Chapter 16 Geology, Hydrology & Hydrogeology

16.1 Introduction

This section of the report describes the geology, hydrology and hydrogeology along the route corridors and considers how they contribute to the selection of an emerging preferred route corridor.

16.2 Geology

16.2.1 Introduction

The N4 Carrick-on-Shannon to Dromod Road Improvement Project incorporates an upgrade of the existing N4 and includes a bypass of Carrick-on-Shannon town. The Route Corridor selection for the Bypass (Section 1) has been reduced down to five main Route Corridor Options, three of which are located north of the town (1.1, 1.2 and 1.3) and two to the south (1.4 and 1.5). An alternative Route to the retrofit option (Section 2) is explored to the east of the N4 extending from the tie in with the recently opened Dromod Roosky bypass section north of Dromod to the townland of Annaduff (2.1). Finally there are two further options to bypass the village of Aghamore, one to the east (2.2) and the other to the west (2.3). Refer to route selection Drawings RCSR-1601 to 1604 that show the alternative route corridors being considered.

16.2.2 Methodology & Data Sources

In preparation of the Route Corridor Selection Report, the geological, hydrological and hydrogeological impacts of all the Route Corridor Options 1.1, 1.2, 1.3, 1.4, 1.5, 2.1, 2.2 and 2.3 were assessed and reported in general accordance with the NRA Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes, Chapter 4.

The majority of the data was collected and assessed in the form of a desk study using information made available from the Geological Survey of Ireland (GSI), historical factual and interpretative reports from site investigation related to the Jamestown / Drumsna Bypass in 1991 and more recent detailed investigation of a possible northern bypass of Carrick-on-Shannon in 2007.

Detailed ground Investigation was carried out by Priority Geotechnical Limited for RPS Consulting Engineers in 2007 along the Northern Route Corridor Option 1.3. This investigation included 19No. Cable tool Boreholes, 61 No. Rotary Boreholes, 81 No. Trial Pits, 10 No. Slit Trenches, 196 No. Dynamic Probes and 30 No. Static Probes.

Preliminary site investigation was carried out in 2001 by IGSL Ltd during a previous Route selection stage for a Carrick-on-Shannon bypass scheme. They used hand held Macintosh probes to determine the extent of soft ground in areas close to the River Shannon. These give some insight to the ground conditions related to various Route corridors.

Specific areas of interest along the alternative Route corridors were evaluated by a site reconnaissance survey by ROD geotechnical staff on the 17th of June 2009; this was also used as an opportunity to scope out suitable locations for preliminary investigation.

Site specific preliminary investigation mainly targeting areas of soft ground was undertaken by Priority Geotechnical Ltd. in November 2009 focusing specifically on areas highlighted by the GSI as peat, fen or alluvium. This investigation included 16 No. Cable tool boreholes; 2 No. Rotary Boreholes; 18 No. Trial Pits, 218 No. Dynamic Probes; 24 No. Macintosh Probes and 12 No. Slit Trenches. Draft logs were available at the time of writing this report.

An impact assessment was used to compare the different Route corridors in an effort to inform the Route Corridor Selection with respect to the geological, hydrological and hydrogeological conditions.

16.2.3 Solid Geology, Subsoils and Soils

The Geological Survey of Ireland (GSI) has mapped out areas of soft ground, such as peat bog, fen and alluvium deposits in this region (see Drawings RCSR-1601 to 1604). These are zones of greatest risk along the proposed alternative route corridors. Specific areas along each route corridor were visually inspected during the site visit undertaken on the 17th of June 2009 and these locations are indicated on Drawings RCSR-1601 to 1604 by a series of encircled numbers and letters.

The following sections describe the ground conditions assumed / encountered along each route corridor option and a brief assessment of the associated geotechnical issues.

Solid Geology

<u>Section 1</u>

Section 1 encompasses the five bypass Route corridor options and part of the N4 retrofit from node B to node I (refer to Drawing RCSR-1603). The following paragraphs describe the solid geology that underlies these bypass options including the relevant sections of the retrofit within section 1. A generalised bedrock geology map of the area is shown in Drawing RCSR-1607 of this report and a generalised hydrogeology map (Drawing RCSR-1606**)** shows aquifer classification.

Northern Route Corridor Options 1.1 and 1.2

Northern Route corridor option 1.1 has the shortest retrofit section from node B to M. Bedrock information for this section (from Annaduff to Mountcampbell) from previous reports is detailed in the following paragraphs. This Route corridor becomes an offline bypass option from node M to node F where it ties back into the existing N4 west of Carrick-on-Shannon.

Similarly Northern Route corridor option 1.2 incorporates part of the N4 retrofit from Annaduff to Tully before diverging as an offline bypass section from node L to F. The following paragraphs detail ground investigation results concerning bedrock along this section.

Historical reports were made available by Leitrim Co. Co. and Roscommon NRDO relating to the Jamestown / Drumsna Bypass (1991) and give some indication of what the ground conditions were prior to the construction of what is now the existing N4. The reports include information from Annaduff (Node B) to Correen (west of Node I) and are discussed below.

Rotary core holes (D1 to D5) were drilled between Annaduff and Mountcampbell Wood in an area of high elevation. Bedrock was encountered in D1 at 7m BGL but not in any of the other holes that were sunk to depths of 14m, 14.5m, 12m, and

12mBGL respectively. This rock was described on the log as dark grey, fine-grained (burrowed) Limestone with fine pyrite and clay fissures throughout, and classified as fairly weak.

Mountcambell Wood was originally a densely forested area of high elevation. As such bedrock was not met in any exploratory hole drilled in this area in 1991, all of which terminated in boulder clay.

Mountcampbell Wood to Tully Rd is a low lying section located very close to the River Shannon. Trial pits in this area all terminated at approximately 3.6mBGL while borehole BH26 terminated at 5.2mBGL on hard strata presumed bedrock.

The remainder of these northern Route corridors are mainly founded in the Croghan Limestone formation which is described in the GSI database as dark cherty limestone with shale. There is limited core information available for this section and therefore depths and strengths of the rock remain undetermined.

Northern Route Corridor Option 1.3

Northern Route Corridor Option 1.3 incorporates part of the N4 retrofit from Annaduff to just east of Liseeghan (node I). See above paragraphs for discussion of bedrock findings from Annaduff to Tully from the Jamestown/Drumsna Bypass (1991).

Along the section between Tully and Kiltycarney bedrock was encountered at shallow depths in rotary core holes along this section (D6 to D8) between 0.9m and 4.7mBGL comprising mainly of Limestone with some Shale content.

Boreholes and trial pits put down between Kiltycarney and Correen all terminated between 1.75m and 3.5mBGL on hard stratum presumed to be Bedrock of hard mudstone or large boulders.

Numerous rotary cores were drilled along Route Corridor Option 1.3 by Priority Geotechnical in 2007 in accordance with the detailed GI investigation outlined by RPS for Leitrim Co. Co.

The offline Bypass section begins at node I as identified on Drawing RCSR-1602. Just north of the townland of Lisseeghan, rotary cores were sunk to depths of 13m to 15.5mBGL but did not encounter rock.

Bedrock was met in rotary holes near the townland of Keenaghan between 52 and 54mOD, approximately 18mBGL. Unconfined compression strength (UCS) tests recorded strengths ranging from 63 to 95MPa. The rock was described in core logs as moderately weak to moderately strong grey Limestone (becoming stronger with depth) moderately weathered with fractures along the bedding and clay smears on fracture surfaces.

North of Keenaghan near a third class road shallow rock was encountered at approximately 2.55mBGL (53.5mOD). The core logs describe this as strong grey Limestone with clay/limestone bands and clay smearing on fracture surfaces. Factures are medium to closely spaced. UCS tests proved strengths of 34 to 79MPa.

Near the town land of Aghameeny rotary cores were sunk to depths of 12mBGL and did not encounter rock head.

In the townland of Ballynamony adjacent to the closed landfill, rotary cores achieved rock at 38.06mOD (9.5mBGL) in BHR18 on the east side of the R280, increasing to 46.04mOD (12.5mBGL) in BR102 on the west side of the road. This suggests that rock head is dipping approximately 6.5° from west to east over approximately 70m. The rock is described as strong grey slightly fossiliferous, crystalline limestone with calcite veining and clay smearing on fracture surfaces.

To the east of Cloonsheebane between the R280 and the third class road no rock was encountered in a rotary hole drilled up to 20mBGL in BR015, however to the west of Cloonsheebane (location 19 on Drawing RCSR-1602) shallow rock was determined at 1.5m BGL (43.20mOD) in BHR08 and described as very strong to strong grey limestone with calcite veining and occasional crinoids fossils. Limestone is slightly weathered with clay smearing on fracture surfaces. Fractures are parallel to bedding, closely to medium spaced. UCS tests indicated a high variability in the rock strength from 5 to over 100MPA from core samples.

Further west along this Route near Portaneoght rotary cores were drilled to depths of 15m BGL in BR014 (64.81mOD), BHR06 (66.72 mOD) and BR013 (60.13 mOD) and did not encounter rock.

Finally the last set of rotary core holes were drilled at the river Shannon crossing. In this area rock level varied from 31.5mOD on the east bank of the Shannon to 37.5mOD on the west bank. The corresponding depths ranged approximately from 9mBGL on the east to 3mBGL on the west. Rock in the river itself was determined at 0.6mBGL approximately 36.5mOD. Borehole logs described the rock as strong light grey Limestone with moderately weak to strong, very fossiliferous dark grey/black clay/limestone bands fractures are medium to extremely spaced.

These site investigation results clearly testify to the undulating topography of the region where rock was not encountered in some holes sunk up to 20m BGL while shallow rock was met at 1.5mBGL in low lying areas between drumlin peaks.

Southern Route Corridors 1.4 and 1.5

Route Corridor Option 1.4 includes the longest section of online improvement before diverging at node J as an offline southern bypass of Carrick-on-Shannon. (Refer to Route Corridors 1.1, 1.2 and 1.3 for details of bedrock encountered along the N4 from Annaduff to Correen).

Route corridor option 1.5 diverges from the retrofit at node K (refer to Drawing RCSR-1603). Ground investigation results previously discussed from Annaduff to Tully also apply to this section.

As with the northern Route corridors, the GSI mapping indicates that the Croghan formation is the underlying bedrock and is comprised of dark cherty limestone and shale.

From previous investigations (IGSL 1991) a cable percussion borehole was put down on the east bank of the of the River Shannon close to the proposed crossing of Route 1.4 which terminated at 7m BGL on an obstruction (possibly bedrock).

On Route 1.4 trial pit SA03 near location 8 on Drawing RCSR-1602 terminated on a flat sheet of limestone at 2.5mBGL.

Trial pits SC01 and SC02 on Route corridor option 1.5 (locations 25 and 27 of Drawing RCSR-1601) both terminated at 0.6mBGL on flat sheets of Limestone, indicating that rock is quite shallow on the Roscommon side of this route.

Section 2

Section 2 encompasses the retrofit option from Faulties at node C to Drumsna at node B and includes the alternative offline option 2.1 to the east of the N4 and the Aghamore Bypass options 2.2 and 2.3. The following sections describe the bedrock underlying these Route corridors.

Route Corridor Option 2.1

The alternative offline proposed Route Corridor Option 2.1 is located to the east of the existing N4 and has very little ground investigation associated with it. From generalised bedrock mapping obtained from the GSI database the Route appears to be founded in various bedrocks. It begins in an area of Ordovian Metasediments known as the Finnalaghta Formation comprised of blue-grey greywacke and black argillite, then it crosses over Dinantian Sandstones of the Fearnaght Formation comprised of pale conglomerate and pale sandstones. Adjacent the village of Aghamore it crosses an area dominated by Ordovian Volcanics known as the Aghamore formation of lava and volcaniclastic breccias. The remaining section from node O to N is founded in the Ballymore Limestone formation; comprised mainly of dark fine grained limestone and shale.

Depth to bedrock was proven by various trial pits along the route. TPEA04 and TPEA03 were excavated close to the disused Finnalaghta quarry and terminated on rock at shallow depths of 1.8mBGL and 1.1mBGL. TPEA02 is located close to the boundary of the Aghamore formation with rock encountered at 2.6mBGL described as volcanic bedrock. While TPEA01 is located between nodes O and N and terminated at 3.5mBGl on extremely large Limestone boulders that are possibly part of the Ballymore Limestone formation.

Route Corridor Options 2.2 and 2.3

These Route Corridors bypass the village of Aghamore and are located between nodes P and O on Drawing RCSR-1607. Route Corridor Option 2.2 passes to the east of the village while Route Corridor Option 2.3 passes to the west. Both are underlain by Ordovian Volcanics known primarily as the Aghamore formation made up of lava and volcaniclastic breccias.

Five cable percussion holes were put down in Aghamore, two on route 2.3 to the west, two to the east on Route Corridor Option 2.2 and one on Route Corridor Option 2.1(east). All boreholes terminated at less than 3m deep; BHR10 0.6mBGL, BHR08 0.4mBGL, BHR09 0.75mBGL while BHR11BGL terminated at 2.55mBGL and BHEA02 terminated at 1.75mBGL on obstructions.

Rotary cores were drilled at the location of BHR10 (west) and at BHR09 (east) to prove bedrock. Rock was proved from 2.5mBGL to 7.2mBGL and described as strong to very strong, massive, vesicular SPILITE with quartz veining moderately weathered with clay smearing along fracture surfaces. Fractures are very closely spaced dipping 50 to 60 degrees.

BHR09 encountered rock head at 5.5mBGL, described as strong to very strong, green massive amygdaloidal SPILITE with quartz veins. Moderately weathered with clay smearing on fracture surfaces, fractures are very closely spaced and dip 50 to 60 degrees. This rotary hole terminated at 11.6mBGL.

Soils and Subsoils

Section 1

The following Table 16.1 gives a brief summary of the type and depths of soft ground that were encountered during the Detailed Ground Investigation in 2007, the subsequent Preliminary Ground Investigation in November 2009 (undertaken by Priority Geotechnical) and the soils and subsoils identified as part of the Jamestown/ Drumsna Bypass site investigation (1991) by Geotech Specialists Ltd. The areas are identified by both the town land and numbers that coincide with the site reconnaissance visit as shown on Drawings RCSR-1601 to 1604.

Table 16.1 Summary of Soft Ground Conditions in Section 1

SECTION 1: SOFT GROUND					
Route	**Location /Townland**	**Surface feature**	**Soil Type**	**Length (m)**	**Depth Range (m)**
1.1	Drumsna to Mountcampbell Wood (B-M)	Low lying undulating gr.	Peat & Organic soils	190	Up to 4.95m
	Lisdauky (13)	Low lying Ground	Peat	140*	7.7
	Garvlough	Stream	Alluvium	80	<1m
	Cornaslieve	Low lying Ground	Peat	50	<1m
	Aghancarra (15B)	Hollow	Peat	325*	9.0
	Cloonsheerevagh (16)	Hollow	Peat	120	2.0-4.4
	Cloonsheebane (20A)	Flood Channel	Peat	270	>0.9
	Corryolus (21)	Fen	Peat	450	0-3.6
	Corryolus (20B)	River Shannon	Alluvium	280	0-6m
1.2	Drumsna to Mountcampbell Wood (B-M)	Low lying undulating gr.	Peat & Organic soils		Up to 5m
	Mountcampbell Wood to Mountcampbell (M -L)	Low lying (40mOD)	Peat & Alluvium	170	2m
	Tully (12)	River Shannon	Alluvium	870	0.4 – 4.0
	Kiltycarney (14)	Stream	Alluvium	100	<1
	Greach (15A)	Stream	Peat	240	0.8-2.4
	Aghancarra (15B)	Hollow	Peat	325*	9.0
	Cloonsheerevagh (16)	Hollow	Peat	120	2.0-4.4
	Cloonsheebane (20A)	Flood Channel	Peat	270	>0.9
1.3	Annaduff to Mountcampbell Wood (B-M)	Low lying undulating gr.	Peat & Organic soils	190	Up to 5m
	Mountcampbell Wood to Mountcampbell (M -L)	Low lying (40mOD)	Peat & Alluvium	170	2m
	Mountcampbell to Tully (L-K)	Flood Plain	Alluvium	150	4m
	Corbally (11)	Failed Embank.	Peat	250	0.4 – 3.7
	Lisseeghan (10)	Stream	Alluvium	320	<3.5m
	Ballnamony (17)	Landfill	Peat	200	1.4-6.4
	Cloonsheebane (19)	Flood Channel	Peat	250	0-2.7
	Corryolus (21)	Fen	Peat	450	0-3.6

SECTION 1: SOFT GROUND					
Route	**Location /Townland**	**Surface feature**	**Soil Type**	**Length (m)**	**Depth Range (m)**
	Corryolus (20B)	River Shannon	Alluvium	280	0-6m
1.4	Drumsna to Mountcampbell Wood (B-M)	Low lying undulating gr.	Peat & Organic soils	190	Up to 5m
	Mountcampbell Wood to Mountcampbell (M -L)	Low lying (40mOD)	Peat & Alluvium	170	2m
	Mountcampbell to Tully (L-K)	Flood Plain	Alluvium	150	4m
	Corbally (11)	Failed Embank.	Peat	250	0.4 – 3.7
	Lisseeghan (10)	Stream	Alluvium	320	<3.5m
	Drumkeeran(8)	Flood Channel	Peat	580	60% >5m
	(Zone G)	Stream	Alluvium	50	<3.5
	Cortober	Tributary Stream	Alluvium	200	70% >5m
	Cortober	Urban Area	Made Gr.	350	0.4 – 1.6
	Cloonman(22)	Tie in	Alluvium	265	1.5-3.0
	Cloonman (Node F)	Tie in	Alluvium	50	4.0-6.0
1.5	Drumsna to Mountcampbell Wood (B-M)	Low lying undulating gr.	Peat & Organic soils	190	Up to 5m
	Mountcampbell Wood to Mountcampbell (M -L)	Low lying (40mOD)	Peat & Alluvium	170	2m
	Mountcampbell to Tully (L-K)	Flood Plain	Alluvium	150	4m
	Lisgarney	Stream	Peat	100	0.3-0.6
	Ballynacleigh (3)	Fen	Peat	330	>4.5m
	Zone J (6)	River Shannon	Alluvium	300	<5m
	Danesfort	Alluvium	Alluvium	75	<5m
	Danesfort (33)	Flood Channel	Peat	300	50%>3.5
	Killulin (29)	Hollow	Alluvium	100	<1
	Mullaghmore (27)	Stream	Alluvium	160	<1
	Meera (25)	Stream	Alluvium	280	0.2-0.6

*Denotes Length is stated for soft ground in excess of 3.5m depth
**GF glacial fine grained soils

Route Corridor Option 1.1

Route corridor option 1.1 begins in Section 1 at node B and becomes a bypass option at node M near the town land of Mountcampbell, north of Drumsna. Investigation results from Annaduff to Mountcampbell (discussed above) apply to this Route corridor also. See Table 16.1 for results of Preliminary ground investigation by Priority Geotechnical undertaken in 2007 and November 2009. Route Corridor Option 1.1 ties into Route Corridor Option 1.2 near the town land of Aghancarra; identified as node H on the Drawing RCSR-1602.

Route Corridor Option 1.2

Route Corridor Option 1.2 is another northern Route that begins at node B as part of the online improvement section and diverges as an offline bypass option at node L near the town land of Tully. Similarly the results of the Jamestown/ Drumsna Bypass from Annaduff to Tully apply to this route corridor. See Table 16.1 for a summary of ground conditions identified during investigations in 2007 and November 2009. Route Corridor Option 1.2 merges with the alignment of Route Corridor Option 1.3 at node G as shown on Drawing RCSR-1602.

Route Corridor Option 1.3

This was the RPS preferred Route corridor option in 2007 and as such was taken to detailed ground investigation stage. Site investigation data is available for the entire Route with specific focus at the tie in sections east and west of the town, stream crossings, road crossings, the Ballynamony landfill, the Fen and main River Shannon crossing.

This Route Corridor Option begins in Section 1 at node B located just north of Annaduff. Ground investigation results from Drumsna to Correen from the Jamestown /Drumsna Bypass report apply to this section also. Table 16.1 gives details of the Preliminary ground investigation by Priority Geotechncial undertaken in November 2009 and the Detailed Investigation in 2007. The tie in point of the offline Route Corridor Option 1.3 is located near the town land of Lisseeghan (at node I on Drawing RCSR-1602) and ties back in to the existing N4 at node F (Drawing RCSR-1601).

Route Corridor Option 1.4

Route Corridor Option 1.4 is a southern bypass option that, as before, begins as part of the retrofit at node B and becomes the offline bypass section at node J near the town land of Lisseeghan (see Drawing RCSR-1602).

Investigation results from the Jamestown/ Drumsna Bypass apply to this Route corridor from the townland of Annaduff to Correen. Table 1 gives details of the Preliminary ground investigation by Priority Geotechncial undertaken in November 2009 and the Detailed Investigation in 2007.

This Route Corridor Option encounters a substantial area of bog land highlighted on the map as location 8 (Drawing RCSR-1601). Upon inspection the ground conditions appeared marshy, with an abundance of low scrub plants and an absence of tall trees.

An area of this bog north east of the alignment (zone F) was probed by IGSL in 2001, and proved soft ground greater than 5m deep (Drawing RCSR -1601). Similarly zone J to the south also established soft ground in excess of 5m (refer to Drawing RCSR - 1601). Therefore this is considered a high risk area. It is assumed that approximately 60% of this land could possibly contain zones where depths of soft material exceed 3.5mBGL.

This Route subsequently passes close to the Railway station and through areas of made ground before it ties into the existing N4 to the west of Carrick on Shannon near Cloonmaan close to the tie in location of the Northern Route corridors. Depths of dynamic probes and borehole BHSA01 terminated between 0.4m and 1.6mBGL in this area. However the main concern here is contamination. Samples extracted from the borehole and have been sent to an accredited laboratory to be tested; results are pending.

Route Corridor Option 1.5

Route Corridor Option 1.5 begins in section 1 at node B and diverges to become a southern bypass section at node K near the town land of Tully. As before investigation results from the Jamestown / Drumsna bypass apply to this Route corridor from the townland of Annaduff to Tully.

At location 3 marked on the map (Drawing RCSR-1601) the Route crosses through an area highlighted as Fen. Two trial pits were recently excavated here and encountered soft brown fibrous Peat and very soft blue sandy clay to a depth of 4.5mBGL. Therefore this could potentially be a high risk area where soft deposits greater than 4.5m exist and road construction in this area would require engineering solutions such as piled embankments, stone columns, surcharge and wick drains or possible excavation and replacement of unsuitable materials.

Section 2

Section 2 extends from the node C (Drawing RCSR-1604) near the townland of Faulties to node B Drumsna. This section consists of an online improvement in the form of Route Corridor Option 2.2 which includes a short offline section to the east of the existing N4 to bypass the village of Aghamore. Route Corridor Option 2.3 is an alternative bypass option to the west of Aghamore. Route Corridor Option 2.1 is an offline alternative from Faulties (node C) to Annaduff at node N just south of node B.

Table 16.2 below gives details of the type and depths of soft ground that were encountered during the Preliminary Ground Investigation undertaken by Priority Geotechnical in November 2009. The areas are identified by the townland as shown on Drawings RCSR-1603 and 1604.

Table 16.2 Summary of Soft Ground Conditions in Section 2

SECTION 2 : SOFT GROUND					
Route	**Location / Townland**	**Surface Feature**	**Soil Type**	**Length (m)**	**Depth Range (m)**
2.1	Fearnaght	Infilled Quarry	spoil	130m	7.3m
	Drumgilra	Hollow/ Stream	Peat	180m	<1
	Gortinity	Flood Channel	Peat	300m	Possible >5m
2.2 & 2.3	Moher	Licensed Waste Permit	Spoil	200m	<2
	Gortinty Lake	Lake	Peat	300m	8.2

Route Corridor Option 2.1

Route Corridor Option 2.1 is an alternative option to the retrofit. It begins at node C in the townland of Faulties and runs parallel to the east of the existing N4. Geotechnical risks associated with this Route have been identified from GSI mapping, information supplied by Leitrim Co Co. and supplementary preliminary ground investigation (2009) (see Table 16.2 for soft ground information identified along these route corridors).

Near Fearnaght the alignment passes through a licensed waste permit site registered to Jon's Civil Engineering (See Drawing RCSR-1605). This was originally a disused quarry that was subsequently in-filled with soft soils removed from the recently upgraded Dromod Roosky project. Investigation proved shallow soft deposits less than 1m deep to the east, however on the western side of the corridor extensive deposits of soft ground were encountered. Additional probes were scheduled and soft deposits were proved up to a maximum depth of 7.3mBGL in DPEA25.

Further north between the town lands of Gortinty and Annaduff, just north of an area with a piled embankment the Route crosses a flood channel of the River Shannon. It is possible that the deep peat deposits associated with the piled embankment extend into this area and could prove problematic for road construction. Route 2.1 ties back into the exiting N4 / Retrofit option near the townland of Drumsna.

Route Corridor Option 2.2 and 2.3

These options include an upgrade of the existing N4 and a bypass of the village of Aghamore to either the east (2.2) or west (2.3). The bypass options for the village of Aghamore do not present any significant geotechnical risks associated with soft ground, however this is an area of shallow strong rock that will require significant cuttings. No groundwater was encountered in any of the boreholes located in this area.

Near the townland of Finnalaghta (between nodes C and P) is a licensed waste permit site, registered to Peter Mcloughlin. Half of this site was infilled with boulder clay where soft ground in DPR137 and 138 was determined to approximately 2mBGL. Other dynamic probes in this area were very shallow and generally less than 1mBGL.

In front of the Masonite factory deep peat and soft deposits were proven up to 8.2mBGL by dynamic probes. The average depth was approximately 4.8m of soft ground. Borehole BHR05 encountered dark, plastic, pseudo fibrous, Peat to 5.5mBGL with SPT N values of 0, 0, 1 and 5. This borehole terminated at 11.5mBGL in dark slightly sandy, gravelly Clay with SPT N values of 35 to 48.

Earthworks Volumes

Each bypass option is an offline section which will require cuts in areas of higher elevation and embankment construction in areas of low lying topography. The following paragraphs detail the earthworks volumes associated with the five Bypass Route corridors. All quantities have been estimated on the basis of offline sections only as it is anticipated the cut and fill balances for the online improvement sections in section 1 will be much smaller.

As stated in Chapter 15 it is anticipated that major ground improvement will be necessary in some areas prior to road construction. It is assumed that a portion of this soft ground will be replaced with good quality material and an estimation of the import material required has been carried out in this assessment. Earthworks quantities have also been assumed at each Compact Grade Separated Interchange, Overbridges and Underbridges assuming a 500m length of road construction. Refer to Drawings RCSR-1601 to 1604.

<u>Route Corridor Option 1.1</u>

Route corridor option 1.1 has the longest offline section of the northern Route corridors of approximately 10,000m. It has 10 embankment sections and 10 cut sections. Six of the cut sections are greater than 10m at their deepest point, three range between 3 and 10m and one is less than 3m. The greatest cut section is approximately 650m long and 10.5m at its deepest point.

Of the ten embankment sections none are greater than 10m. The largest embankment is approximately 8.5m at its highest point, seven range in heights from 3 to 10m and 3 are less than 3m high. The longest embankment is 1,110m long, approximately 4.8m at its highest point and located in the town land of Aghancarra.

This Route corridor option has overall cut and fill volumes of approximately 1,160,000m^3 and 1,090,000m^3. This leaves a surplus of approximately 70,000m^3.

Route Corridor Option 1.2

This offline option is approximately 8,000m long; it begins at node L, merges with Route Corridor Option 1.1 at node G and joins the existing N4 at node F. This corridor includes 10 cut sections and 11 embankments sections. Four cut sections are greater than 10m deep, 5 with range between 3 to 10m while one is less than 3m deep. The longest cut section is 650m, located 700m north of Tully's Cross, with a maximum depth of 11m.

Route Corridor Option 1.2 has eleven embankment sections, one of which has a maximum height of 10m, six have maximum heights ranging between 3 and 10m and 4 are less than 3m. The longest embankment section in 1,010m long and located to the east of the Leitrim Road and extends to the townland of Aghancarra with a max height of approximately 4.8m.

