and clay. The feature is non active and is located upgradient of infiltration basin S19B. As the hydraulic gradient is away from this palaeokarst feature there is no risk of reactivation or washout in the karst pathways. The well consolidated silt and clay infilling the feature are of low permeability, there will be no flow through this palaeokarst or the similar buried feature that lies to the south of infiltration basin S19B. Features such as that identified in at Lackagh Tunnel western approach are inert and act as barriers to groundwater flow. They compartmentalise the limestone aquifer into discrete groundwater bodies and restrict groundwater flow direction.

As part of the ground investigation for S19B drilling, trial pitting and geophysics was undertaken in the vicinity of infiltration basin S19B. The trial pit at the location of infiltration basin (SW3/01) encountered slightly sandy gravelly Clay with occasional cobbles and occasional boulders from ground level (13.3m OD) to 1.5m (11.8m OD) where probable limestone bedrock was encountered. As the basin invert lies at 11.15m OD the over excavation will be entirely in bedrock. The resistivity surveying (GP3/8) identifies that competent bedrock underlies S19B but that there is a possibility of a weathered zone being encountered.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

2.2.3 Receptors

The hydraulic gradient within the Lough Corrib Fen 1 (Menlough) GWB is westwards. Hydrogeological receptors that could receive recharge from the infiltration basin include the groundwater itself and any abstraction wells and groundwater dependant terrestrial ecosystems (GWDTE) that lie downgradient from the infiltration basin.

There are no groundwater abstraction wells in the Lough Corrib Fen 1 (Menlough) GWB.

GWDTE downgradient of infiltration basin 19A include the Coolagh Lakes (fed from K25 Western Coolagh Spring) and turlough K31. As described above in the section on karst, both the Coolagh Lakes and turlough K31 are groundwater fed. On this basis, the groundwater below and downgradient of the infiltration basin and GWDTE turlough K31 and Coolagh Lakes are potential receptors.

Western Coolagh Spring supplies the sole significant groundwater inflow to Upper Coolagh Lake, with the only other supply coming from a component of runoff and seepage from the thick subsoils around the periphery of the lakes, including the surface water ponding at Eastern Coolagh Spring (K45).

2.3 Summary

Drainage network S19B comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 2m over excavation in bedrock with backfill of 2m appropriate material. Based on the groundwater monitoring data collected over the monitoring period the infiltration basin will provide 0.3m unsaturated zone during an extreme winter event and 0.6m unsaturated zone during a typical winter. The infiltration basin does not meet the minimum 2m unsaturated subsoil design requirement (Note 1) or the minimum 1m appropriate material requirement (Note 4) during typical peak winter events. The invert level of the infiltration basin has been raised to as high an elevation as possible whilst maintaining the necessary fall on the drainage system.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin. The assessment has identified that turlough K31 lies 300m downgradient and Western Coolagh Spring (K25) lies 800m downgradient. Both K31 and K25 are receptors for the treated runoff from the proposed road development at S19B. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during investigations and following the karst protocol as detailed in the CEMP.

Turlough K31, western Coolagh Spring (K25) and the Lough Corrib cSAC European site S19B are potential receptors to infiltration basin S19A. By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15. Furthermore, to ensure that the infiltrating water flows through the full 2m of the infiltration basin the sides of the over excavation will be lined to ensure that no lateral flow can take place. On this basis the size of the basin has also been oversized to accommodate flow only through the footprint of the over excavation.

On percolating through the 2m thick infiltration basin the treated runoff will enter the aquifer and be diluted by groundwater. Greater dilution with groundwater will occur in the winter when the water table is higher. Whilst in the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

All infiltration basins will be checked by a hydrogeologist on a 5 yearly basis to confirm that there is no unexpected subsidence in the level of the appropriate material. If subsidence is present then the karst protocol will be used to excavate and examine the location to ensure that no karst flow paths have developed in the basin.

The design of the infiltration basin meets and exceeds HD45/15 by incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland. Furthermore, to ensure that the infiltrating water flows through the full 2m of the infiltration basin the sides of the over excavation will be lined to ensure that no lateral flow can take place. On this basis the size of the basin has been oversized to accommodate flow only through the footprint of the over excavation.

On the basis of this hydrogeological assessment the design and measures accommodated in S19B meet all criteria for HD45/15 with the exception of unsaturated thickness during winter peaks. During an extreme peak the unsaturated zone narrows to 0.4m but during a normal winter the unsaturated zone will be 0.7m. During the summer, the unsaturated zone will be 2.6m. On the basis of the pre-treatment prior to the infiltration basin the quality of the road runoff will be significantly improved over the standard concentration for significant contaminants. On the basis of the standard of pre-treatment, the 0.7m unsaturated zone through 2m appropriate subsoil and the dilution in groundwater at the winter peak, then the concentration of significant contaminants is considered to compensate against the reduced unsaturated thickness. Together with the mitigation off the karst protocol, monitoring at both turlough K31 and Western Coolagh Spring K21 for turbidity and long term checks for settlement in the basins then multiple levels of protection will be in place to ensure that there will be no impact to receptors.

3 Drainage network S20

Network S20 of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

3.1 Groundwater Protection Response

A hydrogeological summary for this drainage network is presented below in **Table 7**.

Table 7: Hydrogeology summary for S20

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	14.7m OD
Subsoil thickness	2m
Summer groundwater level (m below invert level)	6.1m (8.6m OD)
Winter groundwater level (m below invert level):	0m (15.7m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an 'Extreme' vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the groundwater protection response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 8** below.

Table 8: Groundwater protection response for S19B

<table>
<tr><th>Relevant requirements from matrix</th><th colspan="2">Site specific answers</th></tr>
<tr><td>1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)</td><td colspan="2">2m subsoil
Summer groundwater level 6.1m below invert
During winter peak storm events groundwater will rise above invert infiltration invert level
*see note 1</td></tr>
<tr><td>2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum</td><td colspan="2">The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics
No karst features recorded within 15m.</td></tr>
<tr><td>3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required</td><td><u>Receptors</u>
Commercial well
Eastern Coolagh Spring (K45)
Ballindooley Lough
Lake at Ballinfoyle</td><td><u>Distance</u>
700m NE
600m E
1100m NE
650m SE</td></tr>
<tr><td>4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system
OR
There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system</td><td colspan="2">2m of appropriate material (HD45/15) will be placed below the invert bedrock</td></tr>
<tr><td>5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present</td><td colspan="2">Not relevant</td></tr>
<tr><td>6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))</td><td colspan="2">There are no surface karst features within 15m</td></tr>
<tr><td>7. The site investigation shall pay particular attention to the possibility of instability in these karst areas</td><td colspan="2">The infiltration basin is located on limestone bedrock. GI undertaken includes:</td></tr>
</table>

Relevant requirements from matrix	Site specific answers
	• geophysics (GP3/25) • boreholes (BH01, BH03, BH04, BH05, BH06) • Packer and falling head tests

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[6] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[7] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S20 meets HD45/15 requirements, with the exception of 2m subsoil an 1m appropriate material having nil unsaturated zone during peak groundwater events. A hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

3.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst
- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)

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[6] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.
[7] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations

3.2.1 Groundwater levels

The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**. The hydrogeological assessment for the infiltration basin at network S20 is based on groundwater levels recorded in the immediate vicinity of the infiltration basin at BH04, LQ MW4, as well monitoring locations BH3/29, BH972 and RC133 to the west and RC1104 and RP-2-03 to the east. The assessment takes into account trial pits and soakaway tests undertaken near the site of the infiltration basin. A schematic section of groundwater levels is shown in **Plate 7** and **Table 9**.

Plate 7: Groundwater levels in the vicinity of S20

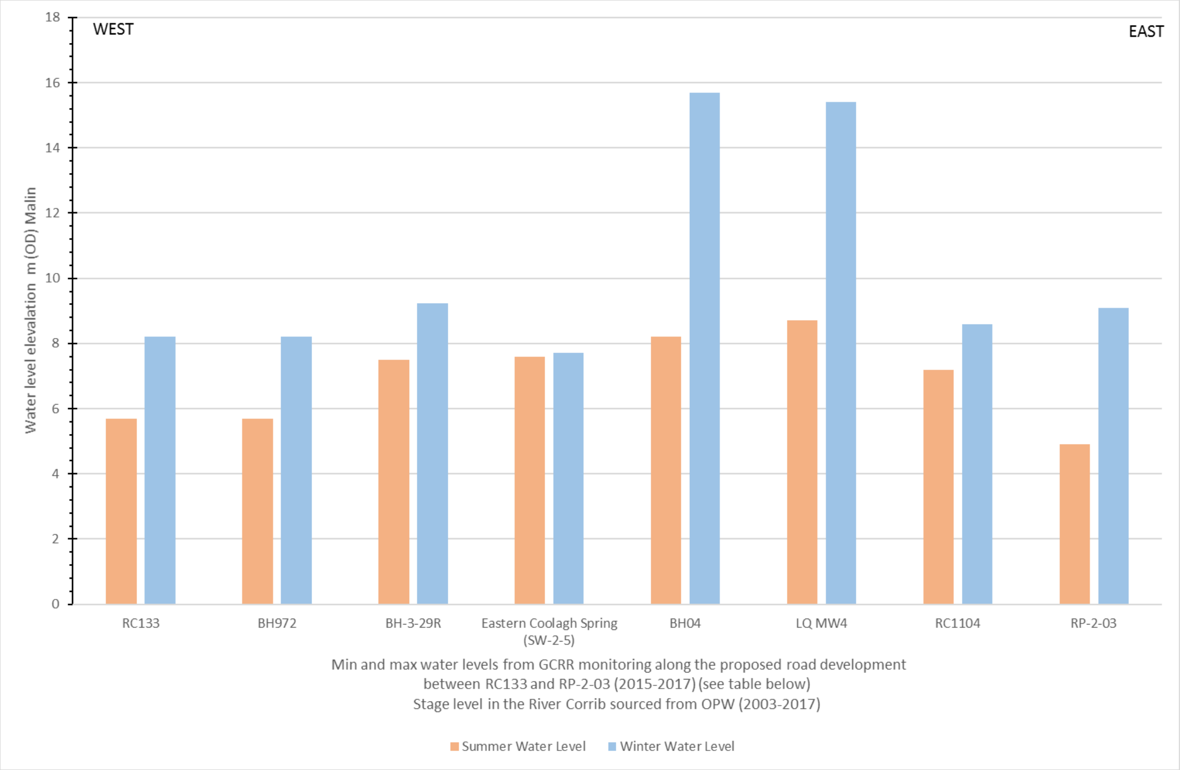

Table 9: Groundwater levels in the area of infiltration basin S20

Monitoring Location	Ground Elevation	Summer Water Level	Winter Water Level	Seasonal Change
	(mOD)	(mOD)	(mOD)	(m)
RC133	11.7	5.7	8.2	2.5
BH972	12.3	5.7	8.2	2.5

Monitoring Location	Ground Elevation	Summer Water Level	Winter Water Level	Seasonal Change
	(mOD)	(mOD)	(mOD)	(m)
BH-3-29R*	13.7	7.5	9.2	1.7
Eastern Coolagh Spring (SW-2-5)	7.4	7.6	7.7	0.1
BH04	32.2	8.2	15.7	7.5
LQ MW4	16.8	8.7	15.4	6.7
RC1104	9.4	7.2	8.6	1.4
RP-2-03	22.4	4.9	9.1	4.2

*Monitoring from Spring 2016-Winter 2016 only.

On the basis of these data there is a groundwater ridge in the vicinity of BH04, with separate groundwater catchments to west and east. The groundwater body to the west is named Lough Corrib Fen 1 (Menlough) and to the east Clare-Corrib (Refer to Hydrogeology HD45 Assessment **Figure 10.5.01** to **Figure 10.5.02**). Infiltration basin S20 lies in the Clare-Corrib GWB.