This Route Corridor Option has overall cut and fill volumes of 631,000m^3 and 1,307,000m^3, this leaves a deficit of approximately 676,000m^3.

Route Corridor Option 1.3

Route Corridor Option 1.3 becomes an offline section at node I and ties back into the existing N4 at Node F and is approximately 6,330m long. This option includes 7 embankments that range between 3 and 10m high; the largest is 8.5m at its highest point and extends 600m long over Hartley's Cross between the townlands of Portaneoght and Ballynamony.

This option also requires 3 cut sections between 3 and 10m in depth and 4 cut sections ranging from 10 to 14m in depth.

This offline option requires approximately 623,000m^3 of cut and 1,070,000m^3 of fill. This produces a deficit of 453,000 m^3 of material.

Route Corridor Option 1.4

This southern Route corridor is approximately 5,000m long, encompassing 5 cut and 5 embankment sections. The cut sections range in depths between 3 and 10m. The longest cut section is approximately 1,280m long with a depth of over 8m at its deepest point.

Of the five embankment sections along this Route Corridor Option one has a maximum height of over 10m, 1 is less than 3m and three range between 3 and 10m at their highest point. The longest embankment section is 450m long with a maximum height of 3.5m.

This Route Corridor Option has overall cut and fill volumes of approximately 327,000m^3 and 1,146, 000m^3, leaving a deficit of approximately 818,000m^3.

Route Corridor Option 1.5

This is the longest southern Route Corridor Option stretching approximately 8,000m. It includes 12 cut and 10 embankment sections. Of the twelve cut sections, one has a maximum depth greater than 10m, nine range between 3 and 10m at their deepest points and two are less than 3m deep. The longest cut section is approximately 580m long with a depth of over 5.5m at its deepest point.

Of the ten embankment sections along this Route Corridor Option two have maximum heights of over 10m, one is less than 3m and seven range between 3 and 10m at their highest point. The longest embankment section is 1,370m long with a maximum height of 5m.

This Route Corridor Option has overall cut and fill volumes of approximately 486,000m^3 and 1,170,000m^3, this leaves a deficit of approximately 684,000m^3.

Table 16.3 below gives a summary of the cut and fill volumes for the five offline bypass options.

Table 16.3 Cut and Fill Summary

Route corridor option	Quantity		Max Depth/ Height (m)		Max Length (m) with Max Depth/Height (m)				Overall Volumes (m^3)		Surplus / Deficit (+/-)
	Cuts	Embkmt.	Cut	Fill	Cut	Dpt. (m)	Fill	Hgt. (m)	Cut	Fill	
1.1	10	10	14	8.6	650	10.5	1,110	4.8	1,160,000	1,0900,000	+70,000
1.2	10	11	14	11.5	650	11	1,010	4.8	631,000	1,307,000	-676,000
1.3	8	10	14	8.3	460	14	750	5.5	623,000	1,076,000	-453,000
1.4	5	5	8.1	10	1,260	8	450	3.5	327,000	1,146,000	-818,000
1.5	12	10	13.5	14	1,370	5	580	5.6	486,000	1,107,000	-684,000

Major Shannon Bridge Crossing

Route Corridor Options 1.1, 1.2 and 1.3

Bridge Foundations

Bridge foundations for the northern route corridors will either be piled foundations or shallow pad foundations. Rock was encountered on the east bank of the River in BR011and BR012 at approximately 9mBGL (31.5mOD) while shallow rock was determined in the river bed ranging in depth from 0.6m to 1.5mBGL (36.29mOD to 33.99mOD) and on the west bank at approximately 3mBGL (37.5mOD). There is limited rock testing results for the east bank although the rock was described on the logs as strong Limestone. Test results for samples extracted from the river bed indicate strong limestone from 1.5 to 5.5mBGL with UCS values from 15MPa to 146MPa. On the west bank samples from 4.7 to 6mBGL indicated strengths of 17MPa to 77MPa. The logs show almost 100% total core recovery and a relatively solid formation with an RQD generally greater than 50%.

Access Route corridors

From the east approach there is a disused access track through the fen area that could be used to track plant machinery to the bridge location during construction. From the west approach there appears to be no such access route and a temporary track will have to be constructed from the existing N4 for the duration of the construction of the bridge. The track could conveniently follow the proposed road corridor from its junction with the existing N4.

Embankment Foundations

The approach embankment to the east is located through a low lying flood channel of the river Shannon. Previous investigations in this Fen area suggest that depths of soft ground are less than 3.5m deep and therefore should not prove problematic for road construction.

An alluvium flood plain is located on both the east and west banks of the River. Detailed investigation in 2007 by Priority Geotechnical Ltd. proved depths of soft material on the east bank up to 6mBGL (ranging from 0.3m to 6mBGL). On the west bank of the Shannon soft ground has been proved to depths of 1.5m to 3.8mBGL. Therefore the east bank will prove more problematic for construction.

Route Corridor Option 1.4

Bridge Foundations

Bridge foundations for the southern bypass options are anticipated to be similar to the northern options and most likely be either bored piled or pad foundations if rock is strong and shallow. Little geotechnical information is currently available at the crossings for this option but the bridge will span from an area high ground to high ground. The depths of overburden may vary at abutment locations but are not expected to be greater than 10m maximum.

Access Route corridors

The most direct access route corridors to this Shannon Bridge Crossing from the east approach lies through residential areas and therefore likely to be unacceptable for construction traffic. A temporary access track will have to be constructed along the proposed route corridor through an area of suspected deep peat deposits. In this area approximately 270m are anticipated to contain soft deposits deeper than 3.5m. The area is particularly prone to flooding. This will inevitably increase the cost of the bridge construction at this location.

A reasonable access road exists to the west; however a live railway line has to be crossed at an existing level crossing, creating increased health and safety concerns.

Approach Embankments

Approach embankments on the east side will be founded on very soft, deep peat deposits. Remedial solutions such as a piled embankments, or excavation and replacement will have to be considered in this area. Surcharging with wick drains and stone columns are solutions that may be used for the soft clay/ alluvium layers beneath Peat; if it is economical to remove the top layer of Peat. Further investigation will be required to determine the more practical and economical solution in this area.

The approach embankment on the west will most likely be founded on boulder clay and may not prove problematic for road construction.

Route Corridor Option 1.5

Bridge Foundations

Similarly Bridge foundations in this area will most likely be piled or shallow pad foundations depending on the type of bridge, the rock strength and level of overburden in this area.

Access Route Corridors

There is an access road on the east approach that leads down to a small boat yard. This road is in bad condition, liable to subsidence and prone to flooding; however with minor improvements it may be a viable access track for plant machinery to reach the bridge location during construction.

There is a narrow access road on the west approach; however this road crosses the live railway line and is probably unsuitable for heavy construction traffic. Across the railway line the road becomes a farmer's access track, and abruptly ends at the base of a steep hill from which the proposed bridge spans. This area is also prone to flooding as it lies within a flood plain.

Approach Embankments

The approach embankment to the east is founded on an area of high ground possibly a drumlin consisting of boulder clay which should not affect road construction.

The west approach will be founded in an area highlighted on the map as Peat by the GSI database. It appears that some sections in this area have been improved by local farmers however it is assumed that approximately half of this area will have soft deposits greater than 3.5m deep.

16.2.4 Soft Ground Conditions and Geohazards

There are numerous sections along all of these Route corridors that encounter soft ground that may prove problematic for road construction.

Section 1

The extents of soft or adverse ground conditions that were encountered during the investigation of the Jamestown/ Drumsna Bypass (1991) are discussed in Section 16.2.3 and detailed in Table 16.1 (Refer to Drawings RCSR-1601 to 1604 and also to N4 Road Realignment (Jamestown/ Drumsna Bypass) Drawings DRG No. 230/173/1A to 12A (1991)). Similarly investigation results from 2007 and 2009 are also detailed in Table 16.1 of Section 16.2.3.

<u>Route Corridor Options 1.1, 1.2, 1.4 and 1.5</u>

Areas of adverse ground conditions have been identified in section 16.2.3previously. Depths of peat less than 3m may be economically excavated and replaced, depths greater than this may require a piled embankment section, improvement by stone columns, vertical drains, surcharge, deep soil mixing etc.

<u>Route Corridor Option 1.3</u>

Nodes K-I

Option 1.3 includes a section of previously failed embankment in the townland of Corbally which occurs along the retrofit section between **nodes K and I** highlighted on Drawing RCSR-1602. It was reported that some problems appeared in road surface during original construction in 1995 and a mesh or geogrid was added to the construction design which counteracted cracking that appeared in the pavement. However in 2004 remedial works were undertaken due to excessive settlements that occurred along a 180m section on the hard shoulder of the west bound carriageway. Settlements at the road edge ranged from 80mm to 175mm.

Construction of this bypass resulted in widening the road along this section. Soft ground was identified to the north of the old road and was excavated prior to construction of the new embankment. However this soft ground probably extended under the old road and the new embankment was built leaving this in place on the south side. The cause of the failure is thought to be a combined result of the fill material from the embankment and the poor foundation of the old road which resulted in subsidence of the new road. Remedial works that took place in 2004 reduced the original slope of the embankment, included a berm construction and incorporated a lightweight aggregate (Hasopor) to build up the embankment after the existing material was excavated and disposed of.

Preliminary investigation (2009) also focused on this area of failed embankment section in Corbally. Soft ground was proven by probes from 0.4m to 3.7mBGL along this 250m section. BHR01 was also sunk in this area to achieve soil samples that could be tested in the lab. This exploratory hole encountered Peat and soft Silt to depths of 1m and 2mBGL returning SPT N values of 3 and 6 respectively. This is followed by firm to stiff gravelly clay with SPT N values of 22. This borehole terminated on an obstruction at 4.4mBGL.

Ballynamony Landfill

The disused Ballynamony landfill on the R280 is a significant geotechnical constraint for Route Corridor Option 1.3. The alignment passes extremely close to the north-east side of the disused landfill (location 17 on Drawing RCSR-1602). Construction near the landfill poses many serious risks of contamination to the surrounding lands and groundwater due to potential removal of landfill material, damage to leachate collection pipes or the HDPE / natural liner in the landfill.

Additional investigation was scheduled in this area adjacent the Ballynamony landfill site and further north of the proposed corridor in 2009. Dynamic probes proved soft ground to depths of between 1.4 and 5.3mBGL. TPNA01 and TPNA02 were also dug in this area with TPNA01 situated on the northern edge of the route corridor. Peat was encountered to a depth of 4.5mBGL and described as black fibrous peat, this was underlain by soft blue clay from 4.5 to 4.7mBGL. TPNA02 was located approximately 50m north of TPNA01 and proved 2.6m of Peat above firm to stiff gravelly clay. This trial pit was terminated at the scheduled depth of 4.5mBGL.

Chemical analysis was scheduled on soil samples extracted from trial pit TPNA02 located just north of the disused landfill in the form of Murphy Suite Analysis. Results indicate that the quantities of Dissolved Organic Carbon (leachate) and Total Organic Carbon (TOC Solid) both exceed the limits as defined by Murphy Environment Hollywood Ltd for disposal as inert waste. This soil may require additional treatment before disposal.

Section 2

<u>Route Corridor Option 2.1</u>

The alignment of Route Corridor Option 2.1 located to the east of the retrofit goes through a licenced waste permit site located in the townland of Fearnacht. This was once a disused quarry that has since been filled in with unsuitable material possibly removed from the site of the Dromod Roosky scheme.

Dynamic probes scheduled on the west side of the corridor encountered soft ground up to a maximum of 7.3mBGL in DPEA25, while probes on the eastern side were generally shallow and terminated less than 1mBGL.

Borehole BHEA03A also encountered soft, possible made ground from 0 to 4mBGL which included pockets of Peat. Firmer Clay deposits were identified from 4m to

7.1m with SPT N values of 16 to 28. From 7.1m to 9.52BGL the log details dark brown sandy gravelly clay with occasional cobbles and pockets of dark fibrous Peat and terminated at this depth (9.52mBGL) on a possible boulder obstruction.

Made ground identified in this infilled Quarry was sent for chemical analysis. Results indicate that this material was deposited as inert waste as all chemical levels are within the specified limits.

Refer to soft ground summary in Section 16.2.3 previously for additional information.

Route Corridor Option 2.2 and 2.3

Between nodes O and N along the retrofit section is an area of piled embankment located just north of Gortinity Lake. This area was highlighted in a report compiled by Mott MacDonald commissioned by Leitrim Co. Co. called "N4 Soft Ground Improvements at Annaduff/Gortinity and Attirory / Attifinlay Geotechnical Desk study" dated July 2000. These two sections of the N4 were in need of improvement resulting from extensive deposits of soft ground in the area. The Annaduff section is of concern to this study however the Attirory area is outside the boundary of the Route corridors.

This is a low lying area surrounded by areas of high elevation to the north, east and west and Gortinty Lake to south. On the typical cross section drawing developed by Mott MacDonald for Leitrim County Council in March 2001 (41901/TRA/DUB/106), the indicative baseline depth of peat / soft clay is approximately 8m from the existing ground level (this level is shown at approx. +39.7mOD). The soft ground extends for approximately 300m and this area was subsequently piled to support the new road. Above the piles are two layers of geogrid, "paragrid" 150/15 reinforcement and a 600mm thick load transfer platform.

Preliminary SI was also scheduled to investigate this area, near Gortinty Lake and at Derryoughter to verify historical reports. Dynamic probes adjacent the Masonite factory determined deep peat and soft deposits up to 8.2mBGL. The average depth of soft ground was approximately 4.8m. BHR05 was also located along this section and encountered dark, plastic, pseudo fibrous, Peat to 5.5mBGL underlain by Silt to 7mBGL. This borehole subsequently terminated at 11.5mBGL in dark slightly sandy, gravelly Clay.

This alternative route is likely to require a widening of the existing piled embankment over a similar 300m length of roadway. This will probably require extensive temporary works to permit the embankment to be widened while still supporting road traffic.

A Licensed waste permit site located at Moher is affected by both Route Corridors 2.2 and 2.3. It has a length of 200 metres but is quite shallow measuring approximately 2 metres in depth.

16.2.5 Karst Features

A search for any Karst features along the Route Corridors was conducted through the GSI Groundwater Department, using it's Karst database. The database search was conducted using online mapping and direct contact with the GSI. Despite the considerable number of features identified to the west of Carrick-on-Shannon, there are limited such features located within the confines of the study area.

The only Karst feature identified within the study area is a "spring", (Toberconellan) located approximately 1.5 kilometres south of the railway station on the outskirts of Carrick-on-Shannon and approximately 300m south of Route Corridor Option 1.5.

The possibility of undisclosed Karst features along any of the Route Corridors cannot be completely discounted but the risk is considered to be relatively low. Attempts should be made to identify and assess karst features at subsequent site investigation stages. Karst features identified from the GSI database are plotted on the generalised bedrock map (refer Drawing RCSR-1607 in Volume 2).

16.2.6 Historical Land Use

It was observed on the site visit that much of the lands identified as peat by the GSI on the outskirts of Carrick-on-Shannon, (particularly to the south) have been improved by local farmers to be used for cattle grazing and to grow silage. The key farming activities in the area are beef and mixed grazing, typical for farms in the north west of Ireland.

16.2.7 Economic Geology

There are two active quarries that are currently involved in extracting the limestone bedrock for aggregate in the vicinity of the study area. The first is Hillstreet Quarries Ltd. and the second is Laragan Quarry which is exploited by Hanley Bros Ltd, these are both located outside the study area and do not pose any constraints but could potentially be a good source of aggregate for the new road improvement scheme. Quarry locations are shown on the Quarries and Minerals locations plan (Drawing RCSR-1605); Hillstreet Quarries Ltd is located at E194600, N291729 while Laragan Quarry is situated approximately 6.5km further south and not shown on the drawing.

Two other quarries are also located within the study area and have been active in recent times. The first is Finnalaghta Quarry situated to the east of the Shannon close to the Route Corridor Option 2.1 (E203949, N293952) and according to the GSI database, this was once a disused sandstone quarry. Presently it is a registered quarry; however due to intensified quarrying in this location action has been taken in the High Court to have it discontinued.

The second is Kiltycarney Quarry located along the retrofit Route Corridor Option 2.2 between nodes K and I on Drawing RCSR-1605 (E197075, N298521). This was authorised for activity during the construction of the Drumsna Bypass, but a condition of permission was that the quarry be rehabilitated within six months of completion of the scheme. This did not occur and therefore this quarry is unauthorised and at present is not active.

The GSI database also highlighted a number of disused quarries south of Carrick-on-Shannon, most of which are located on the outskirts of the study area. However a disused greywacke quarry was identified adjacent to the retrofit Route Corridor Option 2.2 at Fearnaght (E204042, N292657).

16.2.8 Geological Heritage

The Geological Survey of Ireland (GSI) is in partnership with the National Parks and Wildlife Service (NPWS) to identify and select important geological and geomorphological sites throughout the country for designation as Natural Heritage Areas (NHAs) and County Geological Sites (CGSs).

Such a site has been identified within the boundaries of our study area. Finnalaghta Quarry located near **Route Corridor Option 2.1** which has been proposed under the (Irish geological Heritage) IGH4 Cambrian-Silurian theme for NHA designation. This quarry exposes the Finnalaghta Formation. It has a highly unusual structure and provides the most continuous sedimentological section through the turbidites which dominate the formation. Route corridor for alternative 2.1 is presently outside the boundary of IGH4 site and no impacts are anticipated.

16.2.9 Impact Assessment

Excavations for deep cuttings (greater than 10 meters) through steep, sloping ground are at risk of encountering both short term and long term stability problems. The Route selection should avoid alignments with excessive depths or quantities in cutting on the basis of both safety and economic assessments. From this point of view, Options 1.1 and 1.2 are less favourable, although suitable engineering mitigation methods can be deployed to allay this concern when necessary.

To minimise the geotechnical requirements it would also be best to avoid the construction of high embankments (over 5m especially) on the low-lying ground between drumlins and close to the River Shannon that contain significant depths of soft alluvium and peaty deposits. The ground in these areas is more likely to be marshy and wet so differential settlements and instability are concerns which require engineering solutions at increased cost to the project.

Sites and properties along the N4 road are founded on levels substantially below the roadway close to the River Shannon and Gortinty Lough, so earth retaining structures would probably be necessary. From this point of view, Option 1.1 has the advantage over Route Corridor Options 1.3, 1.2, 1.4 and 1.5 as it avoids low lying areas along the retrofit close the River Shannon (location 12 on Drawing RCSR-1603), an area of substantial peat deposits and an area of known previous embankment failure (location 11).

16.2.10 Comparison of Alternative Route Corridors

The comparison and ranking of the alternative route corridors was divided into two parts.

Section 1

The bypass route corridors were compared on geotechnical criteria for the length of the Route that passed through or impacted a) soft alluvium b) peat and fen deposits c) licensed waste permit sites and d) the extent of unfavourable soil and access conditions on the River Shannon bridge approach. Other factors relating to Karst, Land Use, Economic Geology and Geological Heritage are not likely to have significant impact for any of the alternative route corridors and therefore were not ranked.

The Route Corridor with the worst conditions was given the highest marks on a scale of 1 to 5 i.e. 5 being the worst Route and 1 being the best.

Cut and Fill Balance was determined from MX modelling and based on the offline sections of the five bypass route corridors. They were ranked on the basis that a surplus of 20 to 30% was preferred. Route Corridor Option 1.1 had a surplus of 3% and therefore was ranked as 1; all other options produced deficits and were ranked from the lowest to highest accordingly.

The criteria of Peat and Fen were ranked based on the length of route that passed through this type of material. Lengths of route corridors with known depths greater than 3.5m were doubled to account for the additional cost of treating the soil or other engineering solutions that would be required in this area such as piled embankments, stone columns, surcharge and wick drains or excavation and replacement.

Route Corridor 1.3 was penalised for its proximity to the Ballynamony landfill, no other bypass option is located close to landfills or waste permit sites and therefore remaining route corridors were ranked evenly so as the sum of each category would still amount to 15.

The Shannon bridge crossing was ranked on the accessibility of access roads and the length of soft ground that the approach embankment would be founded on. The preferred Route that emerged from this analysis on the basis of soils and geology alone was Route Corridor Option 1.1. The worst Route was the southern Route Corridor Option 1.5. The results are summarised below in Table 16.4.

Section 2

Similarly the route corridors of Section 2 were compared on geotechnical criteria of the length of the Route that passed through or impacted a) soft alluvium b) peat and fen deposits and c) licensed waste permit sites. The Shannon bridge crossing is not applicable to this section.

The route corridors were ranked using the same system as above. Route corridor option 2.1 had the most favourable Cut and Fill Balance with a surplus of 29% and was ranked as 1; Option 2.2 had a balance of 0%, while Option 2.3 has the worst outcome with a deficit of 13% and was therefore ranked 3.

Route corridor option 2.1 was the least impacted by peat and fen areas, as only approximately 8% of the entire length passed through these unfavourable ground conditions. In contrast Route corridor option s 2.2 and 2.3 have approximately 23% of their total length affected by these ground conditions.

None of these route corridors were impacted by alluvium deposits and therefore an equal ranking of 2 was allocated to each route.

Route corridor option s 2.2 and 2.3 pass very close to a waste permit site licensed to Mr. Peter McLoughlin; this area is more extensive than the Jon's Civil Eng waste permit site located on Route corridor option 2.1. Therefore Route corridor option s 2.2 and 2.3 were penalised more heavily than 2.1.

Overall Route corridor option 2.1 emerged as the preferred route, based on the soils and geology of the region, while Option 2.3 emerged as the least favourable.

Table 16.4 Route Corridor Option Ranking

SECTION 1	Marks	Marks	Marks	Marks	Marks
Route Corridor Option	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
Cut & Fill Balance	1	3	2	5	4
Peat and Fen	5	4	3	1	2
Alluvium	1	2	4	5	3
Landfill and Waste Permit	2.5	2.5	5	2.5	2.5
Shannon Bridge Crossing	2	2	2	4	5
Total	**11.5**	**13.5**	**16**	**17.5**	**16.5**
Ranking	**1**	**2**	**3**	**5**	**4**

SECTION 2	Marks	Marks	Marks
Route Corridor Option	**2.1**	**2.2**	**2.3**
Cut & Fill Balance	1.0	2.0	3.0
Peat and Fen	1.0	2.5	2.5
Alluvium	2.0	2.0	2.0
Landfill and Waste Permit	3.0	1.5	1.5
Total	**7.0**	**7.5**	**8.5**
Ranking	**1**	**2**	**3**

16.3 Hydrology

16.3.1 Introduction

Work brief

Hydro Environmental Ltd was commissioned by the Roughan & O'Donovan on behalf of Leitrim County Council to carry out a hydrogeological assessment for the N4 Carrick-on-Shannon to Dromod Route Corridor Selection Study.

This report section was prepared in accordance with the National Roads Authority (NRA) publication '*Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes*'.

The proposed scheme relates to the improvement of 18.5 km of the N4 National Primary Route and associated infrastructure from west of Carrick-on-Shannon / Cortober in the Townland of Cloongownagh, County Roscommon to the northern tie-in of the recently completed N4 Dromod Roosky Bypass in the Townland of Faulties, County Leitrim. The scheme will include a bypass of Carrick-on-Shannon / Cortober and will include a new River Shannon crossing.

Work brief

Based on information obtained during the Constraints Study Report a total of seven feasible route corridors were developed taking into account all physical, planning and environmental constraints that were identified.

The following sections provide a general route description, subdivided into discrete sections based on recognisable features in the landscape. For each section an existing environment summary of the topography, surface water features and subsoil geology relative to drainage is given.

Route Corridor Option 1.1

Route Corridor Option 1.1 leaves the existing N4 at Cloonmaan (Node F), crossing the River Shannon 0.7 km to the northeast. The crossing is approximately 156 m wide. The ground is low lying across the floodplain, passing through part of the pNHA designated Drumharlow Lough in Corryolus. The topography rises to Portaneoght (Node G) before falling again. Subsoils between Nodes F and G are predominantly Devonian Sandstone Tills overlain by a cover of deep poorly drained mineral Surface Water / Groundwater Gleys. A band of Undifferentiated Alluvium associated with the River Shannon, and some Fen Peat around Corryolus are also mapped along the section. The route swings eastwards and then south eastwards to Aghancarra (Node H), crossing two small streams in Cloonsheerevagh and Cornamucklagh that flow southwards towards the River Shannon. Similar Sandstone Till overlain by Gleys with pockets of Fen Peat is mapped along this part of the route. From Aghancarra the corridor passes south eastwards through numerous small low-lying drumlins and crosses five small streams. Subsoils for the initial half of this part are Carboniferous Limestone Tills with the second half predominantly Sandstone Tills. All are overlain by Gleys, with pockets of Fen Peat and Alluvium. Some made ground is present near Drumsna. The route rejoins the existing N4 at Crickeen (Node M), and continues along it to Drumsna (Node B) passing approximately 50 m west of Gortconnellan (Spa) Lough.

Route Corridor Option 1.2

The section is similar to Route Corridor Option 1.1 up to Aghancarra (Node H). It then continues southeast through an area of low drumlins to rejoin the existing N4 at Tully (Node L), crossing four streams. A short distance of Sandstone Till is present south from Node H, with the middle part Limestone Till and then the remainder back in Sandstone Till. These tills are overlain by Surface Water / Groundwater Gleys. Occasional Fen Peat and Alluvium is present. The route follows the existing N4 through woodland bordering the River Shannon to the south, to Crickeen (Node M). The section between Nodes M and B is similar to Route Corridor Option 1.1.

Route Corridor Option 1.3

The section is similar to Route Corridor Option 1.1 up to Portaneoght (Node G). It sweeps eastwards and the southwards through low-lying drumlins, rejoining the existing N4 at Lisseeghan (Node I). The subsoil for this section of the route is predominantly Sandstone Till overlain by Gleys, with some made ground associated with an old County Council landfill site located to the south of the corridor at Cloonsheebane. A small stream is traversed in Keenaghan, flowing into the River Shannon to the southwest. The route follows the existing N4 southeast to Tully (Nodes K and L). Subsoils along this section are initially Limestone Tills moving into Sandstone Tills, overlain by Gleys. Pockets of Fen Peat and Alluvium are present. The remaining section from Node L to B is similar to Route Corridor Option 1.2.

Route Corridor Option 1.4

Route Corridor Option 1.4 leaves the existing N4 at Cuillyconeen (Node E) heading south eastwards through Cortober and then east to cross the River Shannon at Cordrehid. The crossing is approximately 128 m wide. West of the Shannon it crosses three small streams including the Killukin River and associated flood plain. East of the River Shannon the topography rises through Drumkeeran to rejoin the existing N4 at Lisseeghan (Node J). Subsoils along the section to Node J are predominantly Sandstone Tills overlain by Gleys, with Alluvium deposits associated with the streams and River Shannon crossings. A large area of Fen Peat is mapped near Drumkeeran and includes a small pocket of bedrock at or close to surface. The remaining section to Node B is similar to Route Corridor Option 1.3.

Route Corridor Option 1.5

Route Corridor Option 1.5 leaves the existing N4 at Cuillyconeen (Node D) heading south to the R370 and then south east to Danesfort, crossing undulating ground and three small streams including the Killukin River. It proceeds eastwards to cross Lough Corry (approximately 242 m width of water) and then rejoins the existing N4 at Tully (Node K) having crossed three small streams. A part of this section runs along the shore of Lough Corry for approximately 420 m. The ground rises slightly around Lisgarney before Tully. Subsoils are predominantly Sandstone Tills overlain by Gleys with pockets of Fen Peat and Alluvium. Some bedrock outcrop or close to surface is mapped south of the R370 and in Killukin. The area to the south of Ballynacleigh is a mixture of Limestone Tills and Fen Peat. The remaining section (Node K to B) is similar to Route Corridor Options 1.3 and 1.4.

Route Corridor Option 2.1

Route Corridor Option 2.1 leaves the existing N4 south of Drumsna and runs almost parallel to it approximately 150 m to the east, rejoining just north of the southern tie-in at Faulties. Topography along the route is predominantly low lying characterised by numerous small drumlins. Subsoils from Node B to Gortinty are mostly Sandstone Tills to the north and Fen Peat to the south. The remainder to the southern tie-in is predominantly Limestone Till with some areas of bedrock outcrop or subcrop. The tills are overlain by Gleys.