The groundwater levels have a seasonal variation of 7.1m at infiltration basin S20. During the summertime the groundwater levels are up to 6.1m below the invert but during peak time the groundwater level rises up to and above the invert level.

The minimum groundwater levels recorded are representative of typical summer groundwater levels. However, the maximum groundwater levels recorded are for extreme groundwater conditions (as discussed in **Note 1** of **Table 8**) and are not representative of normal groundwater levels, which will be lower. Based upon the seasonal fluctuation recorded over the monitoring period and information on historical groundwater levels, then an estimate can be made on a typical winter groundwater peak. Historical information is available from Lackagh Quarry (Topographical and Hydrogeological Report, Tobin Consulting Engineers, 2006[8]) and this indicates that the groundwater levels in Lackagh Quarry are below 15m OD, or at least 0.7m less than that recorded at monitoring well LQMW04 during the winter 2015/16. Based on this information normal winter groundwater levels remain below 15m OD. The winter of 2016/17 reached peak groundwater levels of 12.6m, which would have maintained an unsaturated zone of 2.1m.

Based on the groundwater level mapping Turlough K20 and Eastern Coolagh Spring (K45) lie in a separate groundwater body.

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[8] Tobin Consulting Engineers, (2006) *Topographical and Hydrogeological Assessment at Coolagh Quarry, Menlough, Galway*.

3.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.01** to **Figure 10.1.02**.

There are no karst features exposed on the floor of Lackagh quarry. There are a number of dolines located around the periphery of the quarry void but these are all located greater than 20m above the quarry floor and are not considered receptors.

The sediment filled palaeokarst feature to the west of Lackagh quarry as identified in the Lackagh Tunnel report is not exposed in the quarry face. This feature and other palaeokarst and palaeotopography in the region are filled well consolidated sediment that is of low permeability. These features form barriers to flow and will compartmentalise the aquifer into groundwater bodies.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

3.2.3 Receptors

There is one commercial abstraction well in the vicinity of infiltration basin S20, which is located 700m to the northeast. Based on the groundwater levels along the alignment groundwater flow from S20 will be south or south eastwards and as such the commercial abstraction well is upgradient.

There are two potential surface water features that have the potential to receive groundwater from infiltration basin S20, these are Ballindooley Lough and a small surface water feature at Ballinfoyle. As the groundwater flow direction from S20 is south or south -westwards Ballindooley Lough lies upgradient of the infiltration basin and is not considered a receptor. The surface water feature at Ballinfoyle lies downgradient of the infiltration basin and is a receptor. For the basis of this report the surface water feature at Ballinfoyle is referred to as Lake at Ballinfoyle and has a location number N74.

Lake at Ballinfoyle is ephemeral being dry up in the summer time, being flooded between October and March (**Plate 8** and **Plate 9**). The lough is located in the valley floor but is not associated with any karst, there are no spring or sinks. The location of the feature is shown on **Figure 10.5.01** to **Figure 10.5.02** as lying within the estimated outline of a buried valley that extends from the Terryland River to Ballindooley Lough, which separates the Clare-Corrib GWB into Ballindooley West and Ballindooley East. Based on groundwater levels to the north and to the west of Lake at Ballinfoyle there is a step change in the groundwater level from the

Ballindooley west part of the GWB at Lackagh quarry to the Ballindooley east part of the GWB at Castlegar.

Plate 8: Conceptual hydrogeology at Lake at Ballinfoyle during low (summer) groundwater levels

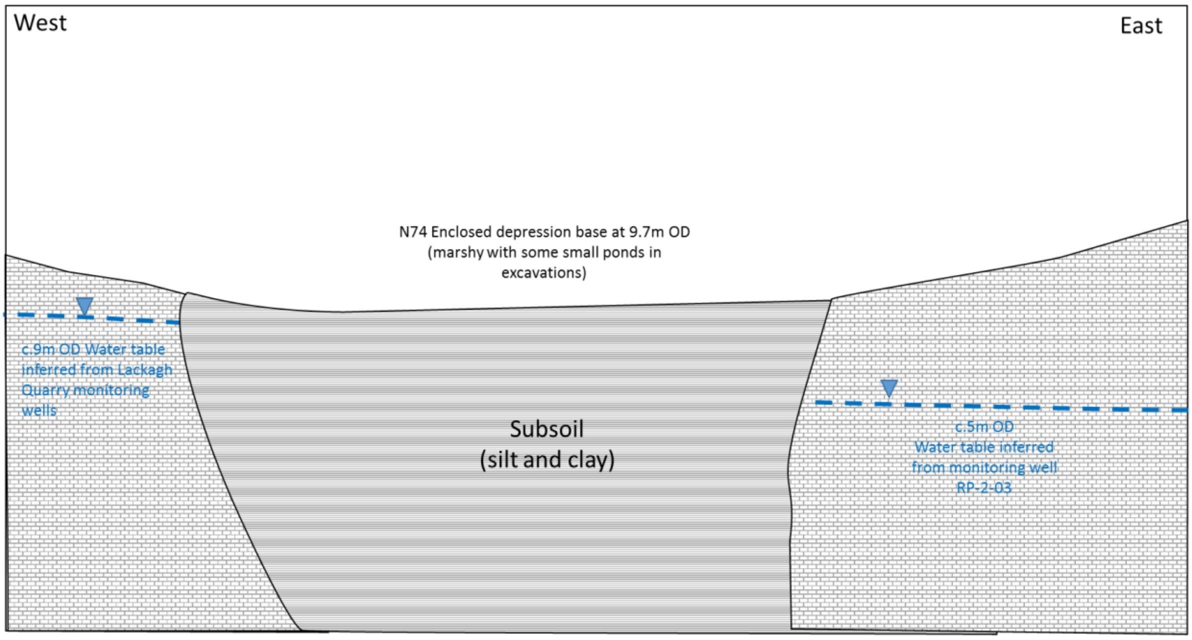
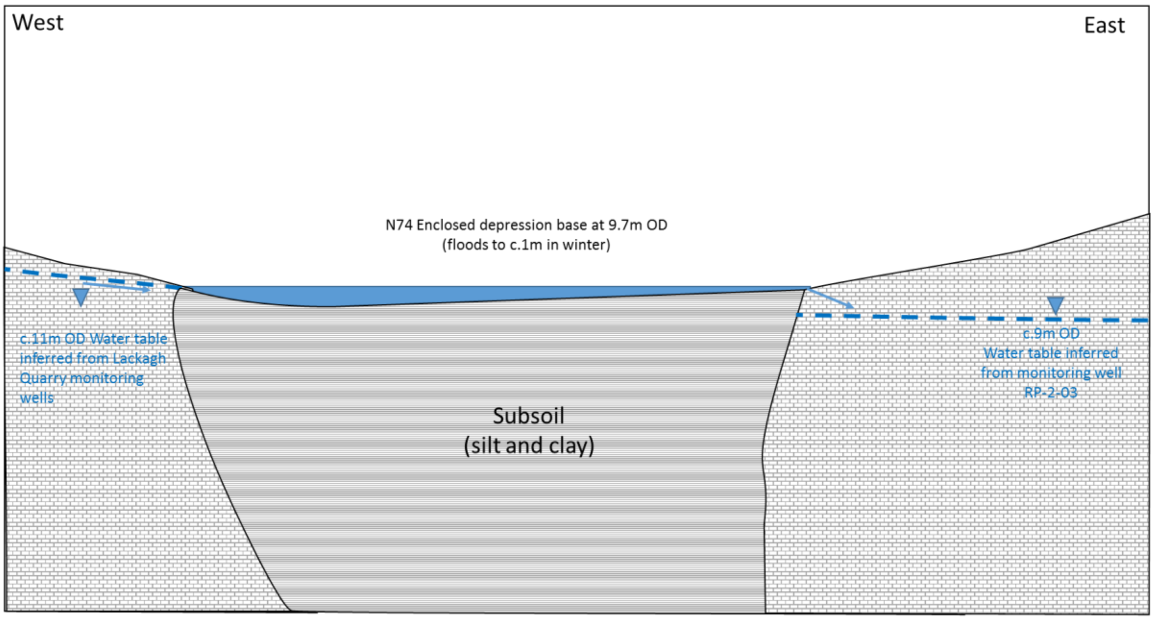


Plate 9: Conceptual hydrogeology at Lake at Ballinfoyle during high (winter) groundwater levels



Castlegar N74 Enclosed depression – Winter Groundwater Level

Lake at Ballinfoyle is a seasonal lake that appears when groundwater levels rise in the limestone aquifer to the west that overspills to the valley floor where it causes ponding on thick low permeability subsoils. The subsoils at this location are likely to be indicative of thick overburden, potentially filling in a buried valley feature.

Geophysics undertaken along the alignment at GP3/10 identifies that there is a wide low resistivity feature in the base of the valley and tis is likely to be a continuation of the thick subsoil at Lake at Ballinfoyle and Ballindooley Lough. The role of the buried valley fill described here shows that there is potential for buried valleys to compartmentalise the groundwater bodies in the region.

3.3 Summary

Drainage network S20 comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 2m over excavation in bedrock with backfill of 2m appropriate material. The infiltration basin does not meet the minimum 2m unsaturated subsoil design requirement (Note 1) or the minimum 1m appropriate material requirement (Note 4) during typical peak winter events. The invert level of the infiltration basin has been raised to as high an elevation as possible whilst maintaining the necessary fall on the drainage system.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin. The assessment has identified that there is no karst within the floor of Lackagh quarry and that other karst receptors such as turloughs and springs are not located within the groundwater body. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during investigations and following the karst protocol as detailed in the CEMP.

Of the receptors identified, Ballindooley Lough is upgradient of S20 infiltration basin as is a commercial well. The only receptor downgradient of the infiltration basin is Lake at Ballinfoyle, which is an ephemeral lake that is ponded on low permeability subsoil and seasonally receives groundwater from the Clare-Corrib (Ballindooley west) GWB. Lake at Ballinfoyle is located 650m southeast of infiltration basin S20.

By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15.

As the treated runoff infiltrates to ground dilution will occur with groundwater. During the winter more dilution will occur as the groundwater level is higher. In the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

All infiltration basins will be checked by a hydrogeologist on a 5 yearly basis to confirm that there is no unexpected subsidence in the level of the appropriate material. If subsidence is present then the karst protocol will be used to excavate and examine the location to ensure that no karst flow paths have developed in the basin.

On the basis of this hydrogeological assessment the design and measures accommodated in S20 meet all criteria for HD45/15 with the exception of unsaturated thickness during winter peaks. On the basis of the pre-treatment prior to the infiltration basin the quality of the road runoff will be significantly improved over the standard concentration for significant contaminants. S20 has been designed in mind that ponding may occur in the base of the basin during peak groundwater conditions. In this regard the footprint of the basin is over sized to provided additional storage in the event of the infiltration rate reducing during peak groundwater levels.

Incorporating pre-treatment of runoff with the infiltration basin along with the mitigation of the karst protocol, monitoring at receptors for turbidity and long term checks for settlement in the basins then multiple levels of protection will be in place to ensure that there will be no impact to receptors.

4 Drainage Network S21A

Network S21A of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

4.1 Groundwater Protection Response

A hydrogeological summary for this drainage network is presented below in **Table 10**.

Table 10: Groundwater protection response for S21A

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	13.75m OD
Subsoil thickness	2m
Summer groundwater level (m below invert level)	4.5m (11.2m OD)
Winter groundwater level (m below invert level):	2.6m (9.3m OD)

Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an 'Extreme' vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 11**.

Table 11: Groundwater protection response for S21A

Relevant requirements from matrix	Site specific answers	
1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)	2m subsoil Summer groundwater level 4.5m below invert During winter peak storm events groundwater will rise 2.6m below invert infiltration invert level ***see note 1**	
2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum	The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics No karst features recorded within 15m	
3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required	<u>Receptors</u> Ballindooley Lough Commercial Well Lake at Ballinfoyle	<u>Distance</u> 100m NE 100m W 600m S
4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system	2m of appropriate material (HD45/15) will be placed below the invert bedrock	

Relevant requirements from matrix	Site specific answers
OR There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system	
5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present	Not relevant
6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features)	There are no surface karst features within 15m
7. The site investigation shall pay particular attention to the possibility of instability in these karst areas	The infiltration basin is located on limestone bedrock. GI undertaken includes: • geophysics (GP3/9 & GP3/10) • boreholes (BH3/30 & BH3/31) • trial pits (TP3/25, TP3/27) • soakaway test (SW3/13)

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[9] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[10] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S21A meets HD45/15 requirements. A hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

[9] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.
[10] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

4.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst
- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)
- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations

4.2.1 Groundwater levels

The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**. The hydrogeological assessment for the infiltration basin at network S21A is based on groundwater levels recorded in the immediate vicinity of the infiltration basin at RC1104 and RP-2-03. The assessment takes into account trial pits and soakaway tests undertaken near the site of the infiltration basin.

The infiltration basin is located in the Clare-Corrib groundwater body close to the margin with an estimated extent of a buried valley. Drainage network S21A has been designed with discharge by an infiltration basin. An alternative drainage design is available for S21A, which includes an option of discharge to surface water. The surface water discharge option will be selected if the infiltration basin is set on thick subsoil rather than bedrock. The ground investigation shows that the infiltration basin is likely to be set on bedrock but as the site is a residential dwelling the ground investigation was undertaken adjacent to the site

During the summertime the groundwater levels are up to 4.6m below the invert and during peak winter events groundwater level rises to 2.6m below the invert.

4.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.01** to **Figure 10.1.02**.

There are no karst features in the immediate viciinity to infiltration basin S21A. Turlough (K72) is located 600m north and upgradient of the basin, whilst there are a number of dolines around the periphery of Lackagh quarry, which are significantly higher in elevation and like turlough K72 are not considered receptors.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

4.2.3 Receptors

There is one commercial abstraction well in the vicinity of infiltration basin S21A, which is located within 100m to the west. There are two surface water bodies in the vicinity of S21A, Ballindooley Lough and a lake at Ballinfoyle.

Ballindooley Lough is located in close proximity to infiltration basin S21A. During winter the lake at Ballindooley expands in size and comes to within 100m of the basin, whilst during the summer the lake is 250m away. Based on the groundwater levels along the alignment groundwater flow from S21A will be southwards. On the basis of the groundwater flow direction, Ballindooley Lough will be upgradient of the basin and not be impacted by it whilst the abstraction well will be oblique and will be a receptor.

The lake at Ballinfoyle is located 600m south of S21A and is ephemeral drying up in the summer time and being flooded between October and March. The lough is located in the valley floor but is not associated with any karst, there are no spring or sinks. The location of the feature is shown on **Figure 10.5.01** to **Figure 10.5.02** as lying within the estimated outline of a buried valley that extends from the Terryland River to Ballindooley Lough, which separates the Clare-Corrib GWB into Ballindooley West and Ballindooley East.

The lake at Ballinfoyle is a seasonal lake that appears when groundwater levels rise in the limestone aquifer to the west that overspills to the valley floor where it causes ponding on thick low permeability subsoils. The subsoils at this location are likely to be indicative of thick overburden, potentially filling in a buried valley feature. Geophysics undertaken along the alignment at GP3/10 identifies that there is a wide low resistivity feature in the base of the valley and tis is likely to be a continuation of the thick subsoil at Ballinfoyle and Ballindooley Lough. The role of the buried valley fill described here shows that there is potential for buried valleys to compartmentalise the groundwater bodies in the region.

Based on groundwater levels to the north and to the west of the lake at Ballinfoyle there is a step change in the groundwater level from the Ballindooley west part of the GWB at Lackagh quarry to the Ballindooley east part of the GWB at Castlegar. With the step change in the groundwater table across the lake at Ballinfoyle will only receive groundwater from the Clare-Corrib (Ballindooley West) GWB and not from Clare-Corrib (Ballindooley East) GWB, which will be too low all year round. On this basis the lake at Ballinfoyle is not a receiving water for groundwater from infiltration basin S21A. Conceptual model for the lake at Ballinfoyle is presented in **Plate 10** and **Plate 11**.

Plate 10: Conceptual hydrogeology of the lake at Ballinfoyle during low (summer) groundwater levels

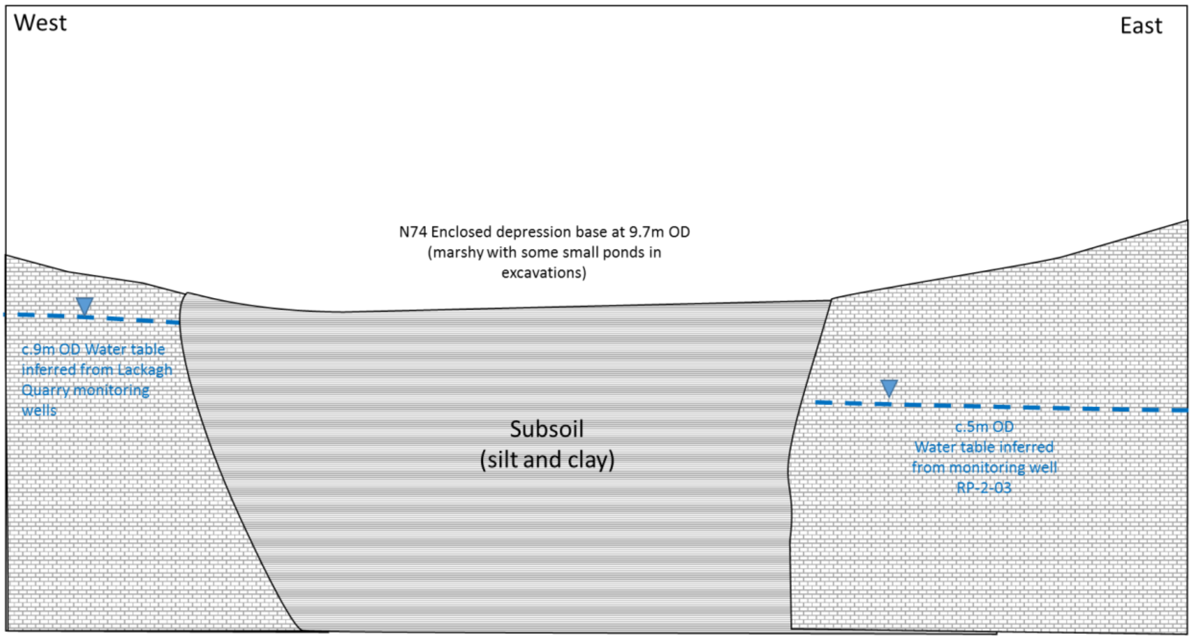
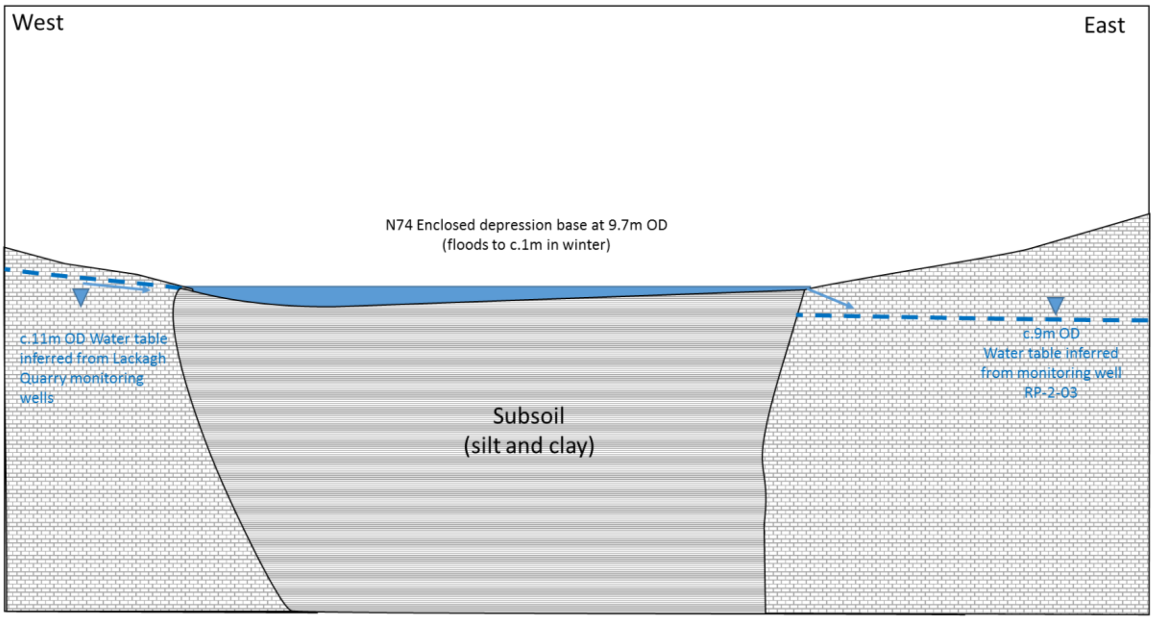


Plate 11: Conceptual hydrogeology of the lake at Ballinfoyle during high (winter) groundwater levels



4.2.4 Summary

Drainage network S21A comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 2m over excavation in bedrock with backfill of 2m appropriate material. The infiltration basin meets the minimum 2m unsaturated subsoil design requirement (Note 1) and the minimum 1m appropriate material requirement (Note 4) during peak winter events.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin and all have been discounted as being significantly upgradient and unconnected to the infiltration basin. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during investigations and following the karst protocol as detailed in the CEMP.

Of the receptors identified, Ballindooley Lough and lake at Ballinfoyle have been reviewed but are not considered to be receptors. The only receptor is the commercial well within 100m of the infiltration basin. As part of the proposed road development the commercial well will be replaced.

By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15. Infiltration basins S21A meets and exceeds the required unsaturated zone thickness during summer and winter.

As the treated runoff infiltrates to ground, dilution will occur with groundwater. During the winter more dilution will occur as the groundwater level is higher. In the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

All infiltration basins will be checked by a hydrogeologist on a 5 yearly basis to confirm that there is no unexpected subsidence in the level of the appropriate material. If subsidence is present, then the karst protocol will be used to excavate and examine the location to ensure that no karst flow paths have developed in the basin.

On the basis of this hydrogeological assessment, the design and measures accommodated in S21B meet all criteria for HD45/15. Incorporating pre-treatment of runoff with the infiltration basin along with the mitigation of the karst protocol, monitoring at receptors for turbidity and long term checks for settlement in the basins then multiple levels of protection will be in place to ensure that there will be no impact to receptors.

5 Drainage Network S21B

Network S21B of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

5.1 Groundwater Protection Response

The hydrogeological summary for this drainage network is presented below in **Table 12**.

Table 12: Hydrogeology summary for S21B

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	18.53m OD
Subsoil thickness	2m
Summer groundwater level (m below invert level)	13.1m (5.1m OD)
Winter groundwater level (m below invert level):	9.4m (9.4m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an 'Extreme' vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 13**.