Route Corridor Option 2.2

Route Corridor Option 2.2 is an upgrade of the existing N4 with a slight eastwards diversion around Aghamore, between Nodes O and P. The landscape is characterised by low lying drumlins with a rise towards the south at Aghamore. The western side of the corridor borders the easten shore of Drumgilra (Gortinty) Lough for approximately 460 m. Subsoil classifications are relatively similar to Route Corridor Option 2.1

Route Corridor Option 2.3

Route Corridor Option 2.3 follows Route Corridor Option 2.2 apart from the section between Nodes O and P running to the west of Aghamore. Subsoil classifications are relatively similar to Route Corridor Option 2.1.

Hydrological / Objective

This section of the Route Corridor Report has been prepared by expanding the desk study work carried out for the Constraints Study to look at all available data specifically relating to the selected route corridor options. It includes an assessment of aerial photography reviewing watercourses and floodplain areas. The desk study details are verified on the ground by a drive-by survey along each route corridor.

The principal criteria that have been used to assess and evaluate the route corridor options are:

- Significant watercourses crossed;
- Floodplains;
- Surface water features; and

- Designated sites of ecological importance.

Any areas that have been highlighted as being of potential hydrological significance are targeted for walkover surveys and the collection of field data in order to assess the significance of any likely environmental impacts at EIS phase.

16.3.2 Methodology

Data sources

The following list of data sources were the main information sources reviewed as part of this route corridor selection report:
Ordnance Survey of Ireland (OSi)

- Discovery Series Mapping (1:50,000)
- Six Inch Raster Maps (1:10,560)

Office of Public Works (OPW)

- Hydrometric water level and flow records
- Arterial drainage scheme maps and flood damage maps

Environmental Protection Agency (EPA)

- Water Quality Monitoring Database and Reports
- Water Framework Directive Classification
- EPA low flow measurements

Met Eireann

- Rainfall data

Roscommon / Leitrim County Council

- Planning Registers
- Roscommon County Development Plan (2002 – 2009)
- Draft Carrick-on-Shannon Local Area Plan (2010 – 2016)
- Leitrim County Development Plan (2009 – 2015)
- Water Services – Abstractions, Discharges & Supply Schemes

National Parks and Wildlife Service (NPWS)

- Designated Areas Mapping
- Site Synopsis Reports

Other sources

- ERU "hydrometric data in Ireland"
- Flood Study Reports – (NERC, 1975)
- Irish Peatland Conservation Council (IPCC)
- Shannon River Basin Management Project
- Route Corridor Options Terrestrial Ecology Report (Draft)

Consultation with Regulatory and Other Bodies

Consultation with Roscommon County Council, Leitrim County Council, the OPW, and EPA was carried out during this phase of the work to obtain information on surface water quality monitoring, flow gauging and water level monitoring, flood event history, and arterial drainage works.

Field Surveys

A brief inspection of the principal crossings of rivers and larger streams was undertaken along each of the proposed route corridors. Any details of control measures such as weirs and any effluent discharge points or water abstractions were noted. The extent of existing flood plains in the vicinity of principal crossings was also inspected and confirmed.

Impact Assessment

In order to assess the relative merits of each of the identified route corridors, an assessment of the likely impact each route will have on the hydrological attributes along each route has been made. Consideration has been given to both the importance of the attributes and the predicted scale and duration of the likely impacts.

The following are typical impacts associated with road schemes on the hydrological environment:

- Interference with river, streams and flood plains at road crossing points, requirement for correct sizing of bridges and culverts.
- Removal of flood storage as a result of the Roadway footprint.
- Diversion of water between drainage basins.
- Interference with local drainage, relocation, discontinuation and combination of existing land drains.
- Increase in runoff characteristics (due to impervious road pavement area and increased transmission time and point loading) resulting in a possible increase in the overall flood peak magnitude and flooding frequency in the receiving stream.
- Water quality impact on receiving streams from routine carriageway runoff (heavy metals, organics, nutrients, hydrocarbons, suspended solids, coliforms, etc) and from accidental spillages (agricultural, oil/chemical spillages, bulk liquid cement).

As only very limited engineering design details and site specific data is available at this stage, much of the preliminary impact assessment is of a qualitative rather than a quantitative nature. A significant degree of professional judgement has therefore been used in identifying and rating the likely impacts. For each route corridor a summary of these associated impacts has been presented in a tabular format.

Comparison of Route Corridor Options

A comparison of route corridors has been made based on the number and degree of likely impacts and along each corridor. This has established an order of preference from a hydrological perspective.

Where a similar number of likely impacts have been identified then the route corridor which affects the least number of high value attributes has been given preference.

Limitations and Gaps in Available Data

Limitations for this stage of reporting exist in the lack of field and site investigation data for the various route corridors. Most of the conclusions and recommendations have been arrived at through desk study research and basic site walkovers. Until the final alignment is known it will not be possible to make detailed appraisals regarding how any cut or fill sections will impact on the hydrological environs.

16.3.3 Catchments and Sub-Catchments

Overview of Catchments Within Study Area

Under the EU Water Framework Directive (2000/60/EC) eight River Basin Districts (RBDs) have been established throughout the island of Ireland. The boundaries of these have been largely based on a 1971 classification by the Water Resources Division of An Foras Forbartha (AFF) which divided the 26 counties of Ireland into seven Water Resource Regions.

The River Shannon rises in a spring fed pool (the Shannon Pot) in the Cuilcagh Mountains on the Cavan-Fermanagh Border. The river flows south through Loughs Allen, Ree and Derg, as well as a number of smaller lakes between Lough Allen and Lough Ree, finally outfalling to the Atlantic Ocean via the Shannon Estuary. The study area falls within the upper reach of the river between Loughs Allen and Ree which is characterised by a wide flat sluggish channel forming numerous small lakes.

The River Shannon is Ireland's largest river having a catchment area from its source to the Shannon Estuary at Limerick City of some 11,330km^2. The Shannon, with its series of natural and artificial controls, has a slow response to rainfall events requiring heavy prolonged winter rainfall conditions to produce flooding. The river flows through three major lakes, Lough Allen (36km^2), Lough Ree (106km^2) and Lough Derg (120km^2) as well as widening out into a number of smaller lakes between Lough Allen and Lough Ree. The natural fall between the outlets of Lough Allen and Lough Derg is 13m over a distance of approximately 190km (0.000068). Such a low hydraulic gradient and the attenuating effect of the large lakes results in a slow moving river with floodwaters remaining on the floodplains for long periods of times and thus producing significant lag time (of many days) between rainfall and resultant runoff in the middle and lower reaches.

The N4 Carrick-on-Shannon to Dromod Route Corridors all fall within the Upper River Shannon Catchment which has a catchment area of approximately 1,400 km^2. The River Shannon and a number of smaller tributary channels are intersected by the various Route Corridors. The tributaries intersected are all minor tributaries with catchment areas of 21km^2 and smaller. A new bridge crossing of the Shannon is proposed either 2km upstream of Carrick-on-Shannon Bridge or 1.4km or 3.4 km downstream.

The Upper River Shannon has a number of hydrometric gauging stations operated by the Office of Public Works (OPW) and the ESB/EPA. Table 16.5 lists the principal gauging stations relevant to this study.

Table 16.5 Details of Relevant Automatic Gauging Stations

St No.	St. Name	River	NGR	AREA	Record	Comment
26085	Jamestown	Shannon	M980971	1364km^2	1957 - 2007	No Rating Curve A.M. Flood Levels only
26089	Drumsna	Shannon	M995970	1371 km^2	1984 - 2007	No Rating Curve A.M. Flood Levels only
26030	Lough Allen (ESB)	Shannon	G961123	425 km^2	1938 - 2003	ESB Daily Read – AM Flow series available
26012	Tinacarra	Boyle Trib of Shannon	G770018	520 km^2	1957 - 2007	Arterial Drainage works 1982-1992 - AM Flow series available
26014	Banada Br.	Lung Trib. of the Boyle River	M634943	222 km^2	1989 - 2005	Arterial Drainage works 1982-1992 - AM Flow series available

Table 16.6 Gauged Mean Annual Maximum Flows

St No.	St. Name	River	AREA	QBAR	Comment
26030	Lough Allen (ESB)	Shannon	425 km^2	34 cumec	Complete daily series
26012	Tinacarra	Boyle River	520 km^2	49.4 cumec	Post arterial drainage series
26014	Banada Br.	Lung River	222 km^2	43.1 cumec	Post arterial drainage series

Catchments Traversed by Each Route Corridor

The proposed Route Corridors are located within the River Shannon Catchment crossing the River Shannon itself and a number of minor tributaries. The options for crossing the River Shannon are located within Section 1 with three crossing points identified, one located upstream of Carrick-on Shannon at Corryolus and downstream of Lough Eidin, the second downstream of Carrick-on-Shannon at Attirory and the final option further downstream crossing Lough Corry near Rinnacurren.

The Killukin River is the largest of the tributaries traversed having a catchment area of 31.5km^2 which inflows to the River Shannon from the South at Cortober. The remaining crossings are very minor being either drainage ditch or relatively small tributary streams, a large portion of which discharge directly to the River Shannon (i.e. first order channels).

16.3.4 Channel Flow

Surface Water Flow

River flow is composed of surface run-off from precipitation and baseflow from groundwater storage. Measurement of flow is generally focused on low flows, as the principle application is related to water supply and/or pollution control. The two most commonly used methods for reporting are the '95-percentile flow' and the 'dry weather flow' (DWF). There is also the N-day sustained low flow e.g. the '7-day sustained low flow'.

September of 1976 produced the lowest stream flows on record throughout Ireland. These low flows are likely to represents at least a 50 year return period low flow and are often used to estimate the DWF. In Ireland a low flow relationship based only on catchment area has been established:

$$Q_{DWF} = 14.5*AREA^{1.6} *10^{-6} \text{ cumec}$$

where, AREA is in km^2.

Although this relationship is statistically significant it has a high associated standard factorial error of 2.5.
Analysis of the EPA nation-wide low flow database gives an average DWF flow rate of 1 l/s per km^2 and 95 percentile low flow of 2 l/s per km^2. A low flow of 0.5 l/s per km^2 will be used to represent the 95-percentile low flow in the small ungauged stream. In the case of very small catchments, say less than 1 km^2 there is a high likelihood of streams drying up completely.

A statistical analysis or river flows has been published for each of the water resource regions, which gives details of the magnitude and frequency of occurrence of river flows based on records from gauging stations operated by various organisations such as the OPW, EPA, ESB and Local Authorities.

The Upper Shannon catchment has two distinctive reaches and has a very shallow gradient within the study area. The River Boyle, the largest tributary of the Upper River Shannon, joins the Shannon at Lough Eidin approximately 4.7 km upstream of Carrick-On-Shannon. The flow in the River Shannon has been controlled for over 200 years to aid navigation and was further modified in the 1920's to facilitate the ESB hydro-electric power station at Ardnacrusha. The water levels in Lough Allen and the discharge from the lake are regulated by a control structure at Bellantra at the outlet of the lake. The present policy of the ESB is to maintain a minimum discharge of 5 m^3/s from Lough Allen under normal flow conditions and to discharge such flow as will result in a desirable maximum water level in the lake of 46.98 OD Malin during flood conditions.

The OPW and EPA websites were searched for details of hydrometric gauging stations within or close to the study area. A total of six stations were located (Table 16.7).

Table 16.7 Gauging Station Located Within Study Area

Number	Location	Location	Gauge Type	Status
26015	Corrascoffy	OPW	Logger/Autographic Recorder	Active Permanent
26085	Jamestown	OPW	Logger/Autographic Recorder	Active Permanent
26089	Drumsna	OPW	Autographic Recorder	Active Permanent
26132	Dromod	Leitrim Co. Co.	Staff Gauge Only	Active Primary

Number	Location	Location	Gauge Type	Status
26223	Killukin	Roscommon Co. Co.	Staff Gauge Only	Suspended
26324	Carrick-on-Shannon	OPW	Logger/Autographic Recorder	Active Permanent

Some hydrometric data was available on the OPW website for three of these stations located at Corrascoffy, Jamestown and Drumsna. The following information was also obtained from the 2007 EPA Hydrometric Station Register (Table 16.8).

Table 16.8 EPA Hydrometric Station Data

Station Number	Waterbody	Location	DTM Area [Km^2] 01/09/2006	Long Average Rainfall 71-00 (mm/annum)	DWF (m^3/s)	95 percentile (m^3/s)
26015	Eslin	Corrascoffy	59.5	1128.5	0.0030	---
26085	Shannon	Jamestown	1379	1307.5	1.4 *	2.3 *
26089	Shannon	Drumsna	1390	1306.2	1.4 *	2.3 *
26132	Eslin	Dromod	65.9	1127.4	---	---
26223	Stream	Killukin	31.4	1127.3	---	---
26324	Shannon	Carrick-on-Shannon	1301	1318.5	---	---

Dry Weather River Flow

For the purposes of estimating dry weather flow in the River Shannon and local streams a rate of 1l/sec per km^2 is reasonable.

Mean River Flow

An average flow using effective rainfall of 750mm per annum gives a flow rate which includes baseflow of 24l/s per km^2. Therefore the average Shannon Flow at Carrick-on-Shannon is of the order of 31cumec.

River Shannon Flood Flow Estimation

Q_{BAR} is the mean annual maximum flood flow referred to in the Flood Study Report (FSR) for the UK and Ireland (NERC, 1975) as the Index Flood. This has a return period of 2.4 years and can be multiplied by appropriate growth factors to provide estimates of different return period flood peak magnitudes.

Lough Allen and the Boyle River gauging stations represent 70% of the total catchment area of the River Shannon to Jamestown gauging station. The respective Q_{BAR}'s are 34 and 49.4 cumec and the average Q_{BAR} rate for these gauges combined is 0.088 cumec per km^2. This rate gives a Q_{BAR} estimate of 120 cumec at Jamestown when linearly scaled up.

If the gauging station is not at the project location but on the same river then the calculated design flood can be adjusted by the multiplier $(A_P/A_G)^{0.8}$ where A_P is the catchment area to the project location and A_G is the catchment area to the gauging station. Using the above rate of 0.088 cumec per km^2 and the catchment area factor a Q_{BAR} estimate for Jamestown of 112 cumec is obtained.

Using the Flood Studies Report National Growth Factor the Q100 flow estimate for the River Shannon at Jamestown is 220 cumec. Adjustment for climate change allowance (20% increase medium term scenario) gives a design flood of 264 cumec at Jamestown.

It is recommended to increase the Flood flow estimates by 20% to account for future climate change effects in keeping with accepted guidelines. The design flows used in the following hydraulic model simulations are presented in Table 16.8 below:

The design flow estimate in the River Shannon at Carrick-on-Shannon Bridge based on a real reduction factor of 0.955 is 252cumec.

The flow velocities in the Upper Shannon in the vicinity of Carrick-on-Shannon are very sluggish given the mild hydraulic gradient and under extreme flood conditions are found to be generally less than 0.4m/s. Locally where the flood plain is restricted such as the existing Carrick-on-Shannon Bridge and the reach between Jamestown and Drumsna flow velocities increase to the order of 1m/s and higher.

Local Stream Flow

The proposed Route Corridors cut across numerous watercourses that discharge to the River Shannon a relatively short distance downstream. The majority of these watercourses are small drains serving a very localised area. These drains are generally sluggish, very vegetated with intermittent flows. There are a number of small streams and Killukin River that are traversed.

The flood Studies runoff factor for this area is SOIL type 5 representing very low winter rainfall acceptance potential or conversely very high runoff factor. The Rainfall for this region is of the order of 1200mm. Therefore a Greenfield flood flow rate QBAR, Q100 and Q100+CC using the IH 124 equation is presented below in Table 16.9 for different catchment areas.

Table 16.9 Flood Flow Estimation for Small Ungauged Catchments

Area km^2	**0.5**	**1**	**5**	**10**	**25**
QBAR	10.4	9.6	8.1	7.5	6.7
Q100	20.3	18.8	15.8	14.6	13.2
Q100+CC	24.4	22.6	18.9	17.5	15.9

Flood Flows in l/s per ha

16.3.5 Drainage

Local Drainage Features

The study area and surrounding land drain to the River Shannon through an extensive network of small tributaries streams, dug drains and lakes. The majority of the watercourses along the route are either drainage ditches or small streams that have in the past been subject to drainage works.

The area is categorised based on soils, gradient and wetness as having a very high winter runoff coefficient.

The main poor draining area along the route corridors are the lands located adjacent to and within the River Shannon Floodplain and its tributary lakes, namely Gortconnellan Lough and Gortinty Lough. Such poor draining areas are accounted for under the section on floodplain areas. There are a number of other poor draining areas identified. These are at Cornamucklagh on Route Corridor Option 1.3, Drumlumman on Route Corridor Options 1.1 and 1.2 and Drumkeeran on Route Corridor Option 1.4.

These areas would be considered of local low value and a proposed road would only have a slight to imperceptible impact on flooding in these areas.

16.3.6 Flooding

Historical Flooding

Regional Flooding

The Arterial Drainage Acts, 1945 and 1995 deal with the improvement of lands by drainage and preventing or sustainably reducing the flooding of lands. The Acts set up the process of Arterial Schemes and provides for the maintenance of these works. They also provide for the implementation of a number of drainage and flood reduction related measures such as approval procedures for bridges and weirs. Reporting requirements for the Drainage Districts are also iterated.

The EU Floods Directive (2007/60/EC) applies to river basins and coastal areas at risk of flooding.

The River Shannon has a long history of flooding with a US Corps of Engineers 1956 report 'River Shannon Flood Problem stating that "The problem of Shannon River flooding has been the subject of much study over the past 150 years. Because of the flat terrain through which the river flows, the almost imperceptible gradient of the stream with its series of lakes and connecting channels, and because of the large volume and long duration of flooding, no simple or obvious solution has heretofore been found".

Between Lough Allen and Lough Derg, a distance of 190 km, there is only a small fall of 13m in elevation. The river flows very slowly and numerous meanders develop, indicating a relatively low energy level.

The study area has extensive areas of high flood risk from the River Shannon. The town of Carrick-on-Shannon adjacent to the River bank has flooded in the past (1999 event with a number of properties and roads flooded).

The largest flood on record for the River Shannon at Carrick-on-Shannon occurred on the 26th November 2009. Flooding on River Shannon at Carrick-on-Shannon exceeded the previous maximum flood (Dec 1999) for 22 days from the 16th November to 7th December 09, refer to Figure 4. A flood level of c. 42.67m O.D. Malin (45.37m O.D. Poolbeg) was recorded at Carrick-on-Shannon gauge (26324). The Jamestown gauge (26085) was overtopped and flood records from the OPW were not available for this event. Leitrim Co. Council survey observations gave a peak flood level estimate for the Jamestown Quay of 42.36m O.D. Malin on the 26th November 2009. A peak flood level of 40.6 mO.D. was observed at the Drumsna Gauge (26089) which is downstream of Jamestown Weir. This event produced flood levels that significantly exceeded the previous historical maximum flood levels by c. 0.5 to 0.6 m and statistically this flood level exceeded the 100year flood quantile (without future climate change allowance). (Annex 16.1 at the end of this chapter contains further details on the November 2009 flood event). It is estimated that a peak flood level of 43 to 43.1m O.D. occurred at the Northern Crossing point (Routes 1,2 and 3), 42.43m O.D. at Route 4 Crossing Point and 42.4m O.D. These estimates were computed using the surveyed flood levels and hydraulic gradient through Carrick on Shannon provided by Leitrim Co. Council.

A description of the Flooding from the River Shannon at various Locations along the Route corridor options is presented in Annex 16.1. Mapping of flood levels surveyed on the 27th November 2009 are presented in Drawing RCSR-1612 and 1613.

The Second largest Flood on record for the River Shannon at Carrick-on-Shannon occurred on the 31 December 1999 and referred to locally as the Millennium Flood. A statistical analysis of the flood flow series estimates the return period for this event to be of the order of 50 years. This flood event also produced historical maximum flood levels at Lough Allen peaking on the 24th December 1999 and on Lough Ree (Thatch Gauge) peaking on the 1st Jan 2000. The records for both Lough Ree and Lough Allen date back as far as 1940. Anecdotal Flood observations gave a peak flood level of 42.09 at Carrick-on-Shannon Bridge. Other peak levels reported were 42.365 at Priest's Lane adjacent to the Sports Ground and 950m upstream of Carrick-on-Shannon Bridge, a flood level of 41.94 near Shannon Lodge and 41.995 in the Car park immediately downstream of Carrick-on-Shannon Bridge. The OPW flew the area to record the 1999 flood level which is shown on Drawings RCSR-1608 to 1611.

The OPW on the 9th January 2000 carried out an aerial survey of the flooding on the River Shannon. By that time flood levels had receded by approximately 0.4m (Refer to Figure 2 at the end of this chapter showing the OPW flood inundation outline).

Flood Impact

Most floodplains perform two major hydrologic functions, (i) they convey floodwaters downstream either as overbank flow or channel bank flow and (ii) they allow a certain amount of water to be stored on the floodplain. The conveyance width of a floodplain is extremely important as it influences the flood gradient required to transmit a given flood rate and thus influences the upstream flood level. Active Sections of Floodplain both convey and store flood water whereas passive (non-conveying) sections of the floodplain only function to store floodwater until such time that the flood level drops. The storage of floodwater produces an attenuation effect on the flood peak. The degree of attenuation will depend on the inflow hydrograph characteristics (whether it is flashy or gradual) and on the amount of flood storage available relative to the flood volume. In the Case of the River Shannon at Carrick-on-Shannon a typical flood wave is slow, rising and falling gradually and consequently the attenuation effect of its floodplain on reducing the flood peak is small. Refer to Figure 2 at the end of this chapter which presents the Dec ''99 (Millennium flood) flood. Flows exceeding 95% of the flood peak magnitude were maintained for over 6 days (extremely flat hydrograph). Investigation of chart records for other recorded A.M. floods at Jamestown revealed even flatter flood hydrographs than the 1999 flood event.

All proposed Route Corridor Options (1.1 to 1.5) in Section 1 cross the River Shannon. The criteria for establishing the most favourable crossing point will be the route that has the least impact to the active section of the floodplain (i.e. length of road within the conveyance width) followed by the overall floodplain footprint (i.e. active and passive floodplain lengths).

Guidelines on Flood Risk and Development

One area of particular interest noted in the Draft Carrick-on-Shannon Local Area Plan 2010 – 2016 was the location of the town along the River Shannon in relation to flood risk management. Under the plan it is intended that a flood risk study of the town will be carried out and that this will influence any zoning or rezoning as appropriate in the town. The following guidelines in relation to flood risk are listed in the plan as well as the County Plan.

1. **Development that is sensitive to the effects of flooding will generally not be permitted in flood prone or marginal areas.**

   [Preventing such development, where flooding would result in significant hardship, financial losses or costs, will avoid increasing the existing level of risk and will protect the proposed new development from the human (stress and ill-heath for example) and financial costs of flood events. It will also eliminate or reduce expenditure on flood protection measures and compensation.]

2. **Appropriately designed development, which is not sensitive to the effects of flooding, may be permissible in flood plains provided it does not reduce the flood plain area or otherwise restrict flow across floodplains.**

   [Examples of such development might include park areas, sport pitches, certain types of industry, warehousing, etc. designed to be flood resistant and/or insensitive. Such development should only be permitted provided it incorporates adequate measures to cope with the ever-existent flood risk, e.g. adequate drainage systems, safety measures, emergency response facilities and/or warning and response systems and where it is considered that flooding would not result in significant hardship/financial loss or cost.]

3. **Development must so far as is reasonably practicable incorporate the maximum provision to reduce the rate and quantity of runoff, *e.g.*:-**
   - **Hard surface areas (car parks, *etc.*) should be constructed in permeable or semi-permeable materials;**
   - **On site storm water ponds to store / or attenuate additional runoff from the development should be provided; and**
   - **Soak-aways or French drains should be provided to increase infiltration and minimize additional runoff.**

   [Such sustainable design/construction measures are desirable in most areas and essential in floodplains, areas liable to flooding, and areas where the conveyancing capacity of watercourses is marginal. In all of these cases development that reduces the rate of absorption or increases the rate of runoff increases the risk of flooding lands and properties downstream.]

4. **For developments adjacent to watercourses of a significant conveyance capacity any structure (including hard landscaping) must be set back from the edge of the watercourse to allow access for channel clearing / maintenance.**

   [A setback of 5 m-10m is required depending on the width of the watercourse.]

5. **Development consisting of construction of embankments, wide bridge piers, or similar structures will not normally be permitted in or across flood plains or river channels.**

   [Such structures restrict/obstruct flow and increase the risk of flooding to property and land upstream. If it is considered necessary, in exceptional cases, to permit such structures, they should be designed to minimize and/or compensate for any potential negative effects.]

6. **All new development must be designed and constructed to meet the following minimum flood design standards:-**

- **For Urban areas or where developments (existing, proposed or anticipated) are involved – the 100 year flood;**
- **For Rural areas or where further developments (existing, proposed or anticipated) are not involved – the 25 year flood;**
- **Along the Coast and Estuaries – the 200 year tide level;**
- **Where streams, open drains or other watercourses are being culverted – the minimum permissible culvert diameter is 900 mm. (Access should be provided for maintenance as appropriate.)**

[The application of higher design standards may be appropriate in certain cases where the level of risk and / or uncertainty warrant it e.g. hospitals or other emergency services, main roads, chemical plants, cultural repositories, areas of karst etc.]

7. **A flood impact assessment and proposals for the storage or attenuation of runoff discharges (including foul drains) to ensure the development does not increase the flood risk in the relevant catchment, must accompany applications for Planning Permission for development of areas exceeding 1 hectare.**

8. **A certification from a competent person that the development will not contribute to flooding within the relevant catchment must accompany applications for Planning Permission for development of areas of 1 hectare or less.**

<u>Floodplains within study area</u>

The principle floodplain within the route corridor study area is the River Shannon Floodplain. This Shannon at Carrick-on-Shannon has an extensive floodplain area and backwaters for a considerable distance upstream many of its tributaries and adjoining loughs. 100 year design flood levels are available for the River Shannon using gauged data for Drumsna and Jamestown hydrometric stations and predictive hydraulic model of the River Shannon from the Waterways Ireland Sluice Gates near Drumsna to 1.4km upstream of Carrick-on-Shannon. This model was developed by Hydro Environmental Ltd. for flood prediction at Carrick-on-Shannon. Historical observations are available at Carrick-on-Shannon for the 1999 flood event and also from the OPW aerial mapping of flood waters outline extracted from aerial photos of the River Shannon in flood taken on the 9th January 2000.

The flood plain area in the vicinity of the route corridor crossings was defined using the 100 year with climate change allowance flood level predictions. These flood level predictions are summarised as follows:

d/s end of Study area	40.0m O.D. Malin
Drumsna	40.7m O.D. Malin
Jamestown	42.5m O.D. Malin
Carrick-on-Shannon	43.0m O.D. Malin
u/s end of Study area	43.2m O.D. Malin

Table 16.10 summarises the total length of River Shannon Floodplain encountered by the Route Corridors along with conveyance width (i.e. active floodplain area) and permanent channel width.

Table 16.9 Total Route length within River Shannon Flood Plain Area

	Section 1				
River Shannon Crossing	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
Total floodplain width	1176m	1176m	1116m	1138m	1760m
Permanent channel	88m	88m	88m	128m	242m
Active conveyance width (which includes channel)	306m	306m	306m	190m	655m
Rank	3	3	2	1	5

Table 16.10 Major Floodplains Encountered along Section 1 excluding River Shannon Road Crossing

Floodplains	1.1	1.2	1.3	1.4	1.5
Gortconnellan Lough	340m	340m	340m	340m	340m
River Shannon floodplain near Tully	640m	640m	640m	640m	640m

Table 16.11 Major Floodplains Encountered along Section 2 of Route Corridors

Floodplains	2.1	2.2	2.3
River Shannon Floodplain at Drumsna	338m	338m	338m
Gortinty Lough / Drumgilra Lough	0	560m	560m
Rank	1	2	2

16.3.7 Surface Water Quality

Regional Surface Water Quality

<u>Rivers</u>

EPA Monitoring River Programme

The EPA carries out water quality assessments of river water quality as part of a nationwide monitoring programme. Data is collected from physico-chemical and biological surveys, sampling both river water and the benthic substrate (sediment) in contact with the water.

Water sampling is carried out throughout the year with the main parameters that are usually analysed for including: conductivity, pH, colour, alkalinity, hardness, dissolved oxygen, biochemical oxygen demand (BOD), ammonia, chloride, ortho-phosphate, oxidised nitrogen and temperature.

Biological surveys are normally carried out between the months of June and October. These look at the relationship between water quality and the relative abundance and composition of the macro-invertebrate communities in the sediment of rivers and streams. The macro-invertebrates include the aquatic stages of insects, shrimps, snails and bivalves, worms and leeches. The greater the diversity, the better the water quality is.

The collated information relating the water quality and macro-invertebrate community composition is condensed to a numerical scale of Q-values or Biotic Index. The indices are grouped into four classes based on river's suitability for beneficial uses such as water abstraction, fishery potential, amenity value, etc (Table 16.12).

Table 16.12 Biological River Water Quality Classification System

Biotic Index (Q value)	Quality Status	Quality Class	Condition
Q5, Q4-5, Q4	Unpolluted	Class A	Satisfactory
Q3-4	Slightly Polluted / Eutrophic	Class B	Transitional
Q3, Q2-3	Moderately Polluted	Class C	Unsatisfactory
Q2, Q1-2, Q1	Seriously Polluted	Class D	Unsatisfactory

Within and close to the study area the rivers that are monitored varied in quality from being slightly polluted to unpolluted. Generally the river reaches downstream of urban areas have a lower quality status than those in more rural areas. There are four monitoring stations that are of relevance to the study area (Table 16.13).

Table 16.13 EPA Monitored River Water Quality Within or Near Study Area

Watershed	River Name	River Code	2002	2005
Shannon Upper	River Shannon (Upper)	26S021010	3	4
Shannon Upper	Killukin River	26K020700	4 - 5	4 - 5
Shannon Upper	Eslin River	26E010500	3 - 4	3 - 4
Shannon Upper	Eslin River	26E010400	4	3 - 4

Water Framework Directive River Classification

The Water Framework Directive (WFD) provides for the protection, improvement and sustainable use of waters, including rivers, lakes, coastal waters, estuaries and groundwater within the EU Member States. It aims to prevent deterioration of these water bodies and enhance the status of aquatic ecosystems; promote sustainable water use; reduce pollution; and contribute to the mitigation of floods and droughts. Member States must aim to achieve 'good' status in all waters by 2015, and must ensure that the status does not deteriorate in any waters.

Assessments made as part of the RBD projects in 2005 assigned all sizeable streams and rivers an environmental objective score based on the likelihood of them achieving an objective of good status by 2015 (Table 16.14).

Table 16.14 WFD Rating System for Water Bodies

Score	Description
1a	At risk of failing to meet the objective of good status in 2015
1b	At risk of failing to meet the objective of good status in 2015 pending further investigation
2a	Expected to meet the objective of good status in 2015 pending further investigation
2b	Expected to meet the objective of good status in 2015

The EPA website mapping section provides details on the assessments, with a total of 7 watercourses being located within the study area that were assigned a score (Table 16.15).

Table 16.15 WFD Classification of River Waters Within Study Area

Watershed	River Name	River Code	Score
Shannon Upper	SH_ShannonUpper_ShannonMAIN_9Upper	SH_26_3090	1a
Shannon Upper	SH_ShannonUpper_Killukin_1	SH_26_1503	1a
Shannon Upper	SH_ShannonUpper_ShannonTRIB_33CarrrickonShannon	SH_26_2461	2a
Shannon Upper	SH_ShannonUpper_ShannonMAIN_8Upper	SH_26_4069	1a
Shannon Upper	SH_ShannonUpper_ShannonTRIB_30Drumsha	SH_26_3069	2a
Shannon Upper	SH_ShannonUpper_ShannonTRIB_27GortconnellanLough	SH_26_1511	1b
Shannon Upper	SH_ShannonUpper_ShannonTRIB_26MuchlaghLough	SH_26_3937	1b
Shannon Upper	SH_ShannonUpper_EslinMAIN_1Lower	SH_26_4022	1a
Shannon Upper	SH_ShannonUpper_EslinMAIN_1Lower	SH_26_4022	1a

The Eslin River is located just outside the area, but is included for its proximity to Section 2.

Lakes

<u>EPA Lake Monitoring Programme</u>

As part of a national water quality monitoring programme a number of lakes throughout the country are sampled and the trophic status assessed. Lake water quality is most commonly assessed by reference to a scheme proposed by the Organisation for Economic Cooperation and Development (OECD) (OECD, 1982). This scheme defines the traditional trophic categories by setting boundaries for the annual average values for total phosphorus, chlorophyll and water transparency, and for the maximum and minimum vales of the latter two parameters.

As insufficient data is available to allow a full assessment based on these criteria, a modified version is used in which annual maximum chlorophyll *a* concentration is the only parameter used. This has been further subdivided into six water quality categories by reference to the maximum levels of planktonic algae measured during the period (Table 16.16). Indicators relating to water quality and the probability of pollution are also shown.

Table 16.16 Trophic Classification Scheme for Lake Waters

Classification Scheme		Category Description				
Lake Trophic Category		**Annual Maximum Chlorophyll (mg/m^3)**	**Algal Growth**	**Degree of Deoxygenation in Hypolimnion**	**Level of Pollution**	**Impairment of Use of Lake**
Oligotrophic	(O)	<8	Low	Low	Very low	Probably none
Mesotrophic	(M)	8 – 25	Moderate	Moderate	Low	Very little
	Moderately (m-E)	25 – 35	Substanti al	May be high	Significant	May be appreciable
Eutrophic	Stronghly (s-E)	35 – 55	High	High	Strong	Appreciable
	Highly (h-E)	55 – 75	High	Probably total	High	High
Hypertrophic	(H)	>75	Very high	Probably total	Very high	Very high

The trophic status provides and indication as to what degree the lake is enriched by the presence of nutrients such as phosphorus and to a lesser extent nitrogen in the form of nitrate. Excessive nutrient presence in lakes will promote the growth of algae which in overabundance cause serious environmental problems e.g. 'algal blooms, where significant accumulations of cyanobacteria that can be swept by winds along the lake shore seriously disrupting the dissolved oxygen regime. Cyanobacteria and algal material can release trace organic components which can impair the amenity value of a lake and render it unfit for drinking water where a supply is sourced.

Within the study area, only Lough Corry is currently monitored as part of the EPA water quality reporting (Table 16.17). A series of lakes (Bofin, Boderg, Scannal, Tap) to the west of Dromod is just outside of the study area. These locations have been sampled by Roscommon County Council, with the following data available for 2003 (Table 16.17).

Table 16.17 Trophic Status for Lake Waters Within Study Area Monitored for EPA Water Quality Programme

WFD Code	Lake Feature	Annual Maximum Chlorophyll (mg/m^3)	Beneficial Uses	Trophic Status
SH_26_710	Lough Corry	17.1	General recreation	Mesotrophic (M)
SH_26_747	Lough Bofin etc	4.8	General amenity	Oligotrophic (O)

Lough Corry is monitored by the Local Authority and the ERTDI, and the series of interconnected lakes by the EPA and ERTDI.

Water Framework Directive lake classification

Under the WFD classification for surface water bodies, there are five lakes that are listed within or close to the study area (Table 16.18).

Table 16.18 WFD Classification of Lake Waters Within Study Area

WFD Code	Lake Feature	Assessment Year	Environmental Objective Score
SH_26_747a	Lough Bofin	2005	1b
SH_26_747b	Lough Boderg	2005	1b
SH_26_747d	Lough Tap	2005	1b
SH_26_710	Lough Corry	2005	1b
SH_26_722	Lough Eidin	2005	2a

Existing Surface Water Data Along Each Route Corridor

Very limited water quality data was available for review at this stage of the study. Only two EPA monitoring locations are present that are relevant to a route corridor, both to Route Corridor Option 1.5 and possibly 1.4. The Killukin River downstream of the Route Corridor Option 1.5 had a biotic index of Q4-5 in 2005 indicating an unpolluted status, and Lough Corry was given a Mesotrophic status for the same year indicating a strong level of pollution present.

16.3.8 Water Supply Sources

Regional Water Supply

Leitrim and Roscommon County Council Water Services departments were contacted regarding water supply within the study area.

Leitrim Water Supply

All of the Leitrim side of the study area is reported to be supplied by the River Shannon, the water being sourced from a location within Carrick-on-Shannon. It is possible that there may be small groundwater group schemes present that serve a couple of houses and are not listed with the local authority.

Roscommon Water Supply

A small part of the area to the west of the River Shannon around Cortober obtains is water supply from the River Shannon source located in Carrick-on-Shannon. The majority of the area obtains water from a groundwater supply located at Rockingham Springs to the west.

Water Supply Sources Along Each Route Corridor

None of the route corridors are located close to the main River Shannon water supply abstraction point in Carrick-on-Shannon. Route Corridor Options 1.1, 1.2 and 1.3 cross the River Shannon at Corryolus approximately 1.5 km upstream of the abstraction point and represent the larger risk to the abstraction point as contamination both construction and operational spills could migrate downstream posing a threat to the supply. Drainage ditches and minor stream tributaries are intercepted by all five route corridors 1.1 to 1.5 a number of which discharge upstream of Carrick-on-Shannon and the water supply source. These potentially could impact on the supply with tributary connections on the north/east side of the river (i.e. 1.1, 1.2 and 1.3) posing a greater threat to the water quality of the source. However the catchment are of the Shannon to Carrick-on-Shannon is approximately 1300km2 and even under dry weather flow there is substantial dilution available to reduce the potential water quality impact of a road scheme.

16.3.9 Surface Water Abstractions

Surface Water Abstractions Along Each Route Corridor

The WFD requires a control regime to surface water abstractions and impoundments. In the Shannon District there are 11 rivers at risk and 20 probably at risk. There are 9 lakes at risk.

Surface water abstraction by the Local Authorities within the study area is carried out at Carrick-on-Shannon for the main water supply scheme for the area. No other abstractions are known at present.

16.3.10 Surface Water Discharges

Surface Water Discharges Within Study Area

The main wastewater treatment plant (WWTP) within the study area is located in Carrick-on-Shannon which discharges into the River Shannon within the town area. This is downstream of the water supply abstraction. There is another smaller WWTP located at Drumsna also discharging to the River Shannon. A new WWTP's is being constructed at Jamestown and a new pumping station as Cortober.

16.3.11 Ecological Issues

Wetland Habitats

During the construction phase of a road scheme there may be a requirement for cut sections to be dewatered which could potentially impact on the hydrological regime of any nearby wetland habitats. The road itself may act as a 'barrier' to surface water flow pathways to / from wetland areas, unless appropriate structures are in place.

Under European and Irish law, the Department of the Environment, Heritage and Local Government is responsible for the designation of conservation sites in Ireland. There are three main types of designation:

- Natural Heritage Area (NHA). This is the basic designation for wildlife, and is an area considered important for the habitats present or which holds species of plants and animals whose habitat needs protection. Listed sites that were published on a non-statutory basis in 1995, but have not since been statutorily proposed or designated are regarded as proposed NHA i.e. pNHA. The GSI is compiling a list of geological / geomorphological sites in need of protection with the list of karst and early fossil sites available to date. Under the Wildlife Amendment Act (2000), NHAs are legally protected from damage from the date they are formally proposed for designation.
- Special Area of Conservation (SAC). This is regarded as a prime wildlife conservation area in the country, and considered to be important on a European as well as Irish level. SACs are selected and designated under the EU Habitats Directive, which is transposed into Irish law as the European Union (Natural Habitats) Regulations, 1997, amended in 1998 and 2005. The Directive lists certain habitats and species that must be protected within SACs. Irish habitats include raised bogs, blanket bogs, turloughs, sand dunes, machair (flat sandy plains on the north and west coasts), heaths, lakes, rivers, woodlands, estuaries and sea inlets. Sites not full listed are regarded as candidate SACs i.e. cSAC.
- Special Protection Area (SPA). This is an area / habitat that under EU Directive requirements needs to be safeguarded. The EU Birds Directive (79/409/EEC) requires designation of SPAs for: listed rare and vulnerable bird species; regularly occurring migratory species, such as ducks, geese and waders; and

wetlands, especially those of international importance (i.e. 1% of the population of a species uses the site, or more than 20,000 birds regularly use the site), which attract large numbers of migratory birds each year. Many existing and future SPAs overlap with SACs.

The NPWS website was queried regarding the presence of any listed wetland habitats within the study area. Only one pNHA site was identified north of Carrick-on-Shannon and encroaching into the northwest of the study area. This is Lough Drumharlow (Site code 001643). The listed species are fallow deer (*Dama dama*) and otter (*Lutra lutra*) located in Cloonagownagh. The lake is also identified as an area for overwintering of Greenland white-fronted geese and whooper swans. Route Corridors 1.1, 1.2 and 1.3 pass through the site.

The development boundary of the current Carrick-on-Shannon LAP is in close proximity to the site, however, it is not envisaged that the boundaries of the town will be extended to include these sensitive lands. The LAP states that "The protection and conservation of this area is important from a local and national perspective and this will be reflected in the approach taken in making the new LAP for Carrick-on-Shannon. Environmental considerations will be taken into account in the making of the Plan."

The only other site of interest is located to the west of the southern part of the area and comprises a series of lakes, Lough Boderg and Lough Bofin (Site code 001642) that are likely to receive surface water drainage from the corridor area. The listed species is the stoat (*Mustela eminea*) located in Carranadow. The three southernmost route corridors, 2.1, 2.2 and 2.3 may have the potential to impact on the lakes via surface drainage.

Overview of Route Corridor Selection Ecological Report

The low lying nature of the study area with the River Shannon meandering through the landscape with its numerous expansions into small lakes has resulted in large areas of swamp, reedbed and damp grassland in the floodplains and lake edges. On drier ground the land is improved grassland, hedgerows and area of woodland.

The Upper Shannon system around Carrick-on-Shannon has been identified by the Shannon Regional Fisheries Board as being very important for coarse angling.

The draft ecological route corridor report was reviewed as part of this hydrological investigation.

Ecological Issues Along Each Route Corridor

<u>Route Corridor Option 1.1</u>

This corridor would impact three areas of ecological importance. Northeast of Node F, and eastwards from the River Shannon the route will pass through a section of the pNHA listed Lough Drumharlow in Corryolus. Riparian habitats at the river crossing may be lost, and the floodplain would become fragmented by the development. The crossing has a National rating and has been assigned a Significant Negative impact.

A wetland area at Aughriman South has a Local (Higher Value) rating with a Significant Negative impact. This is an area of willow dominated woodland and scrub on a former bog. Habitat areas would be lost and fragmentation would occur if the route were developed.

The woodland area in Mountcampbell has a Local (Higher Value) with a Significant Negative impact. The area includes a substantial amount of deciduous woodland with frequent oak. Habitat areas would be lost and fragmentation would occur if the route were developed.

Route Corridor Option 1.2

The corridor would impact one area of ecological importance. The section is similar to Route Corridor Option 1.1 in the Corryolus area where it passes through the pNHA listed Lough Drumharlow in Corryolus. There are no additional impacts, and the crossing has a National rating with a Significant Negative impact.

Route Corridor Option 1.3

The corridor would impact two areas of ecological importance. The section is similar to Route Corridor Option 1.1 in the Corryolus area where it passes through the pNHA listed Lough Drumharlow in Corryolus. The crossing has a National rating with a Significant Negative impact.

An area of wet woodland at Cornamucklagh would be impacted, and has been assigned a Local (Higher Value) rating with a Significant Negative impact. The northern portion of this area may be lost if the route were developed.

Route Corridor Option 1.4

The corridor would impact three areas of ecological importance. The River Shannon crossing at Cordrehid is of relatively low ecological interest as the banks rise quickly and the marginal vegetation on both sides has been disturbed. It has been rated as being of Local importance (Lower Value) with a Minor Negative impact.

The Killukin River has been assigned a Local (Higher Value) rating with a Significant Negative impact. This slow moving meandering river has a well developed floodplain approximately 150 to 200 m wide. Floodplain area would be lost if this route was developed.

A wetland area in Drumkeeran has been assigned a Local (Higher Value) rating with a Significant Negative impact. It is probably developed on a former bog, and is known to flood at times of high waters. The route would remove the southern part of the area and could potentially impede natural flooding to the northeast.

Route Corridor Option 1.5

The corridor would impact three areas of ecological importance. The River Shannon / Lough Corry crossing southwest of Rinnacurreen would result in the loss of riparian habitats along both sides of the river. It has been rated as being of County importance with a Significant Negative impact.

The floodplain habitats alongside the northeast shore of Lough Corry would be impacted, with a substantial loss of associated vegetation. It has been rated as being of County importance with a Significant Negative impact.

A wetland area in Danesfort has been assigned a Local (Higher Value) rating with a Significant Negative impact. The area is a cutover bog.

Route Corridor Option 2.1

The only ecological impact identified along this section was the potential loss of a large number of hedgerows. These would be expected to be rated as Local importance (Lower Value).

Route Corridor Option 2.2

The principal impact would be the potential loss of habitat at Gortinty Lough where the existing road runs along the eastern shore of the lake. If development were to be on the western side of the corridor then there would be a Significant Negative impact, however there would be no impact if developing to the east.

Route Corridor Option 2.3

As for Corridor 2.2, there would be a potential Significant Negative impact to Gortinty Lough if developing along the western side of the corridor.

Ecological Assessment for Corridor Preference

Table 16.19 gives a summary of the ecological sites that were identified and their level of importance.

Table 16.19 Summary Comparison of Ecological Sites and Level of Importance

Ecological Site	Route Corridor Options				
	1.1	1.2	1.3	1.4	1.5
Shannon Crossing (1)	National (2)	National (2)	National (2)		
Shannon Crossing (2)				Local (Low)	
Shannon Crossing (3)					County
Cornamucklagh			Local (High)		
Aughriman South	Local (High)				
Mountcampbell	Local (High)				
Killukin River				Local (High)	
Drumkeeran Wetland				Local (High)	
Lough Corry Floodplain					County
Danesfort Wetland					Local (High)

Table 16.20 gives the order of preference outlined in the ecological report based on the number of occurrences of significant impact level.

Table 16.20 Summary Comparison of Impacts on Ecological Sites

Impact Level	Route Corridor Options							
	1.1	**1.2**	**1.3**	**1.4**	**1.5**	**2.1**	**2.2**	**2.3**
bSignificant (National)	2	2	2	0	0	0	0	0
l Significant (County)	0	0	0	0	2	0	0	0
e Significant (Local, 1 high)	2	0	1	2	1	0	0	0
6**Order of Preference**	**5**	**3**	**4**	**1**	**2**	**3**	**1**	**1**

.
21 gives the order of preference outlined in the Aquatic Environment report based on the number of occurrences of attribute level.

Table 16.21 Preference Order of Route corridors Presented in the Aquatic Environment Report

Route	Number of Crossings	Preference listing
1.1	10 crossings. Impacting on R. Shannon at one location. Remainder low local value.	**1**
1.2	13 crossings. Impacting on R. Shannon at two locations. Remainder low local value.	**2**
1.3	9 crossings. Impacting on R. Shannon at three locations. Remainder low local value.	**3**
1.4	11 crossings. Impacting on R. Shannon at three locations. Two stream crossings high local value. Remainder low local value.	**4**
1.5	14 crossings. Impacting on R. Shannon at four locations. Three stream crossings high local value. Remainder low local value.	**5**
2.1	4 crossings. Two of high local value.	**1**
2.2	3 crossings including impacting on Gortinty Lough (county value).	**2**
2.3	3 crossings including impacting on Gortinty Lough (county value).	**2**

16.3.12 Watercourse Crossings

Overview of Flow in Watercourses in Each Route Corridor Options

Route Corridor Option1.1

This Route corridor option which takes a northern route around Carrick-on-Shannon has a total of 18 minor stream / drainage ditch crossings (i.e. < $0.5km^2$ drainage area), 4 Stream Crossings having catchment areas below $5km^2$ and the large River Shannon Crossing. All watercourse crossings aside from the River Shannon can easily be accommodated using pipe or box culvert sections.

Route 1.1				
Minor Stream/ ditch	**Small Stream**	**Stream**	**Small River**	**River**
WC_37	WC_32c (2.7km2)			Shannon
WC_36	WC_24b (1.2km2)			
WC_58	WC_25 (3.2km2)			
WC_24c	WC_40 (2.7km2)			
WC_26				
WC_59b				
WC_59c				
WC_53				
WC_52				
WC_51				
WC_50				
WC_49				
WC_48				
WC_47				
WC_46				
WC_45				
WC_42				
WC_41				
WC_39				
WC_27				
20	**4**			**1**

Route Corridor Option 1.2

This Route corridor option which takes a northern route around Carrick-on-Shannon has a total of 18 minor stream / drainage ditch crossings (i.e. < 0.5km^2 drainage area), 5 Stream Crossings having catchment areas below 5km^2 and the large River Shannon Crossing. All watercourse crossings aside from the River Shannon can easily be accommodated using pipe or box culvert sections.

Route 1.2				
Minor Stream/ ditch	**Small Stream**	**Stream**	**Small River**	**River**
WC_38	WC_32b (4.3km2)			Shannon
WC_58	WC_24 (2km2)			
WC_58	WC_25 (3.2km2)			
WC_23	WC_59 (1km2)			
WC_26	WC_40 (2.7km2)			
WC_21				
WC_22				
WC_53				
WC_52				
WC_51				
WC_50				
WC_49				
WC_48				
WC_47				
WC_46				
WC_45				
WC_42				
WC_41				
WC_39				
WC_27				
20	**5**			**1**

Route Corridor Option 1.3

This Route Corridor Option which takes a northern route around Carrick-on-Shannon has a total of 16 minor stream / drainage ditch crossings (i.e. < 0.5km^2 drainage area), 1 small Stream Crossing having catchment areas below 5km^2 , 1 stream crossing having catchment area of 6.4km^2 and the large River Shannon Crossing. All watercourse crossings aside from the River Shannon can easily be accommodated using pipe or box culvert sections.

Route 1.3				
Minor Stream/ ditch	**Small Stream**	**Stream**	**Small River**	**River**
WC_58	WC_24 (2km2)	WC_32 (6.4km2)		Shannon
WC_23	WC_25 (3.2km2)			
WC_26				
WC_19b				
WC_21				
WC_22				
WC_53				
WC_52				
WC_51				
WC_50				
WC_49				
WC_48				
WC_47				
WC_46				
WC_45				
WC_44				
WC_43				
WC_27				
WC_33				
WC_34				
WC_35				
21	**2**	**1**		**1**

Route Corridor Option 1.4

This Route Corridor Option which takes a southern bypass route of Carrick-on-Shannon crosses the River Shannon near Attirory. The route corridor has 10 minor stream / drainage ditch crossings (< 0.5km^2 catchment area), 5 small stream crossings (< 5km^2 catchment area), 1 stream crossing having catchment area of 6.4km^2, a small river crossing of the Killukin River (catchment area of 31.5km2) and the Large River Shannon Crossing.

Route 1.4				
Minor Stream/ ditch	**Small Stream**	Stream	**Small River**	**River**
WC_54	WC_57 (1.1km2)	WC_32 (6.4km2)	WC_07b (31.5km2)	R Shannon
WC_55	WC_02c(2.1km2)			
WC_56	WC_04b (3.3km2)			
WC_54	WC_24 (2km2)			
WC_58	WC_25 (3.2km2)			
WC_23				
WC_26				
WC_19b				
WC_21				
WC_22				
WC_27				
11	**5**	**1**	**1**	**1**

Route Corridor Option 1.5

This Route corridor option which takes a southern route around Carrick-on-Shannon crosses the River Shannon near Attirory. The route has 17 minor stream / drainage ditch crossings (< 0.5km^2 catchment area), 7 small stream crossings (< 5km^2

catchment area), 1 stream crossing having catchment area of 7.7km^2, a small river crossing of the Killukin River (catchment area of 29.8km^2) and the Large River Shannon Crossing.

Route 1.5				
Minor Stream/ ditch	**Small Stream**	**Stream**	**Small River**	**River**
WC_15	WC_14 1.77km2	WC_17 (7.73 km2)	WC_07/WC_08 (29.8km2)	Shannon
WC_16	WC_06 (1.73km2)			
WC_18	WC_01(1.89km2)			
WC_09	WC_02a/b (1.62km2)			
WC_10	WC_04 (2.64 km2)			
WC_11	WC_24 (2km2)			
WC_12	WC_25 (3.2km2)			
WC_13				
WC_58				
WC_03				
WC_05				
WC_23				
WC_26				
WC_19				
WC_20				
WC_21				
WC_22				
WC_27				
18	**7**	**1**	**1**	**1**

Route Corridor Option 2.1

This route which runs close to the River Shannon Floodplain has 2 minor stream / drainage ditch crossings and 1 stream crossing (Gort Connellan Lough Stream outflow catchment area 15.8km^2)

Route 2.1				
Minor Stream/ ditch	**Small Stream**	**Stream**	**Small River**	**River**
WC_60		WC_61 (15.8km2)		
WC_63				
WC_66				
3		**1**		

Route Corridor Option 2.2

This route which runs close to the River Shannon Floodplain has 2 minor stream / drainage ditch crossings and 1 stream crossing (Gort Connellan Lough Stream outflow catchment area 15.8km^2)

Route 2.2				
Minor Stream/ ditch	**Small Stream**	**Stream**	**Small River**	**River**
WC_62		WC_61 (15.8km2)		
WC_64				
2		**1**		

Route Corridor Option 2.3

This route which runs close to the River Shannon Floodplain has 2 minor stream / drainage ditch crossings and 1 stream crossing (Gort Connellan Lough Stream outflow catchment area 15.8km^2).