Table 13: Groundwater protection response for S21B

<table>
<tr><th>Relevant requirements from matrix</th><th colspan="2">Site specific answers</th></tr>
<tr><td>1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)</td><td colspan="2">2m subsoil
Summer groundwater level 13.4m below invert
During winter peak storm events groundwater will rise to 9.1m below infiltration invert level
***see note 1**</td></tr>
<tr><td>2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum</td><td colspan="2">The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics
No karst features recorded within 15m</td></tr>
<tr><td>3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required</td><td><u>Receptors</u>
Ballindooley Lough
K97
Terryland estavelle K87
Terryland estavelle K96
Spring K99
Commercial Well</td><td><u>Distance</u>
600m N
100m E
800m S
800m S
450m SE
900m NW</td></tr>
<tr><td>4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system
OR
There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system</td><td colspan="2">2m of appropriate material (HD45/15) will be placed below the invert bedrock</td></tr>
<tr><td>5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present</td><td colspan="2">Not relevant</td></tr>
<tr><td>6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))</td><td colspan="2">There are no surface karst features within 15m</td></tr>
</table>

Relevant requirements from matrix	Site specific answers
7. The site investigation shall pay particular attention to the possibility of instability in these karst areas	The infiltration basin is located on limestone bedrock. GI undertaken includes: • geophysics (GP3/12) • boreholes (BH3/46, BH3/32, RP-2-01 & RP-2-03) • trial pits (TP3/27) • soakaway test (SW3/03)

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[11] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[12] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S21B meets HD45/15 requirements. A hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

5.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst
- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)

[11] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.
[12] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations

5.2.1 Groundwater levels

The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**. The hydrogeological assessment for the infiltration basin at network S21B is based on groundwater levels recorded in the immediate vicinity of the infiltration basin at RP-2-03, BH3/32R and RP-2-01 as well as taking into account the groundwater levels at Ballindooley Lough and Terryland sinks. The assessment takes into account trial pits and soakaway tests undertaken near the site of the infiltration basin.

The aquifer is divided into a number of groundwater bodies (GWB), which are presented in **Figure 10.5.01** to **Figure 10.5.02**. Infiltration basin S21B is located within the Clare-Corrib (Ballindooley East) GWB. The groundwater levels in the area indicate a south-eastern groundwater flow direction towards the Terryland estavelles (K87 and K96).

During the summertime the groundwater levels below infiltration basin S21B range from 5.1m OD to 9.4m OD. With the basin invert at 18.5m OD, during peak winter events up to 9.1m of unsaturated zone will remain below the invert.

BH3/34 lies further to the east along the alignment near the Tuam Road. At this location the groundwater levels are significantly higher, ranging seasonally between 19-26m OD. The groundwater levels in **Figure 10.5.01** to **Figure 10.5.02** show that the water table steepens significantly east of infiltration basin S21B as it crosses doline K97.

5.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.01** to **Figure 10.1.02.**

There is one karst features near to infiltration basin S21B, which is doline K97 located 100m to the east, and several karst features located within 1km including two estavelles (Stream sinks that switch to resurgences in times of high groundwater levels), one swallow hole, two dolines and a spring.

Doline K97 has developed in thick subsoil rather than rock and as such is a suffuse doline rather than a solution or collapse feature. The feature has ponding in the base where runoff has collected. There are no groundwater inflows to feature K97. Based on the ground investigation at infiltration basin S21B the feature at K97 appears to be part of a buried valley that extends from K97 south-eastwards to the Tuam Road. Groundwater levels west and east of the buried valley are different with those to the west ranging between 4-9m OD and those in the east ranging from 12—18m OD BH3/34.

The two estavelles at Terryland sinks are located 800m south of S21B infiltration basin. Both estavelles receive flow from the Terryland River. During high groundwater levels the estavelles reverse flow and discharge groundwater from the conduit system below. The groundwater level at Terryland lies at 4m OD in the summer, which is the lowest point in the Clare-Corrib GWB and will be the focus of groundwater flow within the GWB.

There are two dolines located in the area of S21B, K76 and K104. These features lie at a higher elevation than S21B and are not considered to be receptors. The spring at K99 is a potential receptor which flows to the Terryland River and sinks at the estavelles. The spring lies near BH3/34, in part of the groundwater body that has high groundwater levels. Based upon the observations of thick subsoil in K97 and geophysics line GP3/12, the groundwater level is likely higher at BH3/34 due to thick subsoil compartmentalised the groundwater body. Spring K99 lies downgradient of S21B and is a potential receptor.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

5.2.3 Receptors

There is one commercial abstraction in the vicinity of infiltration basin S21B, which is located 850m to the northwest. There are three surface water bodies in the vicinity of S21B, Ballindooley Lough, Lake at Ballinfoyle and Terryland River.

The groundwater levels along the alignment (**Figure 10.6.001** to **Figure 10.6.012**) show that groundwater flow from S21B will be south eastwards. On this basis Ballindooley Lough and the commercial well lie upgradient of the infiltration basin, Lake at Ballinfoyle lies oblique to the groundwater flow and the Terryland River (specifically the estavelles K87 and K96) lies down gradient. On the basis only Terryland River is a potential receiving water for infiltration basin S21B. The conceptual model for the Terryland River is presented in **Plate 12** and **Plate 13**.

Plate 12: Conceptual hydrogeology at Terryland during low (summer) groundwater levels

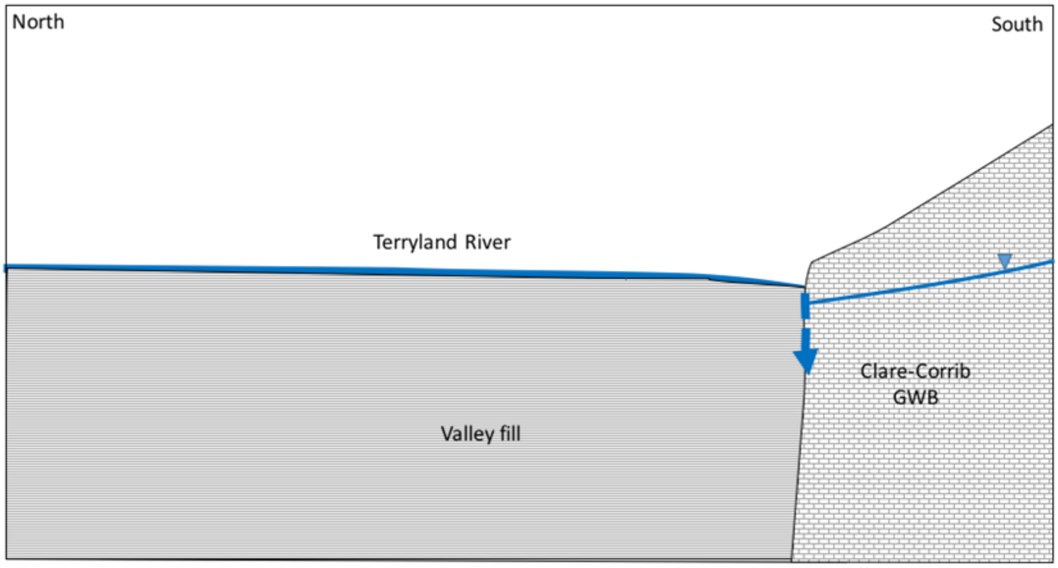
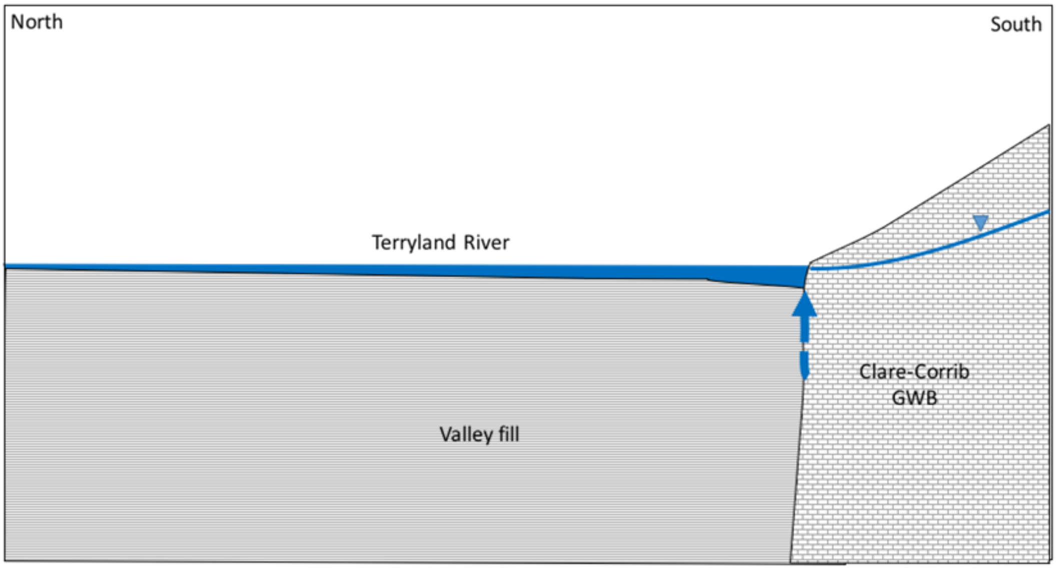


Plate 13: Conceptual hydrogeology at Terryland during high (winter) groundwater levels



5.2.4 Summary

Drainage network S21B comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 2m over excavation in bedrock with backfill of 2m appropriate material. The infiltration basin meets the minimum 2m unsaturated subsoil design requirement (Note 1) and the minimum 1m appropriate material requirement (Note 4) during peak winter events.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin and all have been discounted as being significantly upgradient and unconnected to the infiltration basin. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during investigations and following the karst protocol as detailed in the CEMP.

Of the receptors identified, Ballindooley Lough and Lake at Ballinfoyle have been reviewed but are not considered to be receptors. The only potential receptor is the Terryland River and the underground pathways from the two estavelles where the stream sinks in low groundwater conditions. Under high groundwater conditions the flow in the estavelle reverses and the Terryland River flows westwards into the River Corrib.

By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15. Infiltration basins S21B meets and exceeds the required unsaturated zone thickness during summer and winter.

As the treated runoff infiltrates to ground, dilution will occur with groundwater. During the winter more dilution will occur as the groundwater level is higher. In the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

All infiltration basins will be checked by a hydrogeologist on a 5 yearly basis to confirm that there is no unexpected subsidence in the level of the appropriate material. If subsidence is present, then the karst protocol will be used to excavate and examine the location to ensure that no karst flow paths have developed in the basin.

On the basis of this hydrogeological assessment, the design and measures accommodated in S21B meet all criteria for HD45/15. Incorporating pre-treatment of runoff with the infiltration basin along with the mitigation of the karst protocol, monitoring at receptors for turbidity and long term checks for settlement in the basins then multiple levels of protection will be in place to ensure that there will be no impact to receptors.

6 Drainage Network S22A

Network S22A of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

6.1 Groundwater Protection Response

The hydrogeological summary for this drainage network is presented below in **Table 14**.

Table 14: Hydrogeology summary for S22A

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	14.01m OD
Subsoil thickness	2m
Summer groundwater level (m below invert level)	7.6m (6.4m OD)
Winter groundwater level (m below invert level):	3.1m (10.9m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an ‘Extreme’ vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 15**.

Table 15: Groundwater protection response for S22A

Relevant requirements from matrix	Site specific answers	
1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)	2m subsoil Summer groundwater level 7.6m below invert During winter peak storm events groundwater will rise to 3.1m below infiltration invert level ***see note 1**	
2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum	The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics No karst features recorded within 15m	
3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required	<u>Receptors</u> K97 Terryland estavelle K87 Terryland estavelle K96 Spring K99 Swallow hole K95 Doline K104	<u>Distance</u> 650m E 800m SE 650m SE 500m E 500m NE 150m SE
4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system OR There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system	2m of appropriate material (HD45/15) will be placed below the invert bedrock	
5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present	Not relevant.	
6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))	There are no surface karst features within 15m	

Relevant requirements from matrix	Site specific answers
7. The site investigation shall pay particular attention to the possibility of instability in these karst areas.	The infiltration basin is located on limestone bedrock. GI undertaken includes: • geophysics (GP3/13 & GP3/14) • boreholes (BH3/34, BH3/62 & RC3/62) • trial pits (TP3/31 &TP3/50) • soakaway test (SW3/02, SW3/17 & SW3/18)

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[13] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[14] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S22A meets HD45/15 requirements. A hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

6.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst

[13] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.
[14] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)
- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations.

6.2.1 Groundwater levels

The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**. The hydrogeological assessment for the infiltration basin at network S22A is based on groundwater levels recorded in the immediate vicinity of the infiltration basin at BH3/34 as well as taking into account the groundwater levels at Terryland sinks, the spring at K99, trial pits and soakaway tests undertaken near the site of the infiltration basin.

The aquifer is divided into a number of groundwater bodies (GWB), which are presented in **Figure 10.5.01** to **Figure 10.5.02**. Infiltration basin S22A is located on the margin between the Clarinbridge GWB and the Clare-Corrib GWB. The groundwater bodies are separated by a buried valley feature at the Tuam Road.

Interpretation of the groundwater levels in the area indicate a south-eastern groundwater flow direction towards for both groundwater bodies towards the Terryland estavelles.

During the summertime the groundwater levels below infiltration basin S22A are expected to range between 6.5m OD to 11m OD. With the basin invert at 14.1m OD, during peak winter events up to 3.1m of unsaturated zone will remain below the invert.

BH3/34 lies further to the east along the alignment near the Tuam Road. At this location the groundwater levels are significantly higher, ranging seasonally between 19-26m OD. The groundwater levels in **Figure 10.5.01** to **Figure 10.5.02** show that the water table steepens significantly east of infiltration basin S22A as it crosses doline K97. Based on the location of BH3/34 and the estimated extent of the buried valleys in the area the groundwater in the area of BH3/34 appears to be compartmentalised, which causes the high groundwater levels locally. There are no infiltration basins in the area of BH3/34.

6.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.01** to **Figure 10.1.02**.

There are several karst features near to infiltration basin S22A, doline K97, spring K99, two estavelles at the Terryland River (stream sinks that switch to resurgences in times of high groundwater levels), one swallow hole (K95) and one doline (K104). Based on the groundwater flow direction K97 is upgradient and not considered to be a potential receptor. Swallow hole K95 and doline K104 are located at a higher elevation and also not considered to be a potential receptor. The

Terryland estavelles (K87 and K96) as well as spring K99 are considered to be potential receptors.

The two estavelles at Terryland sinks are located 650m and 800m south of S22A infiltration basin. Both estavelles receive flow from the Terryland River. During high groundwater levels the estavelles reverse flow and discharge groundwater from the conduit system below. The groundwater level at Terryland lies at 4m OD in the summer, which is the lowest point in the Clare-Corrib GWB and will be the focus of groundwater flow within the GWB.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

6.2.3 Receptors

There is one surface water bodies in the vicinity of S22A the Terryland River.

The groundwater levels along the alignment (**Figure 10.6.001** to **Figure 10.6.012**) show that groundwater flow from S22A will be south eastwards towards Terryland River (specifically the estavelles K87 and K96). On the basis only Terryland River is a potential receiving water for infiltration basin S22A.

6.2.4 Summary

Drainage network S22A comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 2m over excavation in bedrock with backfill of 2m appropriate material. The infiltration basin meets the minimum 2m unsaturated subsoil design requirement (Note 1) and the minimum 1m appropriate material requirement (Note 4) during peak winter events.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin and all have been discounted as being significantly upgradient and unconnected to the infiltration basin. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during investigations and following the karst protocol as detailed in the CEMP.

Of the receptors identified the only potential receptor is the Terryland River and spring K99 (which drains to the Terryland estavelles). Under low groundwater conditions the Terryland River sinks into the estavelles and the conduit network below. Under high groundwater conditions the flow in the estavelle reverses and the Terryland River flows westwards into the River Corrib.

By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15. Infiltration basins S22A meets and exceeds the required unsaturated zone thickness during summer and winter.

As the treated runoff infiltrates to ground, dilution will occur with groundwater. During the winter more dilution will occur as the groundwater level is higher. In the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

All infiltration basins will be checked by a hydrogeologist on a 5 yearly basis to confirm that there is no unexpected subsidence in the level of the appropriate material. If subsidence is present, then the karst protocol will be used to excavate and examine the location to ensure that no karst flow paths have developed in the basin.

On the basis of this hydrogeological assessment, the design and measures accommodated in S22A meet all criteria for HD45/15. Incorporating pre-treatment of runoff with the infiltration basin along with the mitigation of the karst protocol, monitoring at receptors for turbidity and long term checks for settlement in the basins then multiple levels of protection will be in place to ensure that there will be no impact to receptors.

7 Drainage Network S22B

Network S22B of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

7.1 Groundwater Protection Response

A hydrogeological summary for this drainage network is presented below in **Table 16**.

Table 16: Hydrogeology summary for S22B

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)

Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	37.93m OD
Subsoil thickness	2m
Summer groundwater level (m below invert level)	5.2m (32.8m OD)
Winter groundwater level (m below invert level):	3.9m (34.0m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an ‘Extreme’ vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 17**.

Table 17: Groundwater protection response for S22B

<table>
<tr><th>Relevant requirements from matrix</th><th colspan="2">Site specific answers</th></tr>
<tr><td>1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)</td><td colspan="2">2m subsoil
Summer groundwater level 5.2m below invert
During winter peak storm events groundwater will rise to 3.9m below infiltration invert level
*see note 1</td></tr>
<tr><td>2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum</td><td colspan="2">The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics
No karst features recorded within 15m</td></tr>
<tr><td>3. During all stages of design particular attention must be paid to receptors (such as;</td><td><u>Receptors</u></td><td><u>Distance</u></td></tr>
</table>

Relevant requirements from matrix	Site specific answers	
public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required	Terryland estavelle K87 Terryland estavelle K96 Spring K99 Doline K104	850m SE 1000m SE 800m SE 350m SE
4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system OR There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system	2m of appropriate material (HD45/15) will be placed below the invert bedrock	
5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present	Not relevant	
6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))	There are no surface karst features within 15m	
7. The site investigation shall pay particular attention to the possibility of instability in these karst areas	The infiltration basin is located on limestone bedrock. GI undertaken includes: • geophysics (GP3/13 & GP3/14) • boreholes (BH3/34, BH3/36, BH3/47, BH3/62 & RC3/62) • trial pits (TP3/31 &TP3/50) • soakaway test (SW3/02, SW3/12, SW3/17 & SW3/18)	

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[15] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[16] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent

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[15] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.

[16] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S22B meets HD45/15 requirements. A hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

7.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst
- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)
- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations.

7.2.1 Groundwater levels

The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**. The hydrogeological assessment for the infiltration basin at network S22B is based on groundwater levels recorded in the immediate vicinity of the infiltration basin at BH3/36 as well as taking into account the groundwater levels at Terryland sinks, the spring at K99, trial pits and soakaway tests undertaken near the site of the infiltration basin.

The aquifer is divided into a number of groundwater bodies (GWB), which are presented in **Figure 10.5.01** to **Figure 10.5.02**. Infiltration basin S22B is located in Clarinbridge GWB, east of the estimated extent of the buried valley at the Tuam Road. Interpretation of the groundwater levels in the area indicate a south-eastern groundwater flow direction towards the Terryland estavelles.

During the summertime the groundwater levels below infiltration basin S22B are expected to range between 32.8m OD and 34m OD. With the basin invert at 39.7m

OD, during peak winter events up to 3.9m of unsaturated zone will remain below the invert.

The groundwater levels in **Figure 10.5.01** to **Figure 10.5.02** show that the water table steepens significantly eastward from BH3/36 towards Briarhill.

7.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.01** to **Figure 10.1.02**.

There are four karst features near to infiltration basin S22B, spring K99, two estavelles at the Terryland River (stream sinks that switch to resurgences in times of high groundwater levels) and one doline (K104). Based on the groundwater flow direction doline K104, the Terryland estavelles (K87 and K96) and spring K99 are downgradient of the infiltration basin. The doline is a point input feature and as such will not receive groundwater from the basin. The Terryland estavelles and spring K99 are considered to be potential receptors.

The two estavelles at Terryland sinks are located 850m and 1000m south of S22B infiltration basin. Both estavelles receive flow from the Terryland River. During high groundwater levels the estavelles reverse flow and discharge groundwater from the conduit system below. The groundwater level at Terryland lies at 4m OD in the summer, which is the lowest point in the Clare-Corrib GWB and will be the focus of groundwater flow within the GWB.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

7.2.3 Receptors

There is one surface water bodies in the vicinity of S22B the Terryland River.

The groundwater levels along the alignment (**Figure 10.6.001** to **Figure 10.6.012**) show that groundwater flow from S22B will be south eastwards towards Terryland River (specifically the estavelles K87 and K96). On the basis only Terryland River is a potential receiving water for infiltration basin S22B.

7.2.4 Summary

Drainage network S22B comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 2m over excavation in bedrock with backfill of 2m appropriate material. The infiltration basin meets the minimum 2m unsaturated subsoil design requirement (Note 1) and the minimum 1m appropriate material requirement (Note 4) during peak winter events.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin and all have been discounted as being significantly upgradient and unconnected to the infiltration basin. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during investigations and following the karst protocol as detailed in the CEMP.

Of the receptors identified the only potential receptor is the Terryland River and spring K99 (which drains to the Terryland estavelles). Under low groundwater conditions the Terryland River sinks into the estavelles and the conduit network below. Under high groundwater conditions the flow in the estavelle reverses and the Terryland River flows westwards into the River Corrib.

By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15. Infiltration basins S22B meets and exceeds the required unsaturated zone thickness during summer and winter.

As the treated runoff infiltrates to ground, dilution will occur with groundwater. During the winter more dilution will occur as the groundwater level is higher. In the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

8 Drainage Network S22C2

Network S22C2 of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 1m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

S22C2 serves drainage from a side road rather than the main alignment.

8.1 Groundwater Protection Response

A hydrogeological summary for this drainage network is presented below in **Table 18**.

Table 18: Hydrogeology summary for S22C2

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	38.64m OD
Subsoil thickness	1m
Summer groundwater level (m below invert level)	15.5m (23.1m OD)
Winter groundwater level (m below invert level):	15.2m (23.4m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an 'Extreme' vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 19**.

Network S22C2 of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 1m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

The report below details the HD45/15 assessment for the drainage network.

Table 19: Groundwater protection response for S22C2

<table>
<tr><th>Relevant requirements from matrix</th><th colspan="2">Site specific answers</th></tr>
<tr><td>1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)</td><td colspan="2">1m subsoil
Summer groundwater level 15.5m below invert
During winter peak storm events groundwater will rise to 15.3m below infiltration invert level
*see note 1</td></tr>
<tr><td>2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum</td><td colspan="2">The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics
No karst features recorded within 15m</td></tr>
<tr><td>3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required</td><td>Receptors
Terryland estavelle K87
Terryland estavelle K96
Spring K99
Doline K104</td><td>Distance
650m SE
700m SE
500m SE
150m SE</td></tr>
<tr><td>4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system
OR
There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system</td><td colspan="2">1m of appropriate material (HD45/15) will be placed below the invert bedrock</td></tr>
<tr><td>5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present</td><td colspan="2">Not relevant</td></tr>
<tr><td>6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))</td><td colspan="2">There are no surface karst features within 15m</td></tr>
<tr><td>7. The site investigation shall pay particular attention to the possibility of instability in these karst areas</td><td colspan="2">The infiltration basin is located on limestone bedrock. GI undertaken includes:
• geophysics (GP3/13 & GP3/14)</td></tr>
</table>

Relevant requirements from matrix	Site specific answers
	• boreholes (BH3/34, BH3/62 & RC3/62) • trial pits (TP3/31 &TP3/50) soakaway test (SW3/02, SW3/17 & SW3/18)

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[17] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[18] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S22B meets HD45/15 requirements. A hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

8.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst
- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)
- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations.