Route 2.3				
Minor Stream/ ditch	**Small Stream**	**Stream**	**Small River**	**River**
WC_62		WC_61 (15.8km2)		
WC_65				
2		**1**		

Table 16.22 Summary Details of all Watercourse Crossings

water course Crossing ref	Route	Channel order	Location	Area (km2)	Channel Class	Easting	Northing
1	1.5	1st order	Cuillyconeen	1.9	small stream	191537	299665
2a	1.5	2nd order	Ardchanoyle	0.52	small stream	191718	298984
2b	1.5	1st order	Tawlaght	0.92	small stream	191756	298959
2c	1.4	2nd order	Cloonmaan	2.1	small stream	192176	299575
2d	1.4	3rd order	Cloonmaan	0.35	minor stream / drainage ditch	192286	299472
3	1.5	2nd order	Mullaghmore	<.25	minor stream / drainage ditch	192014	298570
4	1.5	1st order	Mullaghmore	2.6	small stream	192040	298516
4b	1.4	1st order	Drishoge	3.3	small stream	192544	299099
5	1.5	2nd order	Mullaghmore	0.16	minor stream / drainage ditch	192135	298379
6	1.5	2nd order	Killukin	1.73	small Stream	192346	297825
7	1.5	1st order	Killukin	29.8	Small River	192781	297426
7b	1.4	1st Order	Corktober	31.5	small River	193855	298614
8	1.5	1st order	Killukin	29.8	Small River	192822	297400
9	1.5	3rd order	Lanesfort	<0.25	minor stream / drainage ditch	193107	297258
10	1.5	3rd order	Lanesfort	<0.25	minor stream / drainage ditch	193218	297204
11	1.5	2nd order	Lanesfort	<0.25	minor stream / drainage ditch	193264	297181
12	1.5	1st order	Lanesfort	<0.25	minor stream / drainage ditch	193866	297067
13	1.5	1st order	Lanesfort	<0.25	minor stream / drainage ditch	193998	297073
14	1.5	1st order	Rinnacurreen	1.8	Small Stream	195295	297431
15	1.5	2nd order	Ballynacleigh	< 0.25	minor stream / drainage ditch	195802	297614
16	1.5	2nd order	Ballynacleigh	< 0.25	minor stream / drainage ditch	195874	297635
17	1.5	1st order	Drummaunroe	7.7	Stream	196125	297671
18	1.5	2nd order	Drummaunroe	0.4	minor stream / drainage ditch	196529	297759
19	1.5	1st order	Tully	0.87	minor stream / drainage ditch	197196	298057
19b	1.3, 1.4	1st order	Tully	0.5	minor stream / drainage ditch	197077	298271
20	1.5	1st order	Tully	0.37	minor stream / drainage ditch	198052	298465
21	1.2,1.3,1.4,1.5	1st order	Kildorragh	<.25	minor stream / drainage ditch	198261	298551
22	1.2,1.3,1.4,1.5	1st order	Kildorragh	<.25	minor stream / drainage ditch	198374	298574
23	1.2,1.3,1.4,1.5	1st order	Mountcampbell	0.24	minor stream / drainage ditch	198537	298587
24	1.2,1.3,1.4,1.5	1st order	Mountcampbell	2	small stream	198642	298605
24b	1.1	1st order	Drishoge	1.2	small stream	198949	299251
24c	1.1	1st order	Drishoge	< .25	minor stream / drainage ditch	198838	299338
25	1.1,1.2,1.3,1.4,1.5	1st order	Mountcampbell	3.2	small stream	199417	298460
26	1.1,1.2,1.3,1.4,1.5	1st order	Mountcampbell	< .25	minor stream / drainage ditch	199503	298405
27	1.1,1.2,1.3,1.4,1.5	1st order	Crickeen	< .25	minor stream / drainage ditch	199752	298145
32	1.3,1.4	1st order	Corbally	6.4	Stream	196295	298667
32b	1.2	1st order	Greagh	4.3	small stream	197199	299640
32c	1.1	1st order	Garvlough	2.7	small stream	197494	300156
33	1.3	2nd order	Lisseeghan	<0.25	minor stream / drainage ditch	196113	299026
34	1.3	1st order	Lisseeghan	0.5	minor stream / drainage ditch	196100	299263
35	1.3	1st order	Keenaghan	0.6	minor stream / drainage ditch	196013	300122
36	1.1	2nd order	Garvlough	1.1	small stream	197405	300184
37	1.1	3rd order	Cornaslieve	<0.25	minor stream / drainage ditch	196953	300343
38	1.1	1st order	Cornaslieve	<0.25	minor stream / drainage ditch	196538	300371
39	1.1,1.2	2nd order	Aghancarra	<.25	minor stream / drainage ditch	196048	300892
40	1.1,1.2	1st order	Aghancarra	2.7	small stream	195827	301084
41	1.1,1.2	2nd order	Cloonmulligan	<.25	minor stream / drainage ditch	195472	301325
42	1.1,1.2	2nd order	Cloonsheebane	0.24	minor stream / drainage ditch	194846	301534
43	1.3	2nd order	Cloonsheebane	<.25	minor stream / drainage ditch	195095	301134
44	1.3	2nd order	Cloonsheebane	<.25	minor stream / drainage ditch	194636	301224
45	1.1,1.2,1.3	1st order	Cloonsheebane	<.25	minor stream / drainage ditch	194094	301264
46	1.1,1.2,1.3	1st order	Lisnagal	<.25	minor stream / drainage ditch	193993	301224
47	1.1,1.2,1.3	1st order	Lisnagal	<.25	minor stream / drainage ditch	193686	301008
48	1.1,1.2,1.3	1st order	Lisnagal	<.25	minor stream / drainage ditch	193463	300858
49	1.1,1.2,1.3	1st order	Corryolus	<.25	minor stream / drainage ditch	192716	300410
50	1.1,1.2,1.3	1st order	Corryolus	<.25	minor stream / drainage ditch	192670	300370
52	1.1,1.2,1.3	1st order	Cloonmaan	<.25	minor stream / drainage ditch	192152	300015
53	1.1,1.2,1.3	2nd order	Cloonmaan	<.25	minor stream / drainage ditch	192005	299840
54	1.4	2nd order	Dishoge	<0.25	minor stream / drainage ditch	192908	298918
55	1.4	2nd order	Dishoge	< 0.25	minor stream / drainage ditch	194291	298614
56	1.3	2nd order	Drumkeeran	< 0.25	minor stream / drainage ditch	195127	298515
57	1.4	1st order	Drumkeeran	1.1	Small stream	195457	298510
58	1.1,1.2,1.3,1.4,1.5	3rd order	Gortconnellan Loug	<0.25	minor stream / drainage ditch	200043	297736
59a	1.2	2nd order	Minkill	1	small stream	197517	299263
59b	1.1	3rd order	Aughriman South	<.25	minor stream / drainage ditch	198160	299906
59c	1.1	2nd order	Aughriman South	<.25	minor stream / drainage ditch	198429	299767
60	2.1	3rd order	Aghamore	<.25	minor stream / drainage ditch	203322	294747
61	2.1,2.2,2.3	1st order	Gortconnellan Loug	15.8	stream outflow	200359	297265
62	2.2,2.3	2nd order	Derryoughter	<.25	minor stream / drainage ditch	201462	296404
63	2.1	3rd order	Gortinty	<.25	minor stream / drainage ditch	201430	296632
64	2.2	2nd order	Antifield	<.25	minor stream / drainage ditch	202765	295178
65	2.3	2nd order	Antifield	<.25	minor stream / drainage ditch	202642	295121
66	2.1	3rd order	Drumcoora	<.25	minor stream / drainage ditch	202862	295366

Summary of Watercourse Crossings

Table 16.23 gives a summary of the number of main watercourses that will be crossed by each corridor based on OSI 1:50,000 and EPA river classification mapping.

Table 16.23 Summary of Main OS/EPA Mapped Watercourse Crossings within Route Corridor Options

Route Corridor Option	Section 1					Section 2		
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3
Drainage ditch / minor streams (<0.5km2	20	20	21	11	18	3	2	2
Small Stream crossing	4	5	2	5	7	1	1	1
Stream crossings	0	0	1	1	1	0	0	0
Small River crossings	0	0	0	1	1	0	0	0
Large River crossings	1	1	1	1	1	0	0	0

The River Shannon will need to be crossed no matter which combination of route corridors is used, with the three options being located at Corryolus to the northwest of Carrick-on-Shannon (Route Corridor Options 1.1, 1.2 and 1.3), Cordrehid / Attiroy southeast of the town (Route Corridor Option 1.4), and a narrowing of Lough Corry south of Rinnacurreen (Route Corridor Option 1.5).

In places the crossings only extend partially across the corridor and the final alignment would need to be known to see if an actual crossing would be required. A number of small streams also came close to the corridor boundaries on the Discovery Series mapping and it will be necessary to walk the area to confirm whether or not they extend into the corridor.

Summary of Possible Structures

An estimation of the number of watercourse crossings (bridges and culverts) in each route corridor is given in the following table (Table 16.24).

Table 16.24 Summary of Watercourse Crossings Within Each Route Corridor

Structure	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3
Bridge	1	1	1	2	2	0	0	0
Culvert	24	25	24	17	26	4	3	3
Order of Preference	2	3	1	4	5	3	1	1

Crossings Within Each Route Corridor Option

<u>Route Corridor Option 1.1</u>

Ten EPA coded watercourse crossings have been identified within the route corridor (Table 16.25). The section includes one major bridge crossing, over the River Shannon.

Table 16.25 Summary of Watercourse Crossings within Route Corridor Option 1.1

Nodes	Code	Townland	Easting	Northing	Flow Direction
F to G	26_3561	Corryolus	192540	300240	River Shannon flowing NW to SE.
G to H	26_153	Cloonsheerevagh	194840	301530	Flow from S to N.
G to H	26_3498	Aghancarrra	195820	301100	Flow SE to NW along centre of corridor for a few hundred metres from Kilmaddaroe Lough to Bran Lough. Channel may be crossed twice.
H to M	26_3491	Aghancarrra	196050	300890	Flow from S to N into 26_3498.
H to M	26_94	Cornaslieve	196961	300355	Flow from SW to NE
H to M	26_3486	Garvlough	197400	300190	Flow from N to S.
H to M	26_3493	Garvlough	197490	300160	Flow from N to S.
H to M	26_2478	Drishoge	198940	299260	Flow from N to S.
H to M	26_3069	Mountcampbell	199480	298500	Flow from NE to SW into nearby Shannon.
H to M	26_3080	Mountcampbell	199540	298440	Flow from NE to SW into nearby Shannon.

Another three (possibly four) small channels / field drains are crossed that are identified on large scale mapping.

Route Corridor Option 1.2

Eleven EPA coded watercourse crossings have been identified within the route corridor (Table 16.26). The section includes one major bridge crossing, over the River Shannon.

Table 16.26 Summary of Watercourse Crossings within Route Corridor Option 1.2

Nodes	Code	Townland	Easting	Northing	Flow Direction
F to G	26_3561	Corryolus	192540	300240	River Shannon flowing NW to SE.
G to H	26_153	Cloonsheerevagh	194840	301530	Flow from S to N.
G to H	26_3498	Aghancarrra	195820	301100	Flow SE to NW along centre of corridor for a few hundred metres from Kilmaddaroe Lough to Bran Lough. Channel may be crossed twice.
H to L	26_3491	Aghancarrra	196050	300890	Flow from S to N into 26_3498.
H to L	26_94	Cornaslieve	196760	300130	Flow from W to E.
H to L	26_3555	Greagh	197200	299640	Flow from NE to SW.
H to L	26_2080	Minkill	197510	299260	Flow from E to W.
H to L	26_3060	Kildorragh	197960	298750	Flow from N to S.
L to M	26_2478	Mountcampbell	198630	298585	Flow from N to S.
L to M	26_3069	Mountcampbell	199430	298440	Flow from NE to SW into nearby Shannon.

Nodes	Code	Townland	Easting	Northing	Flow Direction
L to M	26_3080	Mountcampbell	199490	298400	Flow from NE to SW into nearby Shannon.

Another seven small channels / field drains are crossed that are identified on large scale mapping. These include a concentration of channels in Portaneoght draining from the higher ground that will be traversed by the corridor into the pNHA designated Drumharlow Lough. Another channel drains from the corridor around the boundary of the designated area in Corryolus, into the River Shannon.

Route Corridor Option 1.3

Seven EPA coded watercourse crossings have been identified within the route corridor (Table 16.27). The section includes one major bridge crossing, over the River Shannon.

Table 16.27 Summary of Watercourse Crossings Within Route Corridor Option 1.3

Nodes	Code	Townland	Easting	Northing	Flow Direction
F to G	26_3561	Corryolus	192540	300240	River Shannon flowing NW to SE.
G to I	26_3566	Keenaghan	196010	300130	Flow form NE to SW
J to K	26_3046	Corbally	196285	298660	Flow from N to S into Lough Corry.
K to L	26_3060	Tully	198060	298465	Flow from N to S into nearby Shannon.
L to M	26_2478	Mountcampbell	198630	298585	Flow from N to S.
L to M	26_3069	Mountcampbell	199430	298440	Flow from NE to SW into nearby Shannon.
L to M	26_3080	Mountcampbell	199490	298400	Flow from NE to SW into nearby Shannon.

Another five, possibly six small channels / field drains are crossed that are identified on large scale mapping. These include a concentration of channels in Portaneoght draining from the higher ground that will be traversed by the corridor into the pNHA designated Drumharlow Lough. Another channel drains from the corridor around the boundary of the designated area in Corryolus, into the River Shannon.

Route Corridor Option 1.4

Ten EPA coded watercourse crossings have been identified within the route corridor (Table 16.28). The section includes one major bridge crossing, over a narrowing of Lough Corry / River Shannon.

Table 16.28 Summary of Watercourse Crossings within Route Corridor Option 1.4

Nodes	Code	Townland	Easting	Northing	Flow Direction
E to F	6_4143	Cloonmann	191915	299880	Flow from SE to NW along northern edge of corridor. May not require a crossing.

Nodes	Code	Townland	Easting	Northing	Flow Direction
F to J	26_4144	Tullyleague	192210	299510	Flow from approximately W to E.
F to J	26_795	Drishoge	192540	299090	Flow from W to E.
F to J	26_1506	Cordrehid	193890	298630	Flow from SW to NE.
F to J	26_3090	Cordrehid	194635	298650	Flow from N to S into River Shannon.
J to K	26_3046	Corbally	196285	298660	Flow from N to S into Lough Corry.
K to L	26_3060	Tully	198060	298465	Flow from N to S into nearby Shannon.
L to M	26_2478	Mountcampbell	198630	298585	Flow from N to S.
L to M	26_3069	Mountcampbell	199430	298440	Flow from NE to SW into nearby Shannon.
L to M	26_3080	Mountcampbell	199490	298400	Flow from NE to SW into nearby Shannon.

Another three, possibly four small channels / field drains are crossed that are identified on large scale mapping.

Route Corridor Option 1.5

Twelve EPA coded watercourse crossings have been identified within the route corridor (Table 16.29). The section includes one major bridge crossing, over a narrowing of Lough Corry.

Table 16.29 Summary of Watercourse Crossings within Route Corridor Option 1.5

Nodes	Code	Townland	Easting	Northing	Flow Direction
D to K	26_795	Mullaghmore	192040	298520	Flow from SW to NE.
D to K	26_1496	Killukin	192355	297825	Flow from W to E.
D to K	26_1497	Killukin	192780	297430	Flow from S to N.
D to K	26_710	Rinnacurreen	194400	297100	Lough Corry crossing
D to K	26_2956	Rinnacurreen	195290	297430	Flow from N to S into Lough Corry at this location. Part of the corridor is along lake.
D to K	26_2461	Drummaunroe	196125	297670	Flow from N to S into Lough Corry.
D to K	26_4141	Lisgarney	196530	297745	Flow from S to N into 26_2461.
D to K	26_471	Tully	197196	298057	Flow from N to S.
K to L	26_3060	Tully	198060	298465	Flow from N to S into nearby Shannon.
L to M	26_2478	Mountcampbell	198630	298585	Flow from N to S.
L to M	26_3069	Mountcampbell	199430	298440	Flow from NE to SW into nearby Shannon.
L to M	26_3080	Mountcampbell	199490	298400	Flow from NE to SW into nearby Shannon.

From large scale mapping at least eight further small channels / field drains are crossed, including four that converge where the corridor cuts the R370, draining a large area from the west. In addition to these there are a large number of field drains in Drummaunroe that will be crossed by the corridor, flowing into the 26_2461 channel.

Route Corridor Option 2.1

One EPA coded watercourse crossings has been identified within the route corridor (Table 16.30).

Table 16.30 Summary of Watercourse Crossings within Route Corridor Option 2.1

Nodes	Code	Townland	Easting	Northing	Flow Direction
B to N	26_1511	Drumsna	200350	297245	Flow from N to S into River Shannon from Gortconnellan (Spa) Lough nearby.

Another two possible three small channels / field drains are crossed that are identified on large scale mapping.

Route Corridor Option 2.2

Three EPA coded watercourse crossings have been identified within the route corridor (Table 16.31).

Table 16.31 Summary of Watercourse Crossings within Route Corridor Option 2.2

Nodes	Code	Townland	Easting	Northing	Flow Direction
B to N	26_1511	Drumsna	200350	297245	Flow from N to S into River Shannon from Gortconnellan (Spa) Lough nearby.
N to O	26_1633	Gortinty	201465	296400	Flow from N to S.
O to P	26_2065	Antfield	202770	295190	Flow from E to W into Drumgilra / Gortinty Lough.

The western boundary of the corridor between Nodes N and O cuts along the shore of Drumgilra / Gortinty Lough.

Route Corridor Option 2.3

Three EPA coded watercourse crossings have been identified within the route corridor (Table 16.32).

Table 16.32 Summary of Watercourse Crossings within Route Corridor Option 2.3

Nodes	Code	Townland	Easting	Northing	Flow Direction
B to N	26_1511	Drumsna	200350	297245	Flow from N to S into River Shannon from Gortconnellan (Spa) Lough nearby.
N to O	26_1633	Gortinty	201465	296400	Flow from N to S.

Nodes	Code	Townland	Easting	Northing	Flow Direction
O to P	26_2065	Antfield	202770	295190	Flow from E to W into Drumgilra / Gortinty Lough.

The western boundary of the corridor between Nodes N and O cuts along the shore of Drumgilra / Gortinty Lough.

16.3.13 Impact Assessment

Description of Hydrological Impacts

Road projects given their scale and nature have significant potential for causing impact to the water environment both during their construction and on-going operation and consequently require careful planning and detailed assessment to ensure the best solution is attained.

Most of the potential environmental impacts for watercourses occur close to the points where the proposed route corridors cross the water channel, aside from the potential to cause flooding both upstream and downstream and reduce water and biological quality downstream.

The attributes and impacts that are assessed for each route corridor include the following:

- Watercourses crossed by each route and potential impact on water quality arising from re-alignment works and discharge of surface water run-off;
- Aquatic ecological sites close to and downstream of water crossings;
- Surface water abstraction close to and downstream of water crossings;
- Established amenity value of surface waters traversed by each route corridor; and
- Potential increase (or reduction) in flood risk to existing properties and infrastructure.

Assessment Criteria

Estimation of the importance of hydrological attributes is based on criteria for rating site attributes as outlined in the NRA publication '*Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes*', and presented in Table 16.34.

Table 16.34 Criteria for Rating Site Attributes

Importance	Criteria
Extremely High	Attribute has a high quality or value on an international scale
Very High	Attribute has a high quality or value on a regional or national scale
High	Attribute has a high quality or value on a local scale
Medium	Attribute has a medium quality or value on a local scale
Low	Attribute has a low quality or value on a local scale

The guidelines also define the impact significance level relative to the attribute importance (Table 16.35).

Table 16.35 Criteria for Rating Impact Significance

Impact Level	Attribute Importance				
	Extremely High	Very High	High	Medium	Low
Profound	Any permanent impact on attribute	Permanent impact on significant proportion of attribute			
Significant	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute		
Moderate	Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute	
Slight		Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute
Imperceptible			Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute

Impacts associated with each route corridor

<u>Route Corridor Option 1.1</u>

Table 16.36 provides a summary of the key hydrological attributes that have been identified along the route corridor.

Table 16.36 Preliminary Assessment of Hydrological Impacts for Route Corridor 1.1

Attribute	Description	Level of Impact	Impacts
Floodplain encroachment			
River Shannon Crossing at Corryolus	National	Significant	1
River Shannon at Tully	National	Significant	1
Loughs	High local	Moderate	1
Watercourse Crossings culverting/ bridge impact and water quality impact			
Minor streams and drainage ditches	Low local	Slight	20
Small streams	Medium Local	Slight	4
Large Streams	Medium Local	moderate	
Small Rivers	High local		

Attribute	Description	Level of Impact	Impacts
Large Rivers	National	Significant	1
Local poor draining area	Low local	Slight	1

Route Corridor Option 1.2

Table 16.37 provides a summary of the key hydrological attributes that have been identified along the route corridor and the level of impact.

Table 16.37 Preliminary Assessment of Hydrological Impacts for Route Corridor Option 1.2

Attribute	Description	Level of Impact	Impacts
Floodplain encroachment			
River Shannon Crossing at Corryolus	National	Significant	1
River Shannon at Tully	National	Significant	1
Loughs	High local	Moderate	1
Watercourse Crossings culverting/ bridge impact and water quality impact			
Minor streams and drainage ditches	Low local	Slight	20
Small streams	Medium Local	Slight	5
Large Streams	Medium Local		
Small Rivers	High local		
Large Rivers	National	Significant	1
Local poor draining area	Low local	Slight	1

Route Corridor Option 1.3

Table 16.38 provides a summary of the key hydrological attributes that have been identified along the route corridor and the level of impact.

Table 16.38 Preliminary Assessment of Hydrological Impacts for Route Corridor Option 1.3

Attribute	Description	Level of Impact	Impacts frequency
Floodplain encroachment			
River Shannon Crossing at Corryolus	National	Significant	1
River Shannon at Tully	National	Significant	1
Loughs	High local	Moderate	1
Watercourse Crossings culverting/ bridge impact and water quality impact			
Minor streams and drainage ditches	Low local	Slight	21
Small streams	Medium Local	Slight	2
Large Streams	Medium Local	Slight	1
Small Rivers	High local		
Large Rivers	National	Significant	1
Local poor draining area	Low local	Slight	1

Route Corridor Option 1.4

Table 16.39 provides a summary of the key hydrological attributes that have been identified along the route corridor and the level of impact.

Table 16.39 Preliminary Assessment of Hydrological Impacts for Route Corridor Option 1.4

Attribute	Description	Level of Impact	Impacts
Floodplain encroachment			
River Shannon Crossing at Corryolus	National	Significant	1
River Shannon at Tully	National	Significant	1
Loughs	High local	Moderate	1
Watercourse Crossings culverting/ bridge impact and water quality impact			
Minor streams and drainage ditches	Low local	Slight	11
Small streams	Medium Local	Slight	5
Large Streams	Medium Local	Slight	1
Small Rivers	High local	moderate	1
Large Rivers	National	Significant	1
Local poor draining area	Low local	Slight	1

Route Corridor Option 1.5

Table 16.40 provides a summary of the key hydrological attributes that have been identified along the route corridor and the level of impact.

Table 16.40 Preliminary Assessment of Hydrological Impacts for Route Corridor Option 1.5

Attribute	Description	Level of Impact	Impacts
Floodplain encroachment			
River Shannon Crossing at Corryolus	National	Significant	1
River Shannon at Tully	National	Significant	1
Loughs	High local	Moderate	1
Watercourse Crossings culverting/ bridge impact and water quality impact			
Minor streams and drainage ditches	Low local	Slight	18
Small streams	Medium Local	Slight	7
Large Streams	Medium Local	Slight	1
Small Rivers	High local	moderate	1
Large Rivers	National	Significant	1
Local poor draining area excluding river floodplains	Low local		

Route Corridor Option 2.1

Table 16.41 Preliminary Assessment of Hydrological Impacts for Route Corridor Option 2.1

Attribute	Description	Level of Impact	Impacts
Floodplain encroachment			
River Shannon at Drumsna	National	Significant	1
	High local	moderate	
Watercourse Crossings culverting/ bridge impact and water quality impact			
Minor streams and drainage ditches	Low local	Slight	3
Small streams	Medium Local	Slight	
Large Streams	Medium Local	Slight	1
Small Rivers	High local	moderate	
Large Rivers	National	Significant	
Local poor draining area excluding river floodplains	Low local		

Route Corridor Option 2.2

Table 16.42 Preliminary Assessment of Hydrological Impacts for Route Corridor Option 2.2

Attribute	Description	Level of Impact	Impacts
Floodplain encroachment			
River Shannon at Drumsna	National	Significant	1
Loughs Gortinty Lough	High local	Moderate	1
Watercourse Crossings culverting/ bridge impact and water quality impact			
Minor streams and drainage ditches	Low local	Slight	2
Small streams	Medium Local	Slight	
Large Streams	Medium Local	Slight	1
Small Rivers	High local	moderate	
Large Rivers	National	Significant	
Local poor draining area excluding river floodplains	Low local		

Route Corridor Option 2.3

Table 16.43 Preliminary Assessment of Hydrological Impacts for Route Corridor Option 2.3

Attribute	Description	Level of Impact	Impacts
Floodplain encroachment			
River Shannon at Drumsna	National	Significant	1
Loughs Gortinty Lough	High local	Moderate	1
Watercourse Crossings culverting/ bridge impact and water quality impact			
Minor streams and drainage ditches	Low local	Slight	2
Small streams	Medium Local	Slight	
Large Streams	Medium Local	Slight	1
Small Rivers	High local	moderate	
Large Rivers	National	Significant	
Local poor draining area excluding river floodplains	Low local		

Environmental Mitigation Measures

The following generalised mitigation measures should be considered in detail at the Environmental Impact Statement phase of the scheme.

Baseline Investigation

Once an EPR Corridor has been selected and an idea known regarding the lateral and vertical alignments, it is recommended that baseline field investigations be carried out in sensitive areas such as designated sites and flood plains impacted by the route. This work would be necessary for collating baseline data required by the subsequent EIS phase of reporting, to obtain a better understanding of the existing hydrological regime. The surface water interaction with local karst features should also be investigated.

Construction Phase

As an impact reduction strategy good environmental practices should be implemented during the construction of the development including all ancillary areas, such as site compounds. These good environmental practices should be implemented by means of an environmental management plan and the implementation of a pollution incident control plan during construction to ensure that any incidents are dealt with should they occur. It is recommended that no ancillary areas be located within the subject area and no refuelling be allowed to reduce potential impacts.

If groundwater infiltration areas are required away from the area, then to mitigate potential localised flooding at these areas, detailed site investigation should be carried out to define the infiltration rate during winter periods. Based on these rates the size of infiltration field and necessary detention stormwater storage and controlled outflow to the infiltration field should be determined so as to meet the design drainage requirements without causing ponding of the infiltration field or adjacent lands. This should be undertaken during the detailed design stage of the project.

All proposed culvert crossings along the route should be designed to satisfy the requirements of OPW Section 50 (bridges and culverts), 1945 arterial drainage act and should receive Section 50 consent prior to construction. From an ongoing channel maintenance perspective the minimum (OPW) recommended culvert size is a 900 mm diameter pipe. Culvert sizing should allow for future climate and land use changes. Inlet and outlet structures including Reno mattress should be provided at all culverts. Culverts should be sized so that they can be recessed below existing bed level to a depth of 300mm and have a freeboard of 300 mm (distance between design flood level and soffit) unless severely back-watered from downstream. Blockage potential and security issues should be addressed in the final culvert design.

Culvert alignment should avoid skewed alignment and consequently may require channel straightening to be carried out locally upstream and downstream of the culvert.

All culverts, stream channel improvements and channel diversions should be designed and constructed to meet fishery / wildlife requirements, and reference made to the Aquatic Ecology Assessment Report for details of the measures required.
Major bridge crossings will be required within all corridor options.

Provision should be made for the protection of exposed soil surface from rainfall erosion. Stockpiles and spoil heaps should be located well away from drainage ditches and watercourses.

It is essential to ensure that the use of cement and wet concrete in or close to any of the watercourses or karst features is carefully controlled.

Any spillages of hydrocarbons should be immediately contained on site with suitable materials and the contaminated soil / material removed for appropriate disposal.

<u>Operational Phase</u>
Surface runoff from roads can adversely affect the water quality of the receiving stream as a result of routine road drainage discharges and accidental spillages. Of particular concern to the receiving waters is the impact of the "First Flush" runoff, where accumulated road waste material is washed off from the road surface and drainage system in relatively high concentrations, particularly when this coincides with dry weather flows in nearby streams. High concentrations of suspended solids could potentially rapidly infiltrate via karst features the underlying aquifer blocking the conduit flow paths. Properly designed treatment measures can mitigate such water quality impacts.

Accidental spillages are predominantly a function of traffic flows and pavement area draining to the nearest water body. Mitigation measures to prevent serious impact to the receiving waters comprise a combination of oil interceptors, storage areas and outlet facilities that can be shut off to capture harmful substances prior to discharge.

Road pavements and associated surface drainage have a potential to increase flows in the receiving streams. This results from a more rapid response to rainfall and an increase in runoff volume due to the impervious area. The road pavement draining to an outfall may also divert runoff towards the road's drainage system, which in the absence of the road may flow in another direction. It is normally the reduced time of concentration factor that tends to have the greatest influence on peak flows. This increase in peak flow may cause flooding of third party land where there is either a lack of channel capacity or a restrictive structure (i.e. culvert) downstream of the outfall.

Current practice in Ireland to deal with urban storm runoff is the introduction of sustainable urban drainage (SUDs) practices. This involves source control through the use of soakaways or infiltration fields and the minimisation of impervious areas (porous pavements), or the provision of detention ponds (surface ponds, underground tanks, and swales) to attenuate the flood peak to a permissible maximum runoff rate. These techniques also serve to treat surface water pollution through promotion of primary settlement (sedimentation) and natural filtering.

To mitigate potential flooding in the receiving streams from the road drainage storm runoff a SUDS (Sustainable Urban Drainage Systems) approach is recommended whereby road drainage runoff is attenuated to a permissible runoff rate (generally adopted as equivalent to the natural Greenfield flood flow) prior to it entering the receiving stream. The attenuation may be achieved by using a variety of devices such as, constructed detention ponds (dry or wet), natural surface ponds, lakes or wetlands, attenuated ditches (swales), soakaways and infiltration fields and these should be located away from any identified karst features.

16.3.14 Comparison of Route Corridors

Summary of Key Hydrological Attributes

A review of the existing environment with regards to hydrology has been made to select a preferable order of route corridor selection that will minimise the impact on the environment as well as reducing the likely cost implications from mitigation requirements.

Table 16.44 indicates the order of preference for each corridor based on the most significant Hydrological Attribute categories.

Table 16.44 Route Corridor Option Preferences Relevant to Hydrological Attributes

Hydrological Attribute Category	Route Corridor Option Preferences							
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3
Watercourse crossings	2	3	1	4	5	3	1	1
Floodplains	3	3	2	1	5	1	2	2
Proximity to designated sites	1	1	1	1	1	1	1	1
Aquatic Ecology Preferences	1	2	3	4	5	1	2	2
Total Score	7	9	7	10	16	6	6	6
Order of preference	1	3	1	4	5	1	1	1

Summary of Hydrological Impacts

As discussed elsewhere an assessment has been made of the likely impact each route will have on the various key hydrological attribute categories. Table 16.45 gives an order of preference based on the number of occurrences of impact level.

Table 16.45 Summary of Hydrological Impacts for Route Corridor Options

Impact Level	Route Corridor Options							
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3
Profound								
Significant	3	3	3	3	3	1	1	1
Moderate	1	1	1	2	2		1	1
Slight	25	26	25	18	26	4	3	3
Imperceptible								
Order of Preference	1	3	1	4	5	1	2	2

Order of Hydrological Preference

Considering the number of hydrological attributes that are located within each corridor and the likely level of impact that a route would have on the attribute the following order of preference has been derived (Table 16.46). The overriding consideration in respect to the hydrology is the River Shannon Bridge Crossing and the length of encroachment of the flood conveyance width and potential flood storage loss.

The route preference ranking is based on adding the hydrological Attribute score to the hydrological impacts score.

Table 16.46 Hydrological Route Corridor Option Preference Order

Preference ranking	Route Corridor Options							
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3
Attribute Ranking	1	3	1	4	5	1	1	1
Hydrological Impact Ranking	1	3	1	4	5	1	2	2
TOTAL SCORE	2	6	2	8	10	2	3	3
OVERALL RANKING	**1**	**3**	**1**	**4**	**5**	**1**	**2**	**2**

16.4 Hydrogeology

16.4.1 Introduction

Work Brief

Hydro Environmental Ltd was commissioned by Roughan & O'Donovan on behalf of Leitrim County Council to carry out a hydrogeological assessment for the N4 Carrick-on-Shannon to Dromod Route Corridor Selection Study.

This report section was prepared in accordance with the National Roads Authority (NRA) publication '*Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes*'.

The proposed scheme relates to the improvement of 18.5 km of the N4 National Primary Route and associated infrastructure from west of Carrick-on-Shannon / Cortober in the Townland of Cloongownagh, County Roscommon to the northern tie-in of the recently completed N4 Dromod Roosky Bypass in the Townland of Faulties, County Leitrim. The scheme will include a bypass of Carrick-on-Shannon / Cortober and will include a new River Shannon crossing.

Route Corridor Options

The study area has been divided into two sections, the western tie-in west of Carrick-on-Shannon to Drumsna (Section 1) and from Drumsna to the south-eastern tie-in (Section 2). Based on information obtained during the Constraints Study Report a total of eight feasible route corridors were developed taking into account all physical, planning and environmental constraints that were identified. Five are located in Section 1 and three in Section 2.

The following sections provide a general route description, subdivided into discrete sections based on recognisable features in the landscape. For each section an existing environment summary of the topography, surface water features, subsoil geology, bedrock geology, aquifers, karst features and groundwater vulnerability is given.

<u>Route Corridor Option 1.1</u>

Route Corridor Option 1.1 leaves the existing N4 at Cloonmaan (Node F), crossing the River Shannon 0.7 km to the northeast. The ground is low lying across the floodplain, passing through part of the pNHA designated Drumharlow Lough in Corryolus. The topography rises to Portaneoght (Node G) before falling again. Subsoils between Nodes F and G are predominantly Devonian Sandstone Tills overlain by a cover of deep poorly drained mineral Surface Water / groundwater Gleys. A band of Undifferentiated Alluvium associated with the River Shannon, and some Fen Peat around Corryolus are also mapped along the section. The route swings eastwards and then south eastwards to Aghancarra (Node H), crossing two small streams in Cloonsheerevagh and Cornamucklagh that flow southwards towards the River Shannon. Similar Sandstone Till overlain by Gleys with pockets of Fen Peat is mapped along this part of the route. From Aghancarra the corridor passes south eastwards through numerous small low-lying drumlins and crosses five small streams. Subsoils for the initial half of this part are Carboniferous Limestone Tills with the second half predominantly Sandstone Tills. All are overlain by Gleys, with pockets of Fen Peat and Alluvium. Some made ground is present near Drumsna. The route rejoins the existing N4 at Crickeen (Node M), and continues along it to Drumsna (Node B). The whole corridor is underlain by Dinantian Pure Bedded Limestone comprising Undifferentiated Visean Limestone. This rock is classified as a Regionally Important Karstified Aquifer, with conduit permeability. West of the River Shannon the groundwater is mapped as having a moderate vulnerability rating, with the remainder of the corridor predominantly high to low (mapping based on a interim study only). From Aughriman South to Mountcampbell the groundwater has an extreme rating.

<u>Route Corridor Option 1.2</u>

The section is similar to Route Corridor Option 1.1 up to Aghancarra (Node H). It then continues southeast through an area of low drumlins to rejoin the existing N4 at Tully (Node L), crossing four streams. A short distance of Sandstone Till is present south from Node H, with the middle part Limestone Till and then the remainder back in Sandstone Till. These tills are overlain by Surface Water / Groundwater Gleys. Occasional Fen Peat and Alluvium is present. The route follows the existing N4 through woodland bordering the River Shannon to the south, to Crickeen (Node M). The section between Nodes M and B is similar to Route Corridor Option 1.1. The bedrock and aquifer classification along the entire length is similar to Route Corridor

Option 1.1, as is the groundwater vulnerability apart from the extreme rating starting from just south of Greagh.

Route Corridor Option 1.3

The section is similar to Route Corridor Option 1.1 up to Portaneoght (Node G). It sweeps eastwards and the southwards through low-lying drumlins, rejoining the existing N4 at Lisseeghan (Node I). The subsoil for this section of the route is predominantly Sandstone Till overlain by Gleys, with some made ground associated with an old County Council landfill site located to the south of the corridor at Cloonsheebane. A small stream is traversed in Keenaghan, flowing into the River Shannon to the southwest. The route follows the existing N4 southeast to Tully (Nodes K and L). Subsoils along this section are initially Limestone Tills moving into Sandstone Tills, overlain by Gleys. Pockets of Fen Peat and Alluvium are present. The remaining section from Node L to B is similar to Route Corridor Option 1.2. The bedrock and aquifer classification along the entire length is similar to Route Corridor Option 1.1, as is the groundwater vulnerability apart from the extreme rating starting from just west of Tully.

Route Corridor Option 1.4

Route Corridor Option 1.4 leaves the existing N4 at Cuillyconeen (Node E) heading south eastwards through Cortober and then east to cross the River Shannon at Cordrehid. West of the Shannon it crosses three small streams including the Killukin River and associated flood plain. East of the River Shannon the topography rises through Drumkeeran to rejoin the existing N4 at Lisseeghan (Node J). Subsoils along the section to Node J are predominantly Sandstone Tills overlain by Gleys, with Alluvium deposits associated with the streams and River Shannon crossings. A large area of Fen Peat is mapped near Drumkeeran and includes a small pocket of bedrock at or close to surface. The remaining section to Node B is similar to Route Corridor Option 1.3. The bedrock and aquifer classification along the entire length is similar to Route Corridor Option 1.1. Groundwater is mapped as having an extreme vulnerability for the initial section through Tullyleague and Drishoge with some high rating areas. Further eastwards towards the River Shannon it is mostly moderate with a pocket of low vulnerability south of Cortober. East from the River Shannon to Node J an interim study only has been carried out and the groundwater has a high to low vulnerability rating, with a small pocket of extreme. The remainder is similar to Route Corridor Option 1.3.

Route Corridor Option 1.5

Route Corridor Option 1.5 leaves the existing N4 at Cuillyconeen (Node D) heading south to the R370 and then south east to Danesfort, crossing undulating ground and three small streams including the Killukin River. It proceeds eastwards to cross Lough Corry and then rejoins the existing N4 at Tully (Node K) having crossed three small streams. The ground rises slightly around Lisgarney before Tully. Subsoils are predominantly Sandstone Tills overlain by Gleys with pockets of Fen Peat and Alluvium. Some bedrock outcrop or close to surface is mapped south of the R370 and in Killukin. The area to the south of Ballynacleigh is a mixture of Limestone Tills and Fen Peat. The remaining section (Node K to B) is similar to Route Corridor Options 1.3 and 1.4. The bedrock and aquifer classification along the entire length is similar to Route Corridor Option 1.1. Groundwater vulnerability west of the River Shannon is predominantly rated as moderate with large area of extreme bounded by high mapped south of the R370 and in Killukin. East of the River Shannon the groundwater has a high to low rating with the remainder of the corridor similar to Route Corridor Options 1.3 and 1.4.

Route Corridor Option 2.1

Route Corridor Option 2.1 leaves the existing N4 south of Drumsna and runs almost parallel to it approximately 150 m to the east, rejoining just north of the southern tie-in at Faulties. Topography along the route is predominantly low lying characterised by numerous small drumlins. Subsoils from Node B to Gortinty are mostly Sandstone Tills to the north and Fen Peat to the south. The remainder to the southern tie-in is predominantly Limestone Till with some areas of bedrock outcrop or subcrop. The tills are overlain by Gleys. Bedrock southwards from Node B to Drumgira is classified as Dinantian Pure Bedded Limestone comprising Undifferentiated Visean Limestone. This rock is classified as a Regionally Important Karstified Aquifer, with conduit permeability. Relatively equal bands of Ordovician Volcanics (to Aghamore), Dinantian Sandstones (Fearnaght Formation) (to Moher), Ordovician Metasediments (to Fearnaght) and a return to the Sandstones underlie the remainder of the corridor. The Dinantian Sandstones are classified as a Locally Important Aquifer and the Ordovician rocks as a Poor Aquifer. Groundwater vulnerability has been mapped as having a high to low rating south from Node B to Gortinty with the remainder rated as extreme, including pockets of bedrock outcrop or close to surface.

Route Corridor Option 2.2

Route Corridor Option 2.2 is an upgrade of the existing N4 with a slight eastwards diversion around Aghamore, between Nodes O and P. The landscape is characterised by low lying drumlins with a rise towards the south at Aghamore. Subsoil, bedrock, aquifer and groundwater vulnerability classifications are relatively similar to Route Corridor Option 2.1.

Route Corridor Option 2.3

Route Corridor Option 2.3 follows Route Corridor Option 2.2 apart from the section between Nodes O and P running to the west of Aghamore. Subsoil, bedrock, aquifer and groundwater vulnerability classifications are relatively similar to Route Corridor Option 2.1.

Hydrogeological Objective

This section of the Route Corridor Report seeks to assess and evaluate the route corridor options in relation to hydrogeology. Considering the environmental aspects summarised in the previous section, the main criteria that have been used are:

- Risk to the groundwater – addressing the importance and characteristics (including the presence of karst features) of the underlying aquifer and groundwater usage in the form of groundwater protection schemes, group water schemes and private well sources;
- Impact on designated sites – considering the hydrogeological characteristics of each site within the study area and proximity to the individual route corridors; and
- General impact implications road schemes have on the hydrogeological environment.

The report has been prepared by expanding the desk study work carried out for the Constraints Study to look at all available data specifically relating to the selected route corridor options. It includes an assessment of aerial photography reviewing possible ground surface karst features. The desk study details have been verified on the ground by a drive-by survey along each route corridor.

Any areas that have been highlighted as being of potential hydrogeological significance were targeted for walkover surveys in order to assess the significance of any likely environmental impacts on them.

16.4.2 Methodology

Data Sources

The following list of data sources were the main information sources reviewed as part of this route corridor selection report:

Ordnance Survey

- Discovery Series Mapping (1:50,000)
- Six Inch Raster Maps (1:10,560)

Geological Survey of Ireland (GSI)

- Bedrock Geology Mapping
- Aquifer Mapping
- Groundwater Vulnerability Mapping
- Groundwater Source Protection Mapping
- Teagasc Subsoil Classification Mapping
- Well Database
- Karst Features and Tracer Test Database
- Groundwater Protection Schemes (1999). Department of the Environment, Heritage and Local Government (DoEHLG), Environment Protection Agency (EPA) and Geological Survey of Ireland (GSI)
- Geology of Longford and Roscommon: A geological description of Roscommon, Longford, Westmeath, and adjoining parts of Cavan, Leitrim and Galway, to accompany the bedrock geology 1:100,000 scale map series, sheet 12, Longford - Roscommon. GSI 2003
- Geology of Longford – Roscommon Sheet 12. GSI, 1999

Environmental Protection Agency (EPA)

- Teagasc Suboil Cover Classification Mapping
- Teagasc Subsoil Classification Mapping
- Water Quality Monitoring Database and Reports
- Water Framework Directive Classification
- Towards Setting Guideline Values for The Protection of Groundwater in Ireland

Roscommon and Leitrim County Council

- Planning Register
- Roscommon County Development Plan (2002 – 2009)
- Leitrim County Development Plan (2009 – 2015)
- Carrick-on-Shannon Local Area Plan (2008 – 2014)
- Water Services – Abstractions, Discharges & Supply Schemes

National Parks and Wildlife Service (NPWS)

- Designated Areas Mapping

Consultation with Regulatory and Other Bodies

Consultation was held with various departments of Leitrim County Council and Roscommon County Council as well as the GSI.

Field Surveys

A field survey has not been carried out at this stage as the desk study has not identified any key hydrogeological features that would be of concern regarding any of the route corridors. It is recommended that once the preferred corridor has been selected, then a site walkover be conducted to identify any unmapped features and to carry out a domestic well audit of all the properties along the route.

Impact Assessment

In order to assess the relative merits of each of the identified route corridors, an assessment of the likely impact each route will have on the hydrogeological attributes along each route has been made. Consideration has been given to both the importance of the attributes and the predicted scale and duration of the likely impacts.

As only very limited engineering design details and site specific data is available at this stage, much of the preliminary impact assessment is of a qualitative rather than a quantitative nature. A significant degree of professional judgement has therefore been used in identifying and rating the likely impacts. For each route corridor a summary of these associated impacts has been presented in a tabular format.

In relation to likely significant impacts on hydrogeology, each route corridor option has been assessed and rated on the following attributes:

- Bedrock aquifer type;
- Groundwater resources – water supply sources and aquifer / source protection schemes;
- Hydrogeological features – wetland habitats, springs and holy wells;
- Karst features; and
- Aquifer vulnerability.

Comparison of Route Corridors

A comparison of route corridors has been made based on the number and degree of likely impacts and along each corridor. This has established an order of preference from a hydrological perspective.

Where a similar number of likely impacts have been identified then the route corridor which affects the least number of high value attributes has been given preference.

Limitations and Gaps in Available Data

Limitations for this stage of reporting exist in the lack of field and site investigation data for the various route corridors. Most of the conclusions and recommendations have been arrived at through desk study research. Until the final alignment is known it will not be possible to make detailed appraisals regarding how any cut or fill sections will impact on the hydrogeological environs.

16.4.3 Aquifer Type & Classification

Introduction

The GSI has classified geological strata for hydrogeological purposes as one of three principal types:-

- Major (Regionally Important) Aquifers
- Minor (Locally Important) Aquifers
- Unproductive Rocks (Poor Aquifers) or Aquitards.

These are based on the value of the groundwater resource and the hydrogeological characteristics and are further subdivided into ten aquifer categories (Table 16.47) (DELG/EPA/GSI, 1999):-

Table 16.47 Aquifer Types and Categories

Type	Category	Code
Regionally Important Aquifers	Karstified bedrock dominated by diffuse flow	(Rkd)
	Karstified bedrock dominated by conduit flow	(Rkc)
	Fissured bedrock	(Rf)
	Extensive sand & gravel	(Rg)
Locally Important Aquifers	Sand and gravel	(Lg)
	Bedrock which is Generally Moderately Productive	(Lm)
	Bedrock which is Moderately Productive only in Local Zones	(Ll)
	Locally important karstified bedrock	(Lk)
Poor Aquifers	Bedrock which is Generally Unproductive except for Local Zones	(Pl)
	Bedrock which is Generally Unproductive	(Pu)

The Water Framework Directive (WFD) provides for the protection, improvement and sustainable use of waters, including rivers, lakes, coastal waters, estuaries and groundwater within the EU Member States. It aims to prevent deterioration of these water bodies and enhance the status of aquatic ecosystems; promote sustainable water use; reduce pollution; and contribute to the mitigation of floods and droughts. Member States must aim to achieve 'good' status in all waters by 2015, and must ensure that the status does not deteriorate in any waters.

Under the WFD large geographical areas of aquifer have been subdivided into smaller groundwater bodies (GWB) in order for them to be effectively managed. In 2005, all of the GWBs were assessed and given a score based on the likelihood of them achieving an objective of good status by 2015 (Table 16.48).

Table 16.48 WFD Aquifer Status Classification

Score	Description
1a	At risk of failing to meet the objective of good status in 2015
1b	At risk of failing to meet the objective of good status in 2015 pending further investigation
2a	Expected to meet the objective of good status in 2015 pending further investigation
2b	Expected to meet the objective of good status in 2015

The GWB boundaries are delineated on the EPA website mapping section that also indicates the rating score. A hydrogeological summary description for each is available from the GSI website.

Aquifers in Study Area

There are four bedrock units defined within the study area. The area to the northwest of Drumgilra is underlain by Dinantian Pure Bedded Limestone comprising Undifferentiated Visean Limestone. This is the most predominant unit, covering approximately 26.54 km^2 (88.93%) of the study area. These rocks are classified as a Regionally Important Karstified Aquifer, with conduit permeability (Rfc). For the WFD the aquifer has been identified as the Carrick-on-Shannon GWB, with two separate units present within the study area. The north eastern part of the study area, located to the east of the River Shannon and north of a line between the Townlands of Tully, Minkill, Lisdaulry and Liscallyroan is within the Carrick-on-Shannon 2 Aquifer. The remaining area south of this line to Drumgilra, and west of the River Shannon in the western section of the area lies within the main Carrick-on-Shannon 2 Aquifer. Both of these units were assessed in 2005 as being at risk of failing to meet the WFD objective of good status in 2015.

A short section of the southern part of the study area between Drumgilra and Aghamore is underlain by Ordovician Volcanics, covering approximately 0.97 km^2 (3.25%) of the area. This is classified as a Poor Aquifer, were the bedrock is generally unproductive except for local zones (Pl). Under the WFD classifications of aquifers these rocks are identified as the Kilglass Dromod aquifer. The 2005 assessment indicated that the water body is expected to meet the objective of good status in 2015 pending further investigation.

Between Aghamore and Moher, and from Fearnaght to the southern tie-in at Faulties the bedrock is identified as Dinantian Sandstones (Fearnaght Formation). This unit covers approximately 1.30 km^2 (4.37%) of the area and is classified as a Locally Important Aquifer where the bedrock is generally moderately productive (Lm).

Between Moher and Fearnaght covering approximately 1.03 km^2 (3.45%) the bedrock is Ordovician Metasediments, a Poor Aquifer, were the bedrock is generally unproductive except for local zones (Pl).

Both the Dinantian Sandstones and Ordovician Metasediments are within the same GWB identified as Scramoge North. This is expected to meet the objective of good status in 2015.

The bedrock aquifer maps published on the GSI website have been used to assess the proportion of the route corridors overlying each type of aquifer. As the mapped unit boundaries need to be confirmed on the ground the calculated percentages are given as approximate.

All of the options within Section 1 are underlain by a Regionally Important Aquifer (Table 16.49).

Table 16.49 Percentage of Aquifer Type within Each Route Corridor Option in Section 1

Section 1 Nodes	Route Corridor Options (Km)					Construction	Aquifer Types (Km)		
	1.1	1.2	1.3	1.4	1.5		Rkc	Lm	Pl
FG	2.30	2.30	2.30			Offline	2.30	0.00	0.00
GH	2.42	2.42				Offline	2.42	0.00	0.00
GI			4.03			Offline	4.03	0.00	0.00
HL		3.27				Offline	3.27	0.00	0.00
HM	4.84					Offline	4.84	0.00	0.00
EJ				4.91		Offline	4.91	0.00	0.00
DK					7.83	Offline	7.83	0.00	0.00
IB			4.98			Online	4.98	0.00	0.00
JB				4.93		Online	4.93	0.00	0.00
KB					3.58	Online	3.58	0.00	0.00
LB		2.72				Online	2.72	0.00	0.00
MB	0.98					Online	0.98	0.00	0.00

The three main types of aquifer are represented within the study area Section 2. The north western part is underlain by a Regionally Important Aquifer (40.55%), the central and portion to the south east by a Poor Aquifer (36.00%) and the remainder within the south half a Locally Important Aquifer (23.45%). The proportion underlying each Route corridor option and total route length is presented in Table 16.50.

Table 16.50 Percentage and Route Length of Aquifer Type Within Each Route Corridor Option in Section 2

Section 2 Nodes	Route Corridor Options (Km)			Aquifer Types					
	2.1	2.2	2.3	Rkc		Lm		Pl	
				(km)	(%)	(km)	(%)	(km)	(%)
BN	0.24			0.24	100.00	0.00	0.00	0.00	0.00
BO		3.00	3.00	3.00	100.00	0.00	0.00	0.00	0.00
NC	6.67			2.69	40.33	1.50	22.49	2.48	37.18
OP (east)		1.93		0.09	4.66	0.86	44.56	0.98	50.78
OP (west)			1.93	0.09	4.66	0.61	31.61	1.23	63.73
PC		2.53	2.53	0.00	0.00	1.19	47.04	1.34	52.96

To compare the various route corridors in Section 1, as all are underlain by a similar aquifer, the length of each route has been used, with the shortest having the highest preference considering the sensitivity of the aquifer (Table 16.51).

Table 16.51 Order of Preference Relating to Aquifer Type over Section 1

Section 1 Nodes	Length (Km)	Route Corridor Options (Km)				
		1.1	1.2	1.3	1.4	1.5
FG	2.30	10.54	10.71	11.31	9.84	11.41
GH	2.42					
GI	4.03					
HL	3.27					
HM	4.84					
EJ	4.91					
DK	7.83					
IB	4.98					
JB	4.93					
KB	3.58					
LB	2.72					
MB	0.98					
Order of preference		2nd	3rd	4th	1st	5th

Note: Lengths do not include section of Hughestown Meera from Node A. (see Table 5.1)

To compare the various options within Section 2, an order of preference has been assigned to each aquifer type i.e. 1 for the most preferable (Pl), 2 for Lm and 3 of Rkc. The length of route overlying each type has then been multiplied by this factor to give a relative total that can be used to rank the combinations (Table 16.52).

Table 16.52 Order of Preference Relating to Aquifer Type over Section 2

Section 2 Nodes	Length (Km)	Aquifer Type Rating			Total	Route Corridor Options		
		Rkc	Lm	Pl		2.1	2.2	2.3
BN	0.24	0.72	0.00	0.00	0.72	14.27 (1st)	15.69 (3rd)	15.44 (2nd)
BO	3.00	9.00	0.00	0.00	9.00			
NC	6.67	8.07	3.00	2.48	13.55			
OP (east)	1.93	0.27	1.72	0.98	2.97			
OP (west)	1.93	0.27	1.22	1.23	2.72			
PC	2.53	0.00	2.38	1.34	3.72			

16.4.4 Aquifer Characteristics

Recharge

Aquifer recharge refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and is assumed to consist of input (i.e. annual rainfall) less water losses prior to entry into the groundwater system (i.e. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is important in source protection delineation as it is used to estimate the size of the zone of contribution (i.e. the outer source protection area) (GSI, 2003b). Point recharge occurs within the study area via swallow holes and collapse features associated with the karstified limestone. Diffuse recharge occurs over the entire area via rainfall percolating through the subsoil.

Mean annual rainfall in Roscommon for the 1961 to 1990 period varied from 900 to 1000 mm in the lower lying southern and eastern areas of the county, and from 1000 to 1200 mm in the higher northern and western regions (Fitzgerald and Forrestal, 1996).

As there are no Met Eireann synoptic weather stations within the county the mean annual potential evapotranspiration (PE) has been calculated based on data available from the nearest stations located at Claremorris, Mullingar and Birr. This gives an estimated rate of approximately 400 to 450 mm per annum, with the actual evapotranspiration estimated at about 90 to 95 % of the PE (GSI and Roscommon County Council, 2003).

Potential recharge representing an estimation of the excess soil moisture available for either vertical downward flow to groundwater or lateral flow through soil and overland flow to surface water is restricted in many areas due to the cover of low permeability till, which also reduces the groundwater vulnerability. The mean annual potential recharge (rainfall minus actual evaporation) for County Roscommon is estimated to be in the range of 500 to 800 mm, with the lowest levels in the low-lying areas in the south and east. The actual annual recharge to the groundwater depends on the relative rates of infiltration and surface runoff. In many areas the recharge is likely to be as low as 25% of the potential recharge (GSI, 2003b).

<u>Carrick-on-Shannon GWB</u>

Both point and diffuse recharge occur in this GWB. Swallow holes and collapse features provide the means for point recharge. Diffuse recharge will occur over the entire GWB via rainfall percolating through the subsoil. Where the GWB is covered by 'low' permeability subsoil this can restrict percolation of recharge and increase runoff. Despite the presence of peat and low permeability till, point recharge to the underlying aquifer still occurs by means of swallow holes and collapse features / dolines. Dolines have been recorded even in areas of thick peat deposits. In areas where point recharge is common and / or subsoils are relatively thin, groundwater generally shows a rapid response to recharge. Where gravels overlie the karstic aquifer they provide a permeable pathway for recharge to the underlying karstic aquifer, and can also act to augment storage (GSI 2003e).

<u>Kilglass Dromod GWB</u>

Recharge is diffuse, with most occurring on the higher ground in the southeast of the body where the subsoil thickness is thinnest (GSI 2003f).

<u>Scramoge North GWB</u>

Diffuse recharge will occur over the entire groundwater body via rainfall soaking through the subsoil. The proportion of effective rainfall that recharges the aquifer is largely dependant on the thickness and permeability of the soil and subsoil, and on the slope. Within the Roscommon area percolation of recharge will be restricted by the 'low' permeability subsoils that occur within the body. Detailed mapping is not available for Leitrim (GSI 2003d).

Flow and Storage

Visean Limestones (Carrick-on-Shannon GWB)

Karst features are abundant and widespread through this aquifer, influencing potential flow and storage capacity. Most of the groundwater flows in an epikarstic layer a couple of metres thick and in a zone of interconnected solutionally enlarged fissures and conduits that extends approximately 30m below this layer. Deeper inflows can occur in areas associated with faults or dolomitisation.

There is a notable interconnection between surface water and groundwater in particular on the higher topographic areas such as east of Boyle where the ground is frequently devoid of streams and surface runoff is drained through the numerous karst features including swallow holes, caves and enclosed depressions. Flow paths can be several kilometres in length and are usually extremely complex and difficult to predict, not necessarily following the assumed groundwater table contours. Several turloughs are also present resulting from the up-welling of winter groundwater levels through springs and estavelles.

Localised groundwater flow through solutionally enlarged conduits and fissures is evident from various geophysical work and tracer tests carried out by the GSI. Rapid velocities of large volumes have been recorded in several tracer tests including flow rates of 218 and 279 m/hr to the Rockingham Springs (GSI, 2003c). The conduit flow and frequently associated large springs often result in the bedrock having a relatively low storage capacity with rapid flow in response to rainfall events.