[17] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.
[18] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

8.2.1 Groundwater levels

The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**. The hydrogeological assessment for the infiltration basin at network S22B is based on groundwater levels recorded in the immediate vicinity of the infiltration basin at BH3/36 as well as taking into account the groundwater levels at Terryland sinks, the spring at K99, trial pits and soakaway tests undertaken near the site of the infiltration basin.

The aquifer is divided into a number of groundwater bodies (GWB), which are presented in **Figure 10.5.01** to **Figure 10.5.02**. Infiltration basin S22B is located in Clarinbridge GWB, east of the estimated extent of the buried valley at the Tuam Road. Interpretation of the groundwater levels in the area indicate a south-eastern groundwater flow direction towards the Terryland estavelles.

During the summertime the groundwater levels below infiltration basin S22B are expected to range between 23.1m OD and 23.4m OD. With the basin invert at 38.3m OD, during peak winter events up to 15.1m of unsaturated zone will remain below the invert.

The groundwater levels are shown in **Figure 10.5.01** to **Figure 10.5.02**.

8.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.01** to **Figure 10.1.02**.

There are four karst features near to infiltration basin S22C2, spring K99, two estavelles at the Terryland River (stream sinks that switch to resurgences in times of high groundwater levels) and one doline (K104). Based on the groundwater flow direction doline K104, the Terryland estavelles (K87 and K96) and spring K99 are downgradient of the infiltration basin. The doline is a point input feature and as such will not receive groundwater from the basin. The Terryland estavelles and spring K99 are considered to be potential receptors

The two estavelles at Terryland sinks are located south of S22B infiltration basin. Both estavelles receive flow from the Terryland River. During high groundwater levels the estavelles reverse flow and discharge groundwater from the conduit system below. The groundwater level at Terryland lies at 4m OD in the summer, which is the lowest point in the Clare-Corrib GWB and will be the focus of groundwater flow within the GWB.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

8.2.3 Receptors

There is one surface water bodies in the vicinity of S22C2 the Terryland River.

The groundwater levels along the alignment (**Figure 10.6.001** to **Figure 10.6.012**) show that groundwater flow from S22C2 will be south eastwards towards Terryland River (specifically the estavelles K87 and K96). On the basis only Terryland River is a potential receiving water for infiltration basin S22B.

8.2.4 Summary

Drainage network S22C2 comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 1m over excavation in bedrock with backfill of 1m appropriate material. The infiltration basin meets the minimum 2m unsaturated subsoil design requirement (Note 1) and the minimum 1m appropriate material requirement (Note 4) during peak winter events.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin and all have been discounted as being significantly upgradient and unconnected to the infiltration basin. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during investigations and following the karst protocol as detailed in the CEMP.

Of the receptors identified the only potential receptor is the Terryland River and spring K99 (which drains to the Terryland estavelles). Under low groundwater conditions the Terryland River sinks into the estavelles and the conduit network below. Under high groundwater conditions the flow in the estavelle reverses and the Terryland River flows westwards into the River Corrib.

By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15. Infiltration basins S22C2 meets and exceeds the required unsaturated zone thickness during summer and winter.

As the treated runoff infiltrates to ground, dilution will occur with groundwater. During the winter more dilution will occur as the groundwater level is higher. In the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

9 Drainage Network S22E

Network S22E of the proposed road development comprises of:

- Sealed drains

- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

9.1 Groundwater Protection Response

A hydrogeological summary for this drainage network is presented below in **Table 20**.

Table 20: Hydrogeology summary for S22E

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	44.7m OD
Subsoil thickness	2m
Summer groundwater level (m below invert level)	11.0m (34.7m OD)
Winter groundwater level (m below invert level):	9.1m (35.8m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an 'Extreme' vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 21**.

Table 21: Groundwater protection response for S22E

<table>
<tr><th>Relevant requirements from matrix</th><th colspan="2">Site specific answers</th></tr>
<tr><td>1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)</td><td colspan="2">2m subsoil
Summer groundwater level 13.4m below invert
During winter peak storm events groundwater will rise to 9.1m below infiltration invert level
*see note 1</td></tr>
<tr><td>2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum</td><td colspan="2">The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics
No karst features recorded within 15m</td></tr>
<tr><td>3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required</td><td><u>Receptors</u>
Terryland estavelle K87
Terryland estavelle K96
Spring K99
Doline 104</td><td><u>Distance</u>
1000m S
850m S
650m SE
400m SE</td></tr>
<tr><td>4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system
OR
There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system</td><td colspan="2">2m of appropriate material (HD45/15) will be placed below the invert bedrock</td></tr>
<tr><td>5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil beneath the invert level of the drainage system must be present</td><td colspan="2">Not relevant.</td></tr>
<tr><td>6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))</td><td colspan="2">There are no surface karst features within 15m</td></tr>
</table>

Relevant requirements from matrix	Site specific answers
7. The site investigation shall pay particular attention to the possibility of instability in these karst areas	The infiltration basin is located on limestone bedrock. GI undertaken includes: • geophysics (GP3/13 & GP3/14) • boreholes (BH3/34, BH3/36, BH3/47, BH3/62 & RC3/62) • trial pits (TP3/31 &TP3/50) • soakaway test (SW3/02, SW3/12, SW3/17 & SW3/18)

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[19] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[20] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S22E meets HD45/15 requirements. A hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

9.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development. The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst

[19] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.
[20] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)
- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations.

9.2.1 Groundwater levels

The hydrogeological assessment for the infiltration basin at network S22E is based on groundwater levels recorded in the immediate vicinity of the infiltration basin at BH3/36 as well as taking into account the groundwater levels at Terryland sinks, the spring at K99, trial pits and soakaway tests undertaken near the site of the infiltration basin. Groundwater monitoring locations are shown in Hydrogeology HD45 Assessment **Figure 10.6.001** to **Figure 10.6.012**.

The aquifer is divided into a number of groundwater bodies (GWB), which are presented in **Figure 10.5.01** to **Figure 10.5.02**. Infiltration basin S22E is located in Clarinbridge GWB, east of the estimated extent of the buried valley at the Tuam Road. Interpretation of the groundwater levels in the area indicate a south-eastern groundwater flow direction towards the Terryland estavelles.

During the summertime the groundwater levels below infiltration basin S22E are expected to range between 34.7m OD and 35.8m OD. With the basin invert at 45.7m OD, during peak winter events up to 9.9m of unsaturated zone will remain below the invert.

The groundwater levels in **Figure 10.5.01** to **Figure 10.5.02** show that the water table steepens significantly eastward from BH3/36 towards Briarhill.

9.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.01** to **Figure 10.1.02**.

There are four karst features near to infiltration basin S22E, spring K99, two estavelles at the Terryland River (stream sinks that switch to resurgences in times of high groundwater levels) and one doline (K104). Based on the groundwater flow direction doline K104, the Terryland estavelles (K87 and K96) and spring K99 are downgradient of the infiltration basin. The doline is a point input feature and as such will not receive groundwater from the basin. The Terryland estavelles and spring K99 are considered to be potential receptors.

The two estavelles at Terryland sinks are located south of S22E infiltration basin. Both estavelles receive flow from the Terryland River. During high groundwater levels the estavelles reverse flow and discharge groundwater from the conduit system below. The groundwater level at Terryland lies at 4m OD in the summer, which is the lowest point in the Clare-Corrib GWB and will be the focus of groundwater flow within the GWB.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

9.2.3 Receptors

There is one surface water bodies in the vicinity of S22E the Terryland River.

The groundwater levels along the alignment (**Figure 10.6.001** to **Figure 10.6.012**) show that groundwater flow from S22E will be south eastwards towards Terryland River (specifically the estavelles K87 and K96). On the basis only Terryland River is a potential receiving water for infiltration basin S22E.

9.2.4 Summary

Drainage network S22E comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 2m over excavation in bedrock with backfill of 2m appropriate material. The infiltration basin meets the minimum 2m unsaturated subsoil design requirement (Note 1) and the minimum 1m appropriate material requirement (Note 4) during peak winter events.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin and all have been discounted as being significantly upgradient and unconnected to the infiltration basin. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during investigations and following the karst protocol as detailed in the CEMP.

Of the receptors identified the only potential receptor is the Terryland River and spring K99 (which drains to the Terryland estavelles). Under low groundwater conditions the Terryland River sinks into the estavelles and the conduit network below. Under high groundwater conditions the flow in the estavelle reverses and the Terryland River flows westwards into the River Corrib.

By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the typical water quality standard for road runoff as listed in HD45/15. Infiltration basins S22E meets and exceeds the required unsaturated zone thickness during summer and winter.

As the treated runoff infiltrates to ground, dilution will occur with groundwater. During the winter more dilution will occur as the groundwater level is higher. In the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

10 Drainage Network S40

Network S40 of the proposed road development comprises of:

- Sealed drains
- Containment area
- Hydrocarbon interceptor
- Wetland
- Infiltration basin with 2m appropriate material (as per TII HD45/15 guidelines)

Network S40 is a side road and not part of the main road alignment. As detailed in the drainage strategy the usage of this road will be low.

The wetland and infiltration basin provide attenuation of the significant contaminants identified by TII in HD45/15, whilst the containment area and hydrocarbon interceptor provide protection for accidental fuel spillages. Further dilution and some attenuation will occur in the saturated zone of the aquifer.

10.1 Groundwater Protection Response

A hydrogeological summary for this drainage network is presented below in **Table 22**.

Table 22: Hydrogeology summary for S40

Source protection zone?	No
Aquifer type:	Regionally Important aquifer (Rkc category)
Site specific aquifer vulnerability:	Calculated in Step 1 below
Infiltration basin invert	7.6m OD
Subsoil thickness	1m
Summer groundwater level (m below invert level)	1.9m (5.7m OD)
Winter groundwater level (m below invert level):	1.0m (6.6m OD)
Geology below infiltration invert:	Limestone bedrock
Karst within 15m	No

Step 1: Calculate the site specific groundwater vulnerability

The site specific vulnerability should be calculated based on thickness and permeability of material between the invert level of the drain and the top of the aquifer.

Based on this, and in line with the GSI groundwater vulnerability matrix, the site specific bedrock aquifer will have an ‘Extreme’ (E) vulnerability rating.

Step 2: Determine the appropriate response classification from the matrix

Based on an extreme vulnerability and an Rkc aquifer, the response classification from the matrix will be R2(3).

An R2(3) response indicates that a permeable drainage system can be used subject to a number of requirements. The requirements for R2(3), are those for R1, R2(1), R2(2) and R2(3) and these are presented in **Table 23**.

Table 23: Groundwater protection response for S40

Relevant requirements from matrix (Note ref)	Site specific answers	
1. There is a consistent minimum thickness of 1 m unsaturated subsoil, or 2 m in areas of karstified rock (Rk & Lk), beneath the invert level of the drainage system (Note 1)	1m subsoil Summer groundwater level 1.9m below invert Winter groundwater level 1m below invert ***see note 1**	
2. During all stages of design particular attention must be paid to the presence of karst features and additional assessments undertaken if required. If karst features are identified response R2 (3) must be applied as a minimum	The site assessment has included a desk and site survey for karst features. The ground investigation included drilling and geophysics No karst features recorded within 15m	
3. During all stages of design particular attention must be paid to receptors (such as; public wells, group schemes, industrial water supply sources and springs) and additional assessments undertaken if required	<u>Receptors</u> Turlough (K20) Turlough (K31) Eastern Coolagh Spring (K45) Western Coolagh Spring (K25)	<u>Distance</u> 700m W 150m NW 350m SW 550m SE
4. Where the subsoil is classed using BS5930 as; SAND, GRAVEL or SILT (in circumstances where the clay content is <10%) AND/OR is underlain by limestone bedrock, there is a consistent minimum thickness of 2 m unsaturated subsoil beneath the invert level of the drainage system OR There is a minimum consistent unsaturated thickness 1m of "appropriate material" (Note 3) either natural or man-made beneath the invert level of the drainage system	1m of appropriate material (HD45/15) will be placed below the invert bedrock	
5. Where a gravel aquifer is present, a consistent minimum thickness of 3 m unsaturated subsoil	Not relevant	

beneath the invert level of the drainage system must be present	
6. The drainage system shall be at least 15m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features))	There are no surface karst features within 15m
7. The site investigation shall pay particular attention to the possibility of instability in these karst areas	The infiltration basin is located on limestone bedrock. GI undertaken includes: • geophysics (GP3/8) • borehole (BH3/29) • trial pits (TP3/24, TP3/36) soakaway test (SW3/01)

Note 1. The maximum groundwater levels for the N6 GCRR project were recorded during the winter of 2015/16. Data from Walsh, 2016[21] has identified the winter of 2015/16 to be the wettest on record since 1850 with 189% (602mm) of the long-term average. Nicholson *et al*, 2016[22] report that the largest floods occurred in the west and north-west of Ireland between December 29 and January 6 and that these are the worst floods on record. Like the rainfall and hydrometric data recorded, the groundwater levels recorded by the N6 GCRR project during the winter of 2015/16 represent extreme groundwater levels, which are likely to be the highest that has occurred since the Met Éireann rainfall record began in 1850.

The requirements of the groundwater protection response are:

- Either 2m of unsaturated subsoil or 1m unsaturated appropriate material below invert
- Attention must be paid to karst features
- Attention must be paid to receptors
- No karst features with 15m

Drainage network S40 meets HD45/15 for all requirements, with the exception of 2m subsoil. However, with appropriate material included in the design, as per TII HD45/15 Note 4 only 1m unsaturated zone is required. In this regard on the basis of Note 4, infiltration basin S40 meets and exceeds the TII HD45/15 GPR. Although karst is not present within 15m a hydrogeological assessment is provided below on the infiltration basin that details the groundwater levels, karst and receptors to develop a hydrogeological conceptual model.

10.2 Hydrogeological Assessment

The hydrogeological assessment below assesses the available data to determine the risk to groundwater from the drainage design of the proposed road development.

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[21] Walsh, S., 2016. The Rainfall of the Winter of 2015/16 in Ireland. Irish National Hydrology Conference 2016.

[22] Nicholson, O., Gebre, F., Casey, J and Synnott, R. OPW Response to the Winter of 2015/16 Flooding in Ireland. Irish National Hydrology Conference 2016.

The assessment makes use of groundwater level data collected for the N6 GCRR project as well as information from the project karst survey report, desk study of wells and information on groundwater dependant habitats.

The assessment makes reference to figures presented in the HD45 Hydrogeological Assessment Report. These figures are:

- **Figure 10.1.01** to **Figure 10.1.02** Bedrock Aquifers and Karst
- **Figure 10.5.01** to **Figure 10.5.02** Groundwater Bodies (Revised)
- **Figure 10.6.001** to **Figure 10.6.012** Cross section showing maximum and minimum groundwater levels and ground investigation locations.

10.2.1 Groundwater levels

The hydrogeological assessment for the infiltration basin at network S40 is based on groundwater levels recorded in BH3/29, BH972 and RC133, which are in the immediate vicinity of S40, as well as BH04, LQ MW4, RC1104 and RP-2-03 which are located to the east of S40 at Lackagh Tunnel, Lackagh quarry and Ballindooley. A schematic section of groundwater levels is shown in **Plate 14** and **Table 24**. Groundwater monitoring locations are shown in Hydrogeology HD45 Assessment **Figure 10.6.001** to **Figure 10.6.012**. The assessment takes into account trial pits and soakaway tests undertaken near the site of the infiltration basin.

Plate 14: Groundwater levels in the vicinity of S40

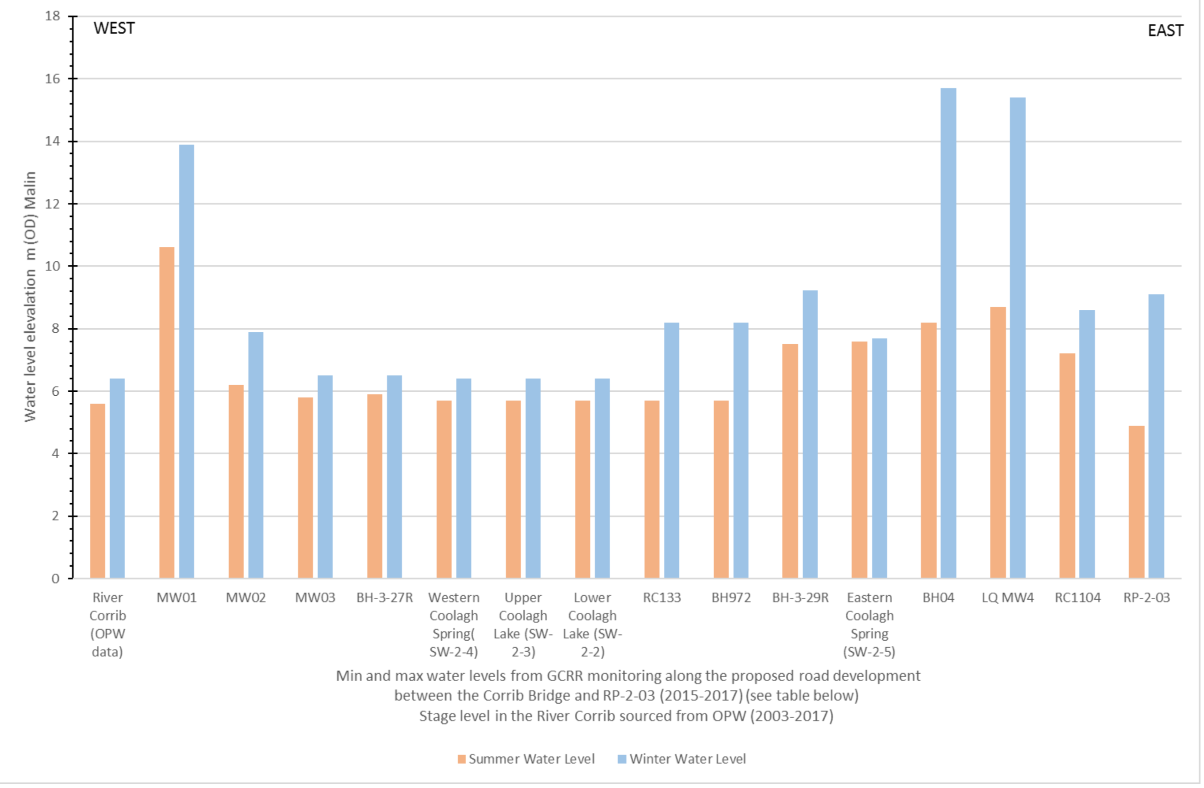


Table 24: Groundwater levels in the area of infiltration basin S40

Monitoring Location	Ground Elevation	Summer Water Level	Winter Water Level	Seasonal Change
	(mOD)	(mOD)	(mOD)	(m)
River Corrib (OPW data)	-	5.6	6.4	0.8
MW01	16.1	10.6	13.9	3.3
MW02	13.4	6.2	7.9	1.7
MW03	6.7	5.8	6.5	0.7
BH-3-27R*	9.1	5.9	6.5	0.6
Western Coolagh Spring (K25) (SW-2-4)	5.4	5.7	6.4	0.7
Upper Coolagh Lake (K45) (SW-2-3)	-	5.7	6.4	0.7
Lower Coolagh Lake (SW-2-2)	-	5.7	6.4	0.7
RC133	11.7	5.7	8.2	2.5
BH972	12.3	5.7	8.2	2.5
BH-3-29R*	13.7	7.5	9.2	1.7
Eastern Coolagh Spring (SW-2-5)	7.4	7.6	7.7	0.1
BH04	32.2	8.2	15.7	7.5
LQ MW4	16.8	8.7	15.4	6.7
RC1104	9.4	7.2	8.6	1.4
RP-2-03	22.4	4.9	9.1	4.2

*Monitoring from Spring 2016-Winter 2016 only.

On the basis of these data there is a groundwater ridge in the vicinity of BH04, with separate groundwater catchments to west and east. The groundwater body to the west is named Lough Corrib Fen 1 (Menlough) and to the east Clare-Corrib (Refer to Hydrogeology HD45 Assessment **Figure 10.5.01** to **Figure 10.5.02**. The summer minimum and winter maximum groundwater levels along the proposed road development are shown in **Figure 10.6.001** to **Figure 10.6.012**.

The groundwater levels in the Lough Corrib Fen 1 (Menlough) GWB identify that the groundwater level at infiltration basin S40 drains westwards towards turlough K31 and Western Coolagh Spring (K25 and monitoring location SW-2-4).

Water level monitoring at Eastern Coolagh Spring indicates that the ponding does not have a significant seasonal response. Bedrock does not outcrop at Eastern

Coolagh Spring and GSI subsoil mapping as well as the GI undertaken for N6 GCRR shows significant increase of thickness at the Coolagh Lakes and K45. On this basis of its location and its geological setting, Eastern Coolagh Spring (K45) is not considered to be a receptor for infiltration basin S40.

Based on this conceptual model, the groundwater level in the Lough Corrib Fen 1 (Menlough) GWB, only overflows to Upper Coolagh Lake where groundwater can rise over the thickness of subsoil deposits, which only occurs at Western Coolagh Spring and not Eastern Coolagh Spring. The conceptual model for the groundwater inflow to Upper Coolagh Lake during high and low groundwater levels is presented in **Plate 15** and **Plate 16** below.

Plate 15: Schematic north south cross-section through Coolagh Lakes (groundwater high)