Transmissivity in karstified aquifers with conduit flow can range up to a few thousand m^2/d. A pumping test carried out at Ballinlough estimated a bulk transmissivity of between 80 m^2/d and 90 m^2/d although the transmissivity of the associated intensely fractured zone is estimated as 400 m^2/d (K.T. Cullen & Co., 1999).

Within the study area the general groundwater flow is likely to be towards the River Shannon. The karstic nature of the bedrock results in very variable localised flow directions.

Wells in these rocks should have (or be capable of having) a large number of 'excellent' yields, in excess of approximately 400 m^3/d (4000 gph). Table 16.53 gives a summary of well productivity and yield categories in this Regionally Important Karstified Aquifer in County Roscommon (GSI, 2003b):

Table 16.53 Summary of Regionally Important Karstified Aquifer yields within County Roscommon

Well productivity index					Well yield (m^3/d)					Spring yield (m^3/d)	
I	II	III	IV	V	E (>400)	G (400-100)	M (100-40)	P (<40)	F (<3)	H	I
5	2		5	7	9	13	2	9	3	7	11

where the well yields are excellent (E), Good (G), Moderate (M), Poor (P) or Fail (F); the spring yields are High (H) or Intermediate (I). No data was available for County Leitrim.

Fearnaght Formation (Scramoge North GWB)

No data is available for well productivities or yields within this Locally Important Aquifer. Stratigrahically, the Fearnaght sandstone sits unconformably on much less permeable Lower Palaeozoic (Ordovician) rocks, and beneath thin bands of the Meath Formation and Moathill Formation rocks which are also less permeable. This would indicate that the sandstone aquifer is likely to form a more permeable pathway for groundwater flow within these strata, and the rock's clean sandstone lithology suggests a potentially highly permeable aquifer (GSI, 2003e).

Groundwater flow is expected to be concentrated in fractures and weathered zones and in the vicinity of fault zones. The dominant sandstone lithology and lack of shale will generally result in a higher frequency of more open fractures and, consequently, higher fissure permeability. Where there has been more intense faulting and folding these zones of high permeability will be more common. Because of the nature of the lithology, the degree of interconnection of fissures is expected to be relatively high, enabling an element of regional groundwater flow. The direction of flow is likely to be in a north westerly direction towards the Carrick-on-Shannon GWB. Flow path lengths can be as long as 0.5 to 2 km in length.

Ordovician Metasediments (Scramoge North GWB)

No data on the hydrogeological properties specific to this Poor Aquifer are available. The rocks would however be expected to have a much lower transmissivity than the overlying Dinantian Sandstones.

Ordovician Volcanics (Kilglass Dromod GWB)

No data on hydrogeological properties specific to this GWB are available. The Ordovician Metasediments of the southwestern segment of the GWB are considered to be a Poor Aquifer. From experience in other areas of Ireland transmissivity values for Ordovician Metasediments similar to those found in this GWB range from 5 to 20 m^2/d, with the median value in the lower end of the range.

These rocks are devoid of intergranular permeability; groundwater flow occurs in fractures and faults. Permeability is highest in the upper few metres of bedrock, but decreases rapidly with depth. In general groundwater flow is concentrated in the upper 15 m of the aquifer. Local zones of high permeability can be encountered near fault zones and in areas of intensive fracturing. Groundwater flow in this body will be of a local nature with flow paths generally short, discharging to small springs, or to the streams and rivers that traverse the aquifer. Flow directions are expected to follow the local surface water catchments.

Hydraulic Conditions

As groundwater percolates downwards through the substrata the underlying aquifer becomes saturated. At the surface level of saturation the groundwater table or phreatic surface is formed. This may slope steeply and often mirrors the overlying topography, generally falling towards the nearest free water surface such as a lake, river of sea. Its stability is dependant on the supply of water from above, falling under dry summer conditions and rising through the wetter winter months.

Where there is an impermeable layer underlying the aquifer and this layer outcrops at the ground surface, then the groundwater will flow at the surface in a seepage zone of spring. When the aquifer is overlain by an impermeable layer it is subject to pressure. When this occurs with the groundwater being fed from a distance it becomes a confined aquifer, with the surface level to which the groundwater table would rise to if allowed termed as the piezometric surface.

Carrick-on-Shannon GWB

Groundwater in the Carrick-on-Shannon GWB is generally unconfined. Discharge is mainly to the streams and rivers crossing the body and to large springs found within it. In winter groundwater will also discharge to the numerous turloughs found throughout the area.

Scramoge North GWB

Groundwater in the Scramoge North GWB is generally unconfined. Discharges will be in the form of baseflow to the streams crossing the GWB, to Loughs Boderg and Bofin and to the adjoining karstic Carrick-on-Shannon GWB to the northwest.

Ordovician Metasediments (Scramoge North GWB)

Groundwater is generally unconfined in this GWB. Discharge will be to the small streams crossing the body, and to the adjoining Carrick-on-Shannon GWB.

Ordovician Volcanics (Kilglass Dromod GWB)

Groundwater is generally unconfined in this GWB but can become partially confined beneath low permeability subsoils.

Artesian Conditions

When boreholes are drilled into confined aquifers, they become artesian wells. If the piezometric surface within the 'artesian aquifer' is above the ground surface elevation then the artesian well is termed a 'flowing well', and a fracture or flaw in the impermeable overlaying material will in such conditions result in an artesian spring.

Occasionally a small area of impermeable material exists in a large aquifer, which may have resulted through geological faulting, or perhaps from the formation of a lens of clay occurring in an otherwise sandy glacial drift. A localised groundwater table, known as a perched groundwater table may result which may often be considerably above the actual true phreatic surface level.

A survey of the wells within the study area to assess the presence of artesian conditions has not been carried out as part of this phase of the study to assess the presence of any artesian conditions.

Groundwater Quality

In karst areas with thin overlying subsoils, the water quality can be affected due to rapid throughflow of groundwater to springs and boreholes. Water quality within the limestone aquifers is variable with over half of the Group Water Schemes in County Roscommon showing some degree of bacteriological contamination from faecal coliforms (GSI, 2003). The water is usually hard, around 300 mg/l as $CaCO_3$. Springs can also be susceptible to high concentrations of suspended solids due to surface runoff (GSI, 1997).

The 'Roscommon County Council Rural Water Monitoring Project', assessed the water quality in group water schemes for the period from March 1999 to March 2000 inclusive. The assessment revealed that many schemes were supplying drinking water of a much lower standard than that specified in European Communities

(Quality of Water Intended for Human Consumption) Regulations, 1988. The following extract from the County Council website summarises the results:

"For presumptive total coliforms it was found that only 2 out of a total of 65 sources consistently had zero presumptive total coliforms thus indicating that all except 2 sources require disinfection.

For presumptive faecal coliforms, it was found that 58% of samples taken from private schemes and 4% of samples from semi-private schemes tested positive.

Excessive levels of colour were observed for 22 out of a total of 61 sources over the study period. Out of a total of 64 sources, 24 exceeded the limit for turbidity, at least once during the study period. High turbidity in water can also cause problems in water treatment, by making disinfection difficult.

Iron, manganese and to a lesser extent aluminium were also present in excessive levels in some waters-18.2% of source samples exceeded the national limit for iron, 21.1% of source samples exceeded the national limit for manganese and 7.7% exceeded the national limit for aluminium.

Results for pH in all, except 3 samples, were within the required range for pH in potable waters and was not a cause for concern.

During the study period 4 samples from 3 different sources exceeded the national limit for nitrite-a possible indication that water is organically polluted. It was found that 6 private sources, all ground waters, exceeded the national limit value for ammonia-indicating a nearby source of organic pollution. Results for nitrate, phosphorus, and heavy metals were not a cause for concern. 41% of private scheme samples and 3% of semi-private samples had no chlorine residual."

Water samples from 28 Public Group Schemes in County Roscommon indicated a dominance of bicarbonate and calcium ions, with the total hardness ranging from hard (250 to 350 mg/l $CaCO_3$) to very hard (>350 mg/l $CaCO_3$), and a generally neutral pH value. Alkalinity was generally less than hardness and typical electrical conductivities ranged from 500 to 700 µS/cm.

No EPA listed and monitored groundwater supplies are present within the study area, and site specific groundwater quality data was not available for this study.

<u>Carrick-on-Shannon GWB</u>

The hydrochemistry of the carbonate rocks, especially pure limestones, is dominated by calcium and bicarbonate ions. Hardness can vary from slightly hard to very hard (typically ranging between 380 to 450 mg/l). Spring waters tend to be softer, as throughput is often quicker with less time for the dissolution of minerals into the groundwater. Alkalinity is variable, but can be high and is generally less than hardness indicating that ion exchange (where calcium or magnesium are replaced by sodium) is not a significant process.

These hydrochemical signatures are characteristic of clean limestone and are frequently associated with lime-scale issues. Electrical conductivities (EC) in limestone can vary greatly with typical values in the order of 500 to 700 µS/cm. Lower values suggest that groundwater residence times are very short.

In some springs and boreholes in karst areas, high turbidity occurs after heavy rainfall. This is caused where sediment that has collected in fissures and cavities is washed out at the start of recharge events, and where there is a direct link between the source and a swallow hole into which surface water containing sediment is flowing.

Microbial pollution is also a significant problem, and due to the high level of interaction between groundwater and surface water in karstic aquifers, pollution can travel very quickly from the surface into the groundwater system. The normal filtering and protective action of the subsoils is often bypassed due to the number of swallow holes, dolines and large areas of shallow rock.

Scramoge North GWB

No relevant hydrochemical data are available in this GWB for assessment.

Kilglass Dromod GWB

Groundwaters from Ordovician Metasediments elsewhere in the country have been found to be quite variable in hydrochemistry. Hardness ranged from 'soft' to 'moderately hard', with a hydrochemical signature of calcium bicarbonate to calcium magnesium bicarbonate. The chemistry can be influenced by the mineralogy of the subsoil, with some areas showing slightly higher hardness and alkalinity, where the overlying tills include limestone clasts which chemically alter the recharging waters.

16.4.5 Aquifer Vulnerability

Groundwater Vulnerability and Guidelines

The risk to groundwater is defined through assessments of groundwater vulnerability, aquifer potential and source protection areas. Vulnerability represents the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities. It depends on the:

- time of travel of infiltrating water (and contaminants);
- relative quantity of contaminants that can reach the groundwater; and
- contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate (DELG/EPA/GSI, 1999).

The above are a function of the following natural attributes of any area:

- type and permeability of the subsoils that overlie the groundwater;
- thickness of the unsaturated zone through which the contaminant moves; and
- recharge type, whether point or diffuse.

As all groundwater is hydrologically connected to the land surface which is receiving the contaminants, the land can therefore be categorised based on the nature of the protecting geological layers between the ground surface and groundwater and the potential of bypassing these layers.

GSI guidelines as outlined in the Groundwater Protection Schemes publication (DELG/EPA/GSI, 1999) define four vulnerability categories: extreme, high, moderate and low. These can be combined with site investigation data i.e. the geological and hydrogeological characteristics to obtain appropriate groundwater vulnerability ratings for any particular area, as outlined below (Table 16.54).

Table 16.54 Groundwater Vulnerability Assessment Criteria (DoELG, EPA, GSI – 1999)

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)	(< 30m radius)
Extreme (E)	0 – 3.0m	0 – 3.0m	0 – 3.0m	0 – 3.0m	n/a
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:	n/a = not applicable. Precise permeability values cannot be given at present. Release point of contaminants is assumed to be 1-2m below ground surface.				

The GSI mapping indicates the vulnerability of the groundwater closest to the ground surface, to contaminants released at depths of 1 to 2 m. It is used for guidance only and should be supported by site investigation, and contaminant specific assessments where appropriate. In unsaturated bedrock aquifers the target for protection is the groundwater table within the bedrock unit, and for saturated aquifers it is the top of the bedrock.

In karst areas groundwater is particularly vulnerable to contamination with an extreme rating as:-

- Water can move rapidly through fissures widened by solution;
- Sinking streams provide direct water entry points to groundwater, with little or no filtration or attenuation of contaminants;
- Solution hollows or dolines may also provide direct entry route corridors through vertical shafts; and
- The characteristic soil cover over karst limestone is very thin, maybe only a few centimetres deep, and so provides little protection (GSI, 2002).

Vulnerability Mapping

<u>Groundwater vulnerability within study area</u>

The GSI has mapped most of the study area lying to the west of the River Shannon as having a moderate groundwater vulnerability rating. Two fingers of extreme vulnerability surrounded by high vulnerability extend north eastwards from Killukin along the R368 towards Cortober and from Knockananima to Tullyleague.

The north eastern part of the study area, located to the east of the River Shannon and north of a line between the Townlands of Tully, Minkill, Lisdaulry and Liscallyroan (Carrick-on-Shannon 2 Aquifer) is given a high to low rating as only an interim study has been carried out. Apart from the high to low section between Crickeen and Derryoughter the remainder of the area to the southeast is mapped as having an

extreme vulnerability with numerous large areas of bedrock outcrop or subcrop present.
The GWB summary of initial characterisation for the various aquifers identified under the WFD assessment that have been prepared by the GSI were reviewed to obtain the following details on groundwater vulnerability within each of the GWBs that are present within the study area.

The GSI groundwater vulnerability maps available for County Roscommon were then queried to obtain details on the vulnerability ratings specific to each corridor. Mapping details were also obtained from the GSI online groundwater maps section.

Carrick-on-Shannon GWB

There are large areas of extreme vulnerability within this body, including areas around Frenchpark, northwest of Strokestown and in the southwest of the body. Areas in the vicinity of swallow holes and dolines (which allow point recharge) are designated as extremely vulnerable. Some swallow holes and dolines occur in areas of reasonably thick peat cover (6 to 9 m). The main areas of moderate and low vulnerability are concentrated in the extreme west of the body, just west of the centre of the body near the Castlerea Bellanagare GWB, southwest of Carrick on Shannon and in the east of the body around Kilglass Lough.

Scramoge North GWB

Most of the GWB is in an area of extreme vulnerability, particularly in the south of the body, and on higher ground. Areas of high vulnerability skirt the extreme vulnerability areas. In more low lying areas where subsoil thickness is greater there are areas of moderate and low vulnerability.

Kilglass Dromod GWB

In County Leitrim where a groundwater vulnerability map is not currently available, there will be areas of extreme vulnerability in the vicinity of rock outcrop and shallow rock in this GWB. Areas of cut peat would be expected to have moderate or low vulnerability due to the peat cover and the underlying lacustrine clay and marl that are generally found beneath large areas of peat in this region, however the vulnerability rating will be dependant on the thickness of the subsoil.

<u>Route Corridor Assessment Methodology</u>

To assess the level of vulnerability present in each of the corridors relative to each other, the GSI groundwater vulnerability maps have been used to calculate an approximate area covered by each category (Tables 16.55 & 16.56).

The methodology and results are for guidance only as there is likely to be some degree of variance in the calculation of areas, and the accuracy of the mapping. Site investigation data when available for the preferred route corridor can be used to re-assess the vulnerability ratings, and considerations will need to be given to whether the alignment is in cut or fill as this will influence the ratings.

Table 16.55 Groundwater Vulnerability for Route Corridor Options within Section 1

Section 1 Nodes	Route Corridor Options					Groundwater Vulnerability (m2)				
	1.1	1.2	1.3	1.4	1.5	Extreme	High	Moderate	Low	High to Low
FG	2.30	2.30	2.30			0	0	65526	4312	15432
GH	2.42	2.42				3004	0	0	0	244921
GI			4.03			15760	0	0	0	386943
HL		3.27				94899	0	0	0	246364
HM	4.84					150678	0	0	0	324198
EJ				4.91		0	0	81012	4312	15432
DK					7.83	98077	58078	326974	0	290270
IB			4.98			235691	0	0	0	278948
JB				4.93		235691	0	0	0	270117
KB					3.58	192366	0	0	0	160597
LB		2.72				119068	0	0	0	160597
MB	0.98					0	0	0	0	109030

Table 16.56 Groundwater Vulnerability for Route Corridor Options within Section 2

Section 2 Nodes	Route Corridor Options			Groundwater Vulnerability (m2)				
	2.1	2.2	2.3	Extreme	High	Moderate	Low	High to Low
BN	0.24			0	0	0	0	18545
BO		3.00	3.00	121498	0	0	0	168982
NC	6.67			516721	0	0	0	144912
OP(east)		1.93		179791	0	0	0	3532
OP(west)			1.93	179209	0	0	0	0
PC		2.53	2.53	216770	0	0	0	0

The percentage of aerial cover has been multiplied by the order of preference i.e. a low vulnerability rating which would be most preferable is assigned a value of 1, moderate 2, high 3 and extreme 4 (Tables 16.57 and 16.58). The areas mapped as high to low based on an interim study by the GSI have been given an average multiplier factor of 2. The overall total for each route can then be assigned a corridor rank in respect to vulnerability.

Table 16.57 Percentage of Cover and Preferential Rating for Each Route Corridor Options within Section 1

Section 1 Nodes & Corridors	Approx Area (m^2)	Groundwater Vulnerability					Rating Total	Rank
		Extreme	High	Moderate	Low	High to Low		
FG	85270	0.00%	0.00%	76.85%	5.06%	18.10%	1.95	
GH	247925	1.21%	0.00%	0.00%	0.00%	98.79%	2.02	
GI	402703	3.91%	0.00%	0.00%	0.00%	96.09%	2.08	
HL	341263	27.81%	0.00%	0.00%	0.00%	72.19%	2.56	
HM	474876	31.73%	0.00%	0.00%	0.00%	68.27%	2.63	
EJ	100756	0.00%	0.00%	80.40%	4.28%	15.32%	1.96	
DK	773399	12.68%	7.51%	42.28%	0.00%	37.53%	2.33	
IB	514639	45.80%	0.00%	0.00%	0.00%	54.20%	2.92	
JB	505808	46.60%	0.00%	0.00%	0.00%	53.40%	2.93	
KB	352963	54.50%	0.00%	0.00%	0.00%	45.50%	3.09	
LB	279665	42.58%	0.00%	0.00%	0.00%	57.42%	2.85	
MB	109030	0.00%	0.00%	0.00%	0.00%	100.00%	2.00	
1.1	153682	16.76%	0.00%	7.14%	0.47%	75.63%	2.33	1st
1.2	216971	22.74%	0.00%	6.87%	0.45%	69.94%	2.45	2nd
1.3	251451	25.08%	0.00%	6.54%	0.43%	67.95%	2.50	3rd
1.4	235691	38.86%	0.00%	13.36%	0.71%	47.08%	2.77	5th
1.5	290443	25.79%	5.16%	29.03%	0.00%	40.03%	2.57	4th

Table 16.58 Percentage of Cover and Preferential Rating for Each Route Corridor Options within Section 2

Section 2 Nodes & Corridors	Approx. Area (m^2)	Groundwater Vulnerability					Rating Total	Rank
		Extreme	High	Moderate	Low	High to Low		
BN	18545	0.00%	0.00%	0.00%	0.00%	100.00%	2.00	
BO	290480	41.83%	0.00%	0.00%	0.00%	58.17%	2.84	
NC	661633	78.10%	0.00%	0.00%	0.00%	21.90%	3.56	
OP(east)	183323	98.07%	0.00%	0.00%	0.00%	1.93%	3.96	
OP(west)	179209	100.00%	0.00%	0.00%	0.00%	0.00%	4.00	
PC	216770	100.00%	0.00%	0.00%	0.00%	0.00%	4.00	
2.1	680178	75.97%	0.00%	0.00%	0.00%	24.03%	3.52	3rd
2.2	690573	75.02%	0.00%	0.00%	0.00%	24.98%	3.50	1st
2.3	686459	75.38%	0.00%	0.00%	0.00%	24.62%	3.51	2nd

There is very little difference between the options in both sections, with a slight preference given to route corridor options 1.1 and 2.2. Considering the whole length of the scheme between both Section 1 and 2, the most preferential route combination in respect to groundwater vulnerability is 1.4 and 2.3 (Table 16.59).

Table 16.59 Preferential Rating for Each Route Corridor Options Combination Relating to Groundwater Vulnerability

Route Corridor Option Combination	Node Order (Northwest to Southeast)	Extreme	High	Moderate	Low	High to Low	Total	Rank
		4	3	2	1	2		
1.4 – 2.3	ADEFJKLMB NOPC	1.65	0.13	0.48	0.00	0.61	2.813	1st
1.4 – 2.1	ADEFJKLMB NC	1.70	0.11	0.40	0.00	0.67	2.825	2nd
1.4 – 2.2	ADEFJKLMB NOPC	1.78	0.10	0.36	0.00	0.68	2.829	3rd
1.2 – 2.3	ADEFGHLM BNOPC	2.02	0.08	0.18	0.03	0.70	2.869	4th
1.3 – 2.3	ADEFGIJKL MBNC	2.03	0.08	0.18	0.03	0.69	2.883	5th
1.1 – 2.3	ADEFGHMB NOPC	2.17	0.09	0.19	0.03	0.61	2.884	6th
1.2 – 2.2	ADEFGHLM BNOPC	1.80	0.00	0.09	0.00	1.00	2.887	7th
1.3 – 2.3	ADEFGIJKL MBNOPC	1.93	0.00	0.10	0.00	0.93	2.887	7th
1.5 – 2.1	ADKLMBNC	1.80	0.00	0.10	0.00	1.00	2.898	9th
1.2 – 2.2	ADEFGHMB NOPC	1.77	0.00	0.10	0.00	1.01	2.900	10th
1.5 – 2.2	ADKLMBNO PC	1.78	0.00	0.10	0.00	1.01	2.923	11th
1.5 – 2.3	ADKLMBNO PC	1.77	0.00	0.10	0.00	1.01	2.964	12th
1.2 – 2.1	ADEFGHLM BNC	1.66	0.00	0.10	0.00	1.07	3.011	13th
1.1 – 2.1	ADEFGHMB NC	1.66	0.00	0.10	0.00	1.06	3.015	14th
1.3 – 2.2	ADEFGIJKL MBNOPC	1.63	0.00	0.12	0.00	1.06	3.083	15th

16.4.6 Karst Landscape & Features

Characteristics of Karst Landscape

Karst is a term used to describe the distinctive landforms that develop on rock types that are readily dissolved by water. In Ireland, limestone (composed of calcium carbonate) and to a lesser extent dolomite (calcium and magnesium carbonate) are by far the most widespread rocks that show karst features. Typically, karst regions lack rivers and other surface waters because the rain is swallowed up by fissures and conduits in the rock and then flows as underground streams in caves. Eventually the waters return to the land surface, often as large springs. Karst areas are indicated by a general absence of permanent surface streams and the presence of swallow holes and enclosed depressions. The water is usually all underground in solutionally enlarged channels, some of which are big enough to be termed caves (GSI, 2002).

Thus a mature karst landscape is devoid of surface water, and the surface may be pitted with deep hollows, conical or saucer shaped, and sometimes hundreds of metres deep and several kilometres in diameter. These dolines (small to medium sized enclosed depressions) act as funnels, collecting rainwater and leading it underground into cave systems.

Formation of Karst Features

Rain water, slightly acidic (carbonic acid) readily dissolves limestone rock. As it infiltrates through soil material it becomes more acidic increasing the capability to dissolve a greater quantity of rock. The water trickles down through cracks in the limestone, progressively enlarging them, which allows a greater quantity of water to enter forming fissures. In time, the fissures are sufficiently enlarged to engulf all rainwater within moments of its falling. In some areas, rivers which rise on non-limestone rocks flow on to the limestone and sink underground in swallow holes. Underground, the waters from fissures unite to form small streams and these in turn join and excavate correspondingly large conduits. Conduits accessible to humans are termed caves. At some point the underground waters return to the surface as springs, except where local geological conditions may cause the waters to emerge from the sea bed some distance off-shore. Caves and karst fissures are common at shallow depths beneath the ground surface but they are also known to exist at great depths (GSI, 2002).

Implications for Road Schemes

Karst regions may provide particular problems for engineering works associated with major road and bridge construction. These problems mainly arise from the unpredictable occurrence, extent and depth of underground cavities which may lead to subsequent road subsidence and inadequate foundation support for bridge structures.

An important feature of karst areas is the absence of surface water which often leads to groundwater being the main source of supply (GSI, 2002). The presence of private well supplies in the vicinity of the road development is therefore important regarding potential impacts to water quantity and in particular to the quality of the water that has an increased vulnerability to contamination.

Karst in Study Area

The GSI karst database was queried regarding the presence of karst features. Only 1 feature, Toberconellan Spring (GSI Code 1729SEK002) was identified within the study area. Details are presented below in Section 16.4.7. Numerous features are recorded further west and associated with the 'Plains of Boyle'.

It is important to note that there are likely to be further unmapped features present on the ground, as well as underground features.

16.4.7 Groundwater Resources

Wetland Habitats

During the construction phase of a road scheme there may be a requirement for cut sections to be dewatered which could potentially impact on the hydrogeological regime of any nearby wetland habitats. The road itself may act as a 'barrier' within groundwater flow pathways. Recharge may also be impacted where fill sections impede surface runoff entering the underlying aquifer.

Under European and Irish law, the Department of the Environment, Heritage and Local Government is responsible for the designation of conservation sites in Ireland. There are three main types of designation:

- Natural Heritage Area (NHA). This is the basic designation for wildlife, and is an area considered important for the habitats present or which holds species of plants and animals whose habitat needs protection. Listed sites that were published on a non-statutory basis in 1995, but have not since been statutorily proposed or designated are regarded as proposed NHA i.e. pNHA. The GSI is compiling a list of geological / geomorphological sites in need of protection with the list of karst and early fossil sites available to date. Under the Wildlife Amendment Act (2000), NHAs are legally protected from damage from the date they are formally proposed for designation.
- Special Area of Conservation (SAC). This is regarded as a prime wildlife conservation area in the country, and considered to be important on a European as well as Irish level. SACs are selected and designated under the EU Habitats Directive, which is transposed into Irish law as the European Union (Natural Habitats) Regulations, 1997, amended in 1998 and 2005. The Directive lists certain habitats and species that must be protected within SACs. Irish habitats include raised bogs, blanket bogs, turloughs, sand dunes, machair (flat sandy plains on the north and west coasts), heaths, lakes, rivers, woodlands, estuaries and sea inlets. Sites not full listed are regarded as candidate SACs i.e. cSAC.
- Special Protection Area (SPA). This is an area / habitat that under EU Directive requirements needs to be safeguarded. The EU Birds Directive (79/409/EEC) requires designation of SPAs for: listed rare and vulnerable bird species; regularly occurring migratory species, such as ducks, geese and waders; and wetlands, especially those of international importance (i.e. 1% of the population of a species uses the site, or more than 20,000 birds regularly use the site), which attract large numbers of migratory birds each year. Many existing and future SPAs overlap with SACs.

The NPWS website was queried regarding the presence of any listed wetland habitats within the study area. Only one pNHA site was identified north of Carrick-on-Shannon and encroaching into the northwest of the study area. This is Lough Drumharlow (Lough Eidin) (Site code 001643). The listed species are fallow deer (*Dama dama*) and otter (*Lutra lutra*) located in Cloonagownagh. The lake is also identified as an area for overwintering of Greenland white-fronted geese and whooper swans. Route Corridor Options 1.1, 1.2 and 1.3 pass through the southern part of the site for approximately 0.73 km. The Route Corridors correspond to the stretch between Nodes F and G, and there is therefore no difference between them.

The development boundary of the current Carrick-on-Shannon Local Area Plan (LAP) is in close proximity to the site, however, it is not envisaged that the boundaries of the town will be extended to include these sensitive lands. The LAP states that "The protection and conservation of this area is important from a local and national perspective and this will be reflected in the approach taken in making the new LAP for Carrick-on-Shannon. Environmental considerations will be taken into account in the making of the Plan."

The only other site of interest is located to the west of the southern part of the area and comprises a series of lakes, Lough Boderg and Lough Bofin (Site code 001642) that are likely to receive surface water drainage from the corridor area. The listed species is the stoat (*Mustela eminea*) located in Carranadow. The three southernmost route corridors, EA, Retrofit and Aghamore Bypass may have the potential to impact on the lakes via surface drainage.