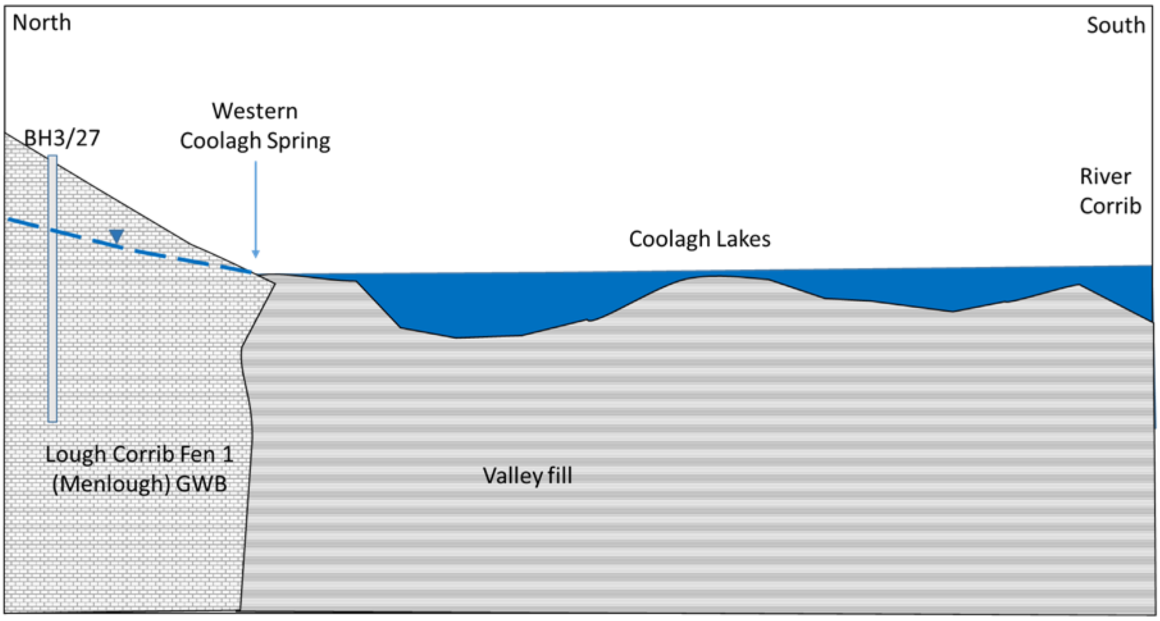
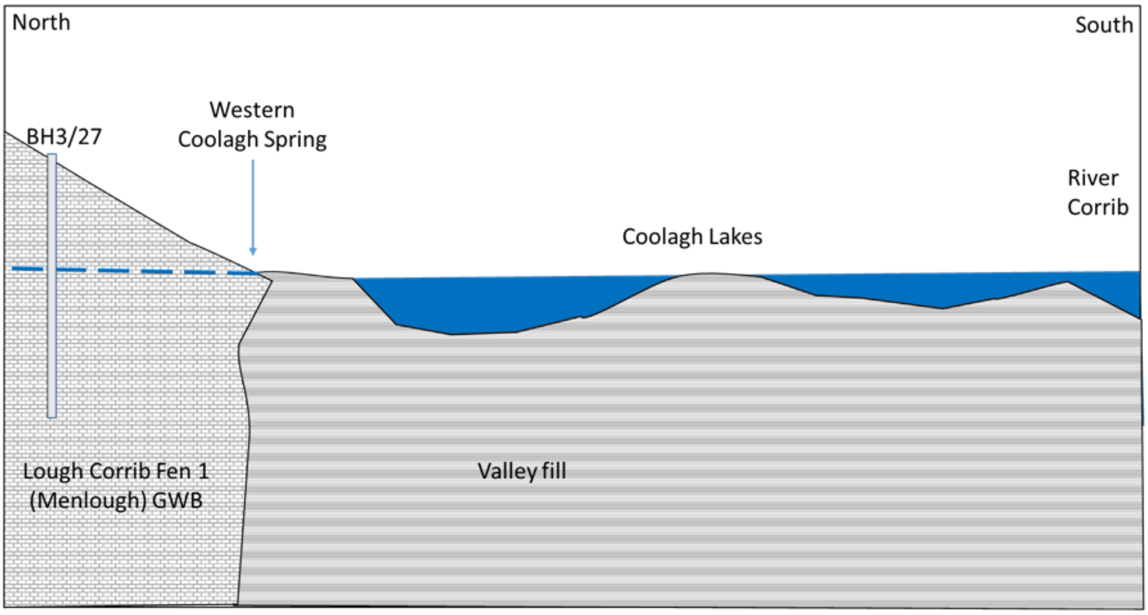


Plate 16: Schematic north south cross-section through Coolagh Lakes (groundwater low)



During the summer groundwater levels in BH972 and RC133 lower to the elevation of the Western Coolagh Spring (K25). Further to the west, there is a small groundwater ridge between Western Coolagh Spring (K25) and the River Corrib (as shown in monitoring wells MW01 and MW02). As such, downgradient of infiltration basin S40 will only extend as far as Upper Coolagh Lake at Western Coolagh Spring (K25). On this basis Western Coolagh Spring and Upper Coolagh Lake is the receptor for infiltration S40.

The minimum groundwater levels recorded are representative of typical summer groundwater levels. However, the maximum groundwater levels recorded are for extreme groundwater conditions (as discussed in **Note 1** of **Table 23**) and are not representative of normal groundwater levels, which will be lower. Based upon the seasonal fluctuation recorded over the monitoring period and information on historical groundwater levels, then an estimate can be made on a typical winter groundwater peak. Historical information is available from Lackagh Quarry (Topographical and Hydrogeological Report, Tobin Consulting Engineers, 2006) and this indicates that the groundwater levels in Lackagh Quarry are below 15m OD, or 0.7m less than that recorded in the winter 2015/16, which represents an 11% reduction in the seasonal range. Given the recorded seasonal range of groundwater during N6 GCRR project 2015 to 2017 monitoring period was 6.7m, then the normal fluctuation would be 6m. By this reasoning a normal winter groundwater range at infiltration basin S40 would rise to 9.5m OD, giving 1.7m unsaturated zone rather than the 9.8m indicated by the 2015-2017 monitoring.

10.2.2 Karst

A karst survey was undertaken at the initial stages of the project to review the GSI karst database but also examine karst features using aerial photographs, LIDAR and ground truthing. The data from the karst survey is detailed in the karst survey report. A summary of the karst survey is presented in **Figure 10.1.01** to **Figure 10.1.02**.

There are three active karst features downgradient of network S40 infiltration basin, these are two turloughs (K20 and K31) and Western Coolagh Spring (K25). Eastern Coolagh Spring (K45) is not a karst feature being located on thick subsoil deposits. Other karst features in the vicinity include the sediment filled palaeokarst feature at the Lackagh Tunnel western portal (refer to N6 GCRR Lackagh Tunnel Report), which extends for 200m east of, and upgradient of, infiltration basin S40. A second palaeokarst feature (or potentially a buried valley feature) is located south of infiltration basin S40. These features, both active karst and palaeokarst, are described below in relation to infiltration basin S40.

Turlough K20 lies 850m northwest of infiltration basin S40. It lies outside of the catchment to S40 in the Lough Corrib Fen 2 groundwater body. Based on the water level data provided and the groundwater bodies delineated by GSI and reinterpreted as part of the N6 GCRR assessment, turlough K20 lies outside of the catchment for S40 and is not hydraulically connected to it.

Based upon the groundwater level data, turlough K31 lies 150m downgradient of infiltration basin S40. The turlough floods seasonally, between October and March. Water level spot measurements were made in K31, which all matched the groundwater level recorded in nearby borehole RC133. The elevation of the groundwater below infiltration basin S40 is slightly below the level at which the turlough begins to flood. As such, groundwater from S40 will not contribute to the water in the turlough.

Western Coolagh Spring (K25) is a perennial karst spring, which discharges into Upper Coolagh Lake. The estimated flow rate varies though out the year from an estimated 30l/s to less than 1ls. The water level at the spring was recorded by logger from summer 2015 to spring 2016 but due to vegetation in the stream it was not possible to measure the flow velocity accurately and measure the exact flow rate. Based on the conceptual model for the Lough Corrib Fen 1 (Menlough) GWB, the catchment for the spring extends upgradient from the spring towards BH04. Western Coolagh Spring (K25) lies 550m south west from S40 and is a receiving water for the infiltration basin.

Eastern Coolagh Spring (K45) has only a very slight seasonal range (0.1m). No discernible flow has been recorded. The location of the spring is on low permeability subsoil deposits with no limestone outcrop. Based on the lack of flow the feature is described as being surface water ponding, which may have been man made as part of the water supply for Lackagh quarry.

The palaeokarst feature identified in the Lackagh Tunnel Report is a deep (104.95m) conical shaped karst feature that has been infilled with well consolidated silt and clay. The feature is non active and is located upgradient of infiltration basin S40. As the hydraulic gradient is away from this palaeokarst feature there is no risk of reactivation or washout in the karst pathways. The well consolidated silt and clay infilling the feature are of low permeability, there will be no flow through this palaeokarst or the similar buried feature that lies to the south of infiltration basin S40. Features such as that identified in at Lackagh Tunnel western approach are inert and act as barriers to groundwater flow. They compartmentalise the limestone aquifer into discrete groundwater bodies and restrict groundwater flow direction.

As part of the ground investigation for S40 drilling, trial pitting and geophysics was undertaken in the vicinity of infiltration basin S40. The basin invert lies at 7.6m OD the over excavation will be entirely in bedrock. The resistivity surveying near to the site (GP3/8) identifies that competent bedrock underlies S40 but that there is a possibility of a weathered zone being encountered.

As per the Construction Environmental Management Plan (CEMP), if karst is encountered during excavation for an infiltration basin then the feature will be mitigated by the karst protocol to ensure that it is not impacted. The karst protocol requires a hydrogeologist to examine the feature and incorporate those listed mitigation measures in order to prevent the intercepted karst becoming a point input for runoff to the groundwater body. The intercepted feature will be managed so that it is sealed from the infiltration basin so that the basin does not discharge to the karst feature.

10.2.3 Receptors

There are no groundwater abstraction wells in the Lough Corrib Fen 1 (Menlough) GWB.

The Coolagh Lakes are part of the Lough Corrib cSAC and as such are a European Habitat. Western Coolagh Spring is the sole significant groundwater inflow to Upper Coolagh Lake, with the only other supply coming from a component of runoff from the thick subsoils around the periphery of the lakes, including the surface water ponding at Eastern Coolagh Spring (K45).

The Lough Corrib Fen 1 (Menlough) GWB does not include point recharge in the form of dolines or shake holes, instead all recharge is diffuse across the GWB catchment. Other than Coolagh Western Spring (K25) there is no evidence indicative of conduit flow in the GWB.

10.3 Summary

Drainage network S40 comprises of a sealed drainage network that directs all flow to an infiltration basin with a containment area and pre-treatment by hydrocarbon interceptor and wetland.

The infiltration basin design comprises of 1m over excavation in bedrock with backfill of 1m appropriate material. Based on the groundwater monitoring data collected over the monitoring period the infiltration basin will provide 1m unsaturated zone during an extreme winter event. The infiltration basin does not meet the minimum 2m unsaturated subsoil design requirement (Note 1) but it does meet the minimum 1m appropriate material requirement (Note 4). The invert level of the infiltration basin has been raised to as high an elevation as possible whilst maintaining the necessary fall on the drainage system.

Attention has been made to karst features and receptors in the vicinity of the infiltration basin. The assessment has identified that turlough K31 lies 150m downgradient and Western Coolagh Spring (K25) lies 550m downgradient. Both K31 and K25 are potential receptors for the treated runoff from the proposed road development at S40. There is potential to encounter karst during the excavation of the basin and this is accommodated in the CEMP by having a hydrogeologist investigate any karst encountered during excavations and following the karst protocol as detailed in the CEMP.

Turlough K31, Western Coolagh Spring (K25) and the Lough Corrib cSAC are potential receptors for the infiltration basin at drainage network S40. By incorporating a containment area as well as pre-treatment by hydrocarbon interceptor and wetland the infiltration basin will exceed the standard water quality for road runoff as listed in HD45/15.

On percolating through the 1m thick infiltration basin the treated runoff will enter the aquifer and be diluted by groundwater. Greater dilution with groundwater will occur in the winter when the water table is higher. Whilst in the summer dilution will be lower but the flow path from source to receptor will be slower, owing to the reduced gradient and flow rate.

All infiltration basins will be checked by a hydrogeologist on a 5 yearly basis to confirm that there is no unexpected subsidence in the level of the appropriate material below the infiltration basin invert. If subsidence is present, then the karst protocol will be triggered and the location of subsidence examined to ensure that no karst flow paths have developed in the basin.

On the basis of this hydrogeological assessment, the design and mitigation measures for infiltration basin S40 meet and exceed the HD45/15 specification for use of permeable drainage. With the mitigation measures of the karst protocol, as well as monitoring at both turlough K31 and Western Coolagh Spring K21 for turbidity and maintenance of infiltration basins by regular surveys then multiple levels of protection will be in place to ensure that there will be no impact to receptors.

11 References

Nicholson, O., Gebre F., Casey, J. & Synnot, R., (2016) *OPW Response to the Winter of 2015/2016 Flooding in Ireland* (National Hydrology Conference, 2016).

Tobin Consulting Engineers, (2006) *Topographical and Hydrogeological Assessment at Coolagh Quarry, Menlough, Galway*.

Walsh S., (2016) *The Rainfall of Winter 2015/16 in Ireland* (National Hydrology Conference, 2016)