Large Springs and Holy Wells

The GSI borehole database and OSi Discovery Series mapping were queried regarding any large springs and holy wells present within the study area.

One location was identified, Toberconellan Spring (GSI Code 1729SEK002) marked as a Holy Well on the Discovery Series map (grid reference 192620, 297240). The well is located approximately 185 m south and upgradient of Route Corridor Option 1.5, linked by a narrow corridor of bedrock at or close to ground surface.

Group and Regional Water Supply Schemes

<u>Regional Water Supply Schemes</u>

On the eastern side of the River Shannon in County Leitrim there is one Regional Water Scheme operated by Leitrim County Council within the study area. This sources surface water from the River Shannon at Carrick-on-Shannon. It is understood that parts of Cortober may also obtain a supply from this source.

West of the River Shannon the Regional Water Scheme is sourced from a groundwater supply at Rockingham Springs. These are located approximately 7 km to the northwest of the study area. The zone of contribution to these springs is further to the south west of them and the source is therefore not of concern regarding the study area.

<u>Group Water Supply Schemes</u>

It is understood that there are no private group water supplies within the study area, however this will need to be confirmed during the domestic well audit for the EIS stage. It is possible that there may be small groundwater supplies servicing a few houses.

Commercial and Industrial Borehole Supplies

The GSI borehole database was queried regarding any commercial and industrial borehole supplies within the study area, with no locations identified. It is possible that there may be commercial properties that do have wells and these would need to be located during the EIS phase of the work.

Domestic Spring, Well and Borehole Supplies

A preliminary domestic well audit was not carried out at this stage of the study, and is recommended for the EIS phase once the final alignment has been selected. The GSI well database was accessed to identify any known listed supplies.

There are twenty four records identified within the study area, seventeen of which are present in the north western part of the study, all relating to site investigations, mostly located along the existing N4 west of Carrick-on-Shannon. A further five are located in Cornamucklagh / Ballynamony in the north of the area that are associated with an old local authority landfill site.

Only one record was listed as a supply well (GSI code 1729NEW102) in Dromore Townland. The location (grid reference 196360, 300800) was given as accurate to within 0.5 km. It is likely to be located east of Node H and close to Route Corridor Options 1.1 and 1.2. The well was bored to 32.1 m below ground level with bedrock presumed at 1.5 m below ground level. It is used for agricultural and domestic supply. A reported 'good' (100 - 400 m^3/d) yield of 130.9 m^3/d is given. Another well with an unknown usage (GSI code 2029SWW004) is located in Fearnaght Townland. The location (grid reference 204070, 292840) was given as accurate to within 1 km, and is likely to close to Route Corridors 2.1, 2.2 and 2.3. It was drilled to 28.9 m and had a reported 'good' (100 - 400 m^3/d) yield of 130.9 m^3/d.

Further mapping has identified a number of wells located within some of the corridor options (Table 16.60). The status and usage of these is unknown until a well audit is carried out.

Table 16.60 Well Features Marked on OSi Maps

Route Corridor Option	Townland	Easting	Northing
2.2 and 2.3	Drumgilra	202472	295425
2.3	Aghamore	203094	294367
2.1	Annaduff	201200	296740
2.1	Finnalaghta	203815	293685
2.1	Fearnaght	204290	292810

Source Protection Schemes

The GSI carries out source protection mapping whereby source protection areas (SPAs) are delineated around significant groundwater supply sources. The areas are subdivided into inner and outer protection areas, based on the 100 day time of travel (TOT) and the catchment area respectively. The associated groundwater vulnerability is superimposed on these sub-divisions, to give source protection zones as listed in Table 16.61 (DoELG, EPA & GSI, 1999).

Table 16.61 Groundwater Vulnerability Rating Relevant to Source Protection Zones

Vulnerability Rating	Source Protection Zone	
	Inner (SI)	Outer (SO)
Extreme (E)	SI/E	SO/E
High (H)	SI/H	SO/H
Moderate (M)	SI/M	SO/M
Low (L)	SI/L	SO/L

SPAs are delineated using several hydrogeological methods, varying in complexity, cost and the level of data and hydrogeological analysis required. Four methods, in order of increasing technical sophistication, that are used by the GSI are:-

- calculated fixed radius;
- analytical methods;
- hydrogeological mapping; and
- numerical modelling.

As each method has limitations the boundaries must be seen as a guide for decision-making which can be reappraised in the light of new knowledge or changed circumstances.

Inner protection zones are designed to protect against the effects of human activities that might have an immediate effect on the source and, in particular, against microbial pollution. The area is defined by a 100-day time of travel (TOT) from any point below the water table to the source. In karst areas, it will not usually be feasible to delineate 100-day TOT boundaries, as there are large variations in permeability, high flow velocities and a low level of predictability. In these areas, the total catchment area of the source will frequently be classed as SI. If it is necessary to use the arbitrary fixed radius method, a distance of 300 m is normally used. A semi-circular area is used for springs. The distance may be increased for sources in karst aquifers and reduced in granular aquifers and around low yielding sources (DoELG, EPA & GSI, 1999).

The outer protection zone area covers the remainder of the zone of contribution (ZOC) (or complete catchment area) of the groundwater source. It is defined as the area needed to support an abstraction from long-term groundwater recharge i.e. the proportion of effective rainfall that infiltrates to the water table. The abstraction rate used in delineating the zone will depend on the views and recommendations of the source owner. A factor of safety can be taken into account whereby the maximum daily abstraction rate is increased (typically by 50%) to allow for possible future increases in abstraction and for expansion of the ZOC in dry periods. In order to take account of the heterogeneity of many Irish aquifers and possible errors in estimating the groundwater flow direction, a variation in the flow direction (typically ±10-20°) is frequently included as a safety margin in delineating the ZOC. If the arbitrary fixed radius method is used, a distance of 1000 m is recommended with, in some instances, variations in karst aquifers and around springs and low-yielding wells (DoELG, EPA & GSI, 1999).

The boundaries of the SPAs are based on the horizontal flow of water to the source and, in the case particularly of the Inner Protection Area, on the time of travel in the aquifer. Consequently, the vertical movement of a water particle or contaminant from the land surface to the water table is not taken into account. This vertical movement is a critical factor in contaminant attenuation, contaminant flow velocities and in dictating the likelihood of contamination, and can be taken into account by mapping the groundwater vulnerability to contamination (DoELG, EPA & GSI, 1999).

Source protection mapping has been carried out by the GSI for County Roscommon. The Boyle Ardcarn Water Supply Scheme is the closest to the study area, located 7 km to the west of the western tie-in. The scheme sources its water from the Rockingham Springs. These springs have a zone of contribution (ZOC) extending from Grange Beg southwest of Boyle Town to the Rockingham Demesne. Large underground conduits and fissure zones have been identified and are known to have rapid response times to groundwater flow across the area to the springs.

Aquifer Protection Schemes

Groundwater protection schemes are county based projects that are undertaken jointly between the GSI and the respective Local Authority, with the overall aim of preserving the quality of groundwater, particularly for drinking water purposes. The schemes are not intended to have any statutory authority, but provide a framework for decision making and guidelines for the Local Authorities in carrying out their functions. Since 2003, the Department of Environment, Heritage and Local

Government has recommended that groundwater protection schemes are incorporated into County Development Plans (GSI website).

A groundwater protection scheme comprises two components:-

- land surface zoning map(s) ('groundwater protection zone map') produced by the GSI; and
- groundwater protection responses for existing and new potentially polluting activities, decided on by the statutory authorities.

Combining the hydrological conditions and the aquifer type, it is possible to produce a vulnerability rating matrix for resource protection zones (Table 16.62).

Table 16.62 Matrix of Resource Protection Zones Relevant to Aquifer Type

Vulnerability Rating	Resource Protection Zones					
	Regionally Important Aquifers (L)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf/Rg	Lm/Lg	Ll	Pl	Pu
Extreme (E)	Rk/E	Rf/E	Lm/E	Ll/E	Pl/E	Pu/E
High (H)	Rk/H	Rf/H	Lm/H	Ll/H	Pl/H	Pu/H
Moderate (M)	Rk/M	Rf/M	Lm/M	Ll/M	Pl/M	Pu/M
Low (L)	Rk/L	Rf/L	Lm/L	Ll/L	Pl/L	Pu/L

16.4.8 Impact Assessment

Description of Hydrogeological Impacts

Road projects given their scale and nature have significant potential for causing impact to the groundwater environment both during their construction and on-going operation and consequently require careful planning and detailed assessment to ensure the best solution is attained.

The attributes and impacts that are assessed for each route corridor include the following:

- High yielding water supply springs and wells along each route corridor and increased risk presented by the road scheme;
- The classification (regionally important, locally important, poor) and extent of aquifers underlying each route corridor and increased risks presented to them by the road scheme (associated with aspects such as removal of subsoil cover, removal of aquifer (in whole or part), drawdown in water levels, alteration in established flow regimes, change in groundwater quality);
- Natural hydrogeological / karst features along each route corridor and the increased risk presented by the road scheme, and
- Groundwater fed ecosystems and the increased risk presented by the road scheme.

Assessment Criteria

Estimation of the importance of hydrogeological attributes is based on criteria for rating site attributes as outlined in the NRA publication '*Guidelines on Procedures for*

Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes', and presented in Table 16.63.

Table 16.63 Criteria for Rating Site Attributes

Importance	Criteria
Extremely High	Attribute has a high quality or value on an international scale
Very High	Attribute has a high quality or value on a regional or national scale
High	Attribute has a high quality or value on a local scale
Medium	Attribute has a medium quality or value on a local scale
Low	Attribute has a low quality or value on a local scale

The guidelines also define the impact significance level relative to the attribute importance (Table 16.64).

Table 16.64 Criteria for Rating Impact Significance

Impact Level	Attribute Importance				
	Extremely High	Very High	High	Medium	Low
Profound	Any permanent impact on attribute	Permanent impact on significant proportion of attribute			
Significant	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute		
Moderate	Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute	
Slight		Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute
Imperceptible			Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute

Impacts Associated with Each Route Corridor

The route corridors have been divided into two groups, those to the north of Drumsa within Section 1 (Route Corridor Options 1.1 to 1.5, from west to east), and to the south within Section 2 (Route Corridor Options 2.1 to 2.3, from west to east).

<u>Route Corridor Option 1.1</u>

There were no key hydrogeological attributes identified along the route that would potentially be impacted by the development. Two spa well (Chalybeate and Sulphur) have been identified on maps for the area downgradient of the route corridor. The importance of these would need to be considered during the EIS phase should this option be selected.

Route Corridor Option 1.2

Table 16.65 gives a summary of the key hydrogeological attributes and likely impacts along the corridor.

Table 16.65 Preliminary Assessment of Hydrogeological Impacts for Route Corridor Options 1.1 and 1.2

Attribute	Attribute Importance	Impact	Level of Impact
Designated pNHA site – Drumharlow Lough	Very High	Removal of part of this wetland area, and possible restriction of shallow subsoil flow	Significant
		Potential impact during construction phase of introducing contaminants to the surrounding area.	Slight

Route Corridor Option 1.3

Table 16.66 gives a summary of the key hydrogeological attributes and likely impacts along the corridor.

Table 16.66 Preliminary Assessment of Hydrogeological Impacts for Route Corridor Option 1.3

Attribute	Attribute Importance	Impact	Level of Impact
Designated pNHA site – Drumharlow Lough	Very High	Removal of part of this wetland area, and possible restriction of shallow subsoil flow	Significant
		Potential impact during construction phase of introducing contaminants to the surrounding area.	Slight
Regionally Important Karstified (conduit) Aquifer – Ballynamony Townland	High	Potential mobilisation of contaminants (if present) associated with a landfill site, and if the adjacent section is in cut, increasing the vulnerability rating by removal of protective overburden material	Moderate

Route Corridor Option 1.4

There were no key hydrogeological attributes identified along the route that would potentially be impacted by the development.

Route Corridor Option 1.5

Table 16.67 gives a summary of the key hydrogeological attributes that have been identified along the route corridor and their importance within the environment. A description and level of potential impacts that the road scheme would have on the attribute is also given.

Table 16.67 Preliminary Assessment of Hydrogeological Impacts for Route Corridor Option 1.5

Attribute	Attribute Importance	Impact	Level of Impact
Regionally Important Karstified (conduit) Aquifer – Toberconellan Spring at Killukin / Glebe	High	Potential drying up of spring / holy well upgradient of the route corridor should the adjacent section be located in cut. Ridge of karstified bedrock at or close to surface between the spring and corridor.	Imperceptible

<u>Route Corridor Option 2.1</u>

There were no key hydrogeological attributes identified along the route that would potentially be impacted by the development.

<u>Route Corridor Option 2.2</u>

There were no key hydrogeological attributes identified along the route that would potentially be impacted by the development.

<u>Route Corridor Option 2.3</u>

There were no key hydrogeological attributes identified along the route that would potentially be impacted by the development.

Environmental Mitigation Measures

The following generalised mitigation measures should be considered in detail at the Environmental Impact Statement phase of the scheme.

<u>Baseline Investigation</u>

Once an Emerging Preferred Route Corridor (EPR) has been selected and preliminary horizontal and vertical alignments determined it is recommended that baseline field investigations be carried out in sensitive area such as the designated site (Lough Drumharlow) to the north west of Carrick-on-Shannon if either Route Corridor Options 1.1, 1.2 or 1.3 is selected. This work would be necessary for collating baseline data required by the subsequent EIS phase of reporting, to obtain a better understanding of the existing hydrological and hydrogeological interactions prior to any works.

Other work would comprise a domestic well audit along the entire length to document the presence of any private water supplies, and any other features such as karst that have not been already mapped.

<u>Construction Phase</u>

As an impact reduction strategy good environmental practices should be implemented during the construction of the development and including all ancillary areas, such as site compounds. These good environmental practices should be implemented by means of an environmental management plan and the implementation of a pollution incident control plan during construction to ensure that any incidents are dealt with should they occur. It is recommended that no ancillary areas be located within any sensitive areas e.g. where karst features are present at ground surface or near to designated sites, and no refuelling be allowed to reduce potential impacts.

During the design of the final alignment it is recommended that adequate drainage systems be incorporated into any sensitive areas e.g. if either Route Corridor Options 1.1, 1.2 or 1.3 is selected then the section of route that would pass through the pNHA designated Drumharlow Lough.

If groundwater infiltration areas are required, then to mitigate potential localised flooding, detailed site investigation should be carried out to define the infiltration rate during winter periods. Based on these rates the size of infiltration field and necessary detention stormwater storage and controlled outflow to the infiltration field should be determined so as to meet the design drainage requirements without causing ponding of the infiltration field or adjacent lands. This should be undertaken during the detailed design stage of the project.

Provision should be made for the protection of exposed soil surfaces from rainfall erosion which would potentially influence groundwater vulnerability by removing the protective layer. Stockpiles and spoil heaps should be located well away from drainage ditches and watercourses.

It is essential to ensure that the use of cement and wet concrete in or close to any of the watercourses or karst features is carefully controlled. Any spillages of hydrocarbons should be immediately contained on site with suitable materials and the contaminated soil / material removed for appropriate disposal.

Operational Phase

Surface runoff from roads can adversely affect the water quality of the receiving stream as a result of routine road drainage discharges and accidental spillages. Of particular concern to the receiving waters is the impact of the "First Flush" runoff, where accumulated road waste material is washed off from the road surface and drainage system in relatively high concentrations, particularly when this coincides with dry weather flows in nearby streams. High concentrations of suspended solids could potentially rapidly infiltrate via karst features that have not been identified to date through available mapping, flowing into the underlying aquifer and blocking the conduit flow paths. Properly designed treatment measures can mitigate such water quality impacts.

Accidental spillages are predominantly a function of traffic flows and pavement area draining to the nearest water body. Mitigation measures to prevent serious impact to the receiving waters comprise a combination of oil interceptors, storage areas and outlet facilities that can be shut off to capture harmful substances prior to discharge.

Current practice in Ireland to deal with urban storm runoff is the introduction of sustainable urban drainage (SUDs) practices. This involves source control through the use of soakaways or infiltration fields and the minimisation of impervious areas (porous pavements), or the provision of detention ponds (surface ponds, underground tanks, and swales) to attenuate the flood peak to a permissible maximum runoff rate. These techniques also serve to treat surface water pollution through promotion of primary settlement (sedimentation) and natural filtering.

To mitigate potential flooding in the receiving streams from the road drainage storm runoff a SUDS (Sustainable Urban Drainage Systems) approach is recommended whereby road drainage runoff is attenuated to a permissible runoff rate (generally adopted as equivalent to the natural Greenfield flood flow) prior to it entering the receiving stream. The attenuation may be achieved by using a variety of devices such as, constructed detention ponds (dry or wet), natural surface ponds, lakes or wetlands, attenuated ditches (swales), soakaways and infiltration fields and these should be located away from any identified karst features.

16.4.9 Comparison of Route Corridors

Route corridor option Combinations

In Section 1 there are five possible route corridors and in Section 2 there are three selections. Over the entire length of the scheme there will be a total of fifteen combinations of possible route corridor options to be considered Table 16.68.

Table 16.68 Route Corridor Options

Section 1		Section 2	
Corridor	**Associated Nodes**	**Corridor**	**Associated Nodes**
1.1	ADEFGHMB	2.1	BNC
		2.2	BNOPC
		2.3	BNOPC
1.2	ADEFGHLMB	2.1	BNC
		2.2	BNOPC
		2.3	BNOPC
1.3	ADEFGIJKLMB	2.1	BNC
		2.2	BNOPC
		2.3	BNOPC
1.4	ADEFJKLMB	2.1	BNC
		2.2	BNOPC
		2.3	BNOPC
1.5	ADKLMB	2.1	BNC
		2.2	BNOPC
		2.3	BNOPC

Summary of Key Hydrogeological Attributes

A review of the existing environment with regards to hydrogeology has been made to select a preferable order of route selection that will minimise the impact on the environment as well as reducing the likely cost implications from mitigation requirements.

Tables 16.69 and 16.70 indicates the order of preference for each corridor in Sections 1 and 2 based on the most significant hydrogeological categories.

Table 16.69 Route Corridor Option Preferences Relevant to Hydrogeological Attributes in Section 1

Route corridor option	Aquifer Type	Groundwater Vulnerability	Karst Features	Designated Sites	Total	Rank
1.1	2	1	1	3	7	1st
1.2	3	2	1	3	9	3rd
1.3	4	3	1	3	11	4th
1.4	1	5	1	1	8	2nd
1.5	5	4	5	1	15	5th

When considering karst features, only one feature was identified (a holy well / spring), upgradient of Route Corridor Option 1.5. This option was considered the least favourable in this respect, however should the option be selected for development then it would be necessary to look at whether the route alignment would be in fill or cut to determine the impact significance. As bedrock is at or close to surface between the spring and the corridor a cut section may have an impact on dewatering the feature, however a fill section would not be expected to have an impact.

Table 16.70 Route Corridor Option Preferences Relevant to Hydrogeological Attributes in Section 2

Route corridor option	Aquifer Type	Groundwater Vulnerability	Karst Features	Designated Sites	Total	Rank
2.1	1	3	1	1	6	1st
2.2	3	1	1	1	6	1st
2.3	2	2	1	1	6	1st

There were no karst features or designated sites present along the section that would be impacted, and the results for the aquifer type and groundwater vulnerability were very similar. In this respect all three corridor options have an equal preference in respect to hydrogeology.

The approach taken for private water sources is that a well / spring audit should be carried out as part of the EIS phase to collate baseline information on all supplies and their usage within the corridor. Once the alignment is known indicating cut and fill sections and distance upgradient or downgradient from the section then an impact assessment can be made for each location potentially at risk. Mitigation measures for either deepening the well, re-drilling in another location or connecting to a group scheme along with general water quality protection in the surrounding area would be carried out.

Summary of Hydrogeological Impacts

As outlined in Section 16.4.8 an assessment has been made of the likely impact each route will have on the various key hydrogeological attribute categories. Table 16.71 gives an order of preference based on the number of occurrences of impact level.

Table 16.71 Summary of Hydrogeological Impacts for Route Corridor Options

Impact Level	Route Corridor Option							
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3
Profound	0	0	0	0	0	0	0	0
Significant	1	1	1	0	0	0	0	0
Moderate	0	0	1	0	0	0	0	0
Slight	1	1	1	0	0	0	0	0
Imperceptible	0	0	0	0	1	0	0	0

Order of Hydrogeological Preference

Considering the number of hydrological attributes that are located within each corridor and the likely level of impact that a route would have on the attribute the following order of preference has been derived (Tables 16.72 and 16.73).

Table 16.72 Hydrogeological Route Corridor Option Preference for Section 1

Section	Corridor	Attribute Preference	Impact Preference	Total	Overall Rank
1	1.1	1	3	4	2nd
	1.2	3	3	6	3rd
	1.3	4	5	9	5th
	1.4	2	1	3	1st
	1.5	5	2	7	4th

Table 16.73 Hydrogeological Route Corridor Option Preference for Section 2

Section	Corridor	Attribute Preference	Impact Preference	Total	Overall Rank
2	2.1	1	1	2	1st
	2.2	1	1	2	1st
	2.3	1	1	2	1st

For Section 2 there is no difference between the three corridor options and all have an equal preference in respect to hydrogeology.

The most preferable combination of corridors over the entire length of the scheme in relation to having the least impact on the hydrogeological regime would therefore be Route Corridor Option 1.4 with any of the Section 2 corridors.

16.4.10 References

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16.4.11 Glossary

95-Percentile Flow The flow rate (expressed in m^3/s) at a given location on a river which over the long-term is equalled or exceeded 95% of the time

7-Day Sustained Low-Flow The flow rate (expressed in m3/s) that is not exceeded for 7 consecutive days in any year.

Acidification The process of becoming an acid or becoming acidic. In the case of lake acidification, acidic waters either sourced from the ground or from rainfall can, over time, cause the water body to change from alkali to acid. While this process has been occurring naturally since the last ice age, it is also caused by pollution or contamination.

Actual Evapotranspiration (AE) (see evapotranspiration below) Under certain circumstances, such as dry weather, then the quantity of water available to crops is reduced. During this time, the actual evapotranspiration is reduced below the potential evapotranspiration. Calculation of AE incorporates a stress factor that is based upon the soil moisture balance.

Aquifer: Any stratum or combination of strata that stores or transmits groundwater (Local Government (Water Pollution) Act, 1990). *More commonly:* A permeable geological stratum or formation that can both store and transmit water in significant quantities.rock that stores and transmits water in significant quantities.

Confined Aquifer: An aquifer in which the groundwater is overlain by impermeable geological strata; confined groundwater is generally subject to pressure greater than atmosphere.

Unconfined Aquifer: An aquifer where the water table is exposed to the atmosphere through openings in the overlying material.

Granular Aquifer: An aquifer composed of discrete grains of material (usually sand and/or gravel) in which groundwater flows through the spaces (pores) between the grains (intergranular flow). Such an aquifer is said to have a *primary* porosity and permeability, as contrasted with secondary porosity and permeability which results from fracturing, etc. Flow through a granular aquifer is said to be *intergranular flow.*

Poor Aquifer: An aquifer which is normally capable of yielding only sufficient water from wells or springs to supply single houses, small farms or small group water schemes. These can be sub divided into: Bedrock aquifers which are generally unproductive except for local zones (Pl) and Bedrock aquifers which are generally unproductive (Pu).

Locally Important Aquifer: An aquifer which is moderately productive, i.e. capable of yielding enough water to boreholes or springs to supply villages, small towns or factories. These are divided into: Sand/gravel aquifers (Lg); Bedrock aquifers which are generally moderately productive (Lm); and Bedrock aquifers which are moderately productive only in local zones (Ll).

Regionally Important Aquifer: An aquifer which is sufficiently productive to be able to yield enough water to boreholes or springs to supply major regional water schemes. These are divided into: extensive sand/gravel aquifers (Rg); karst aquifers (Rk); and fissured aquifers (Rf).

Attenuation: The process of diminishing contaminant concentrations in groundwater, due to filtration, biodegradation, dilution, sorption, volatilisation and other processes. The breakdown or dilution of a contaminant in water.

Base Flow (Hydrogeology): That part of the flow in a stream which is not attributable to direct runoff from precipitation or snowmelt, usually sustained by groundwater discharge. That part of a stream discharge derived from groundwater seeping into the stream.

Base Flow (Hydrology) The groundwater contribution to a surface water course is referred to as base flow. It is the component of the surface water flow not derived directly from run-off. The base flow component of a stream or river volume depends on the hydraulic properties of the contributing aquifer.

Calcareous: Composed of, or containing, calcium carbonate.

Catchment: That area determined by topographic features within which falling rain will contribute to run-off at a particular point under consideration.

Cave: A naturally occurring cavity large enough for human access.

Conduit Flow: A characterisation of some types of Karst aquifers, in which flow is concentrated in conduits created by the dissolution of the limestone bedrock.

Contaminant Loading: The amount (volume and concentration) of a contaminant discharged to soil or groundwater.

Contaminant Transport: The transport of a contaminant through topsoil, subsoil or bedrock.

Carboniferous: The geological time period from 355 to 290 million years ago when most limestones were deposited.

Diffuse Flow: A characterisation of some types of Karst aquifers, in which flow is distributed relatively evenly throughout the rock.

Dissolution: A form of chemical weathering in which water molecules, sometimes in combination with acid or another compound in the environment dissolve parts of a mineral or rock.

Doline / Enclosed Depression: A small to medium sized closed depression, a few metres to a few hundred metres in diameter and depth. Dolines are formed by slow, concentrated solutional removal of rock in an area, from the surface downwards, or by the collapse of overlying rock into a cave or chamber beneath (collapse doline). Dolines function as funnels, allowing point recharge of the karstic aquifer.

Downgradient: The direction in which groundwater or surface water flows (also referred to as down-slope). Opposite of upgradient.

Drumlin: A long, egg-shaped hill that develops when pressure from an overriding glacier reshapes a moraine. Drumlins range in height from 5 to 50 meters and in length from 400 to 2000 meters. They slope down in the direction of the ice flow.

Dry Weather Flow The annual minimum daily mean flow rate (expressed in m^3/s) at a given location on a river with a probability of exceedance of 0.98 (i.e. with a return period of 50 years)

Effective Rainfall: The amount of rainfall that will be able to reach the underlying aquifer. It is determined as the actual rainfall, less evapotranspiration and soil moisture deficit.

Ecology: The study of the relationships among organisms and the relationship between them and their physical environment.

Estevelle: A karst feature that can function as a spring or as a swallow hole depending on underground water levels.

Eutrophication: Eutrophication is the effect of an increase in compounds containing nitrogen or phosphorus in an ecosystem. The term is often used in reference to the resultant increase in the ecosystem's primary productivity (excessive plant growth and decay), and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.

Evapotranspiration: Evaporation from a surface covered by vegetation (usually grass). It depends on both meteorological conditions and on the type of vegetation and is also influenced by the soil moisture status. The term evapotranspiration is used to indicate the combined amount of water evaporated from the soil surface and transpired from the soil moisture storage through vegetation.

Evapotranspiration (PE) water at the vegetation surface. In drier conditions, actual evapotranspiration is usually less than PE. The term potential evapotranspiration (PE) is used when the water supply available to the plant is not limited. If the water supply in the soil is limited, the actual evapotranspiration (AE) will be less than the potential value.

Fault: A fracture in rock along which there has been relative displacement of the two sides.

Fissure: Natural crack in rock which allows rapid water movement.

Groundwater: That part of the subsurface water that is in the saturated zone, i.e. below the water table.

Groundwater Protection Response: Control measures, conditions or precautions recommended as a response to the acceptability of an activity within a groundwater protection zone.

Groundwater Protection Scheme: A scheme comprising two main components: a land surface zoning map which encompass the hydrogeological elements of risk and a groundwater protection response for different activities.

Groundwater Protection Zone: Zones delineated by integrating aquifer categories or source protection areas and associated vulnerability ratings. The zones are shown on a map, each zone being identified by a code e.g. SO/H (outer source area with a high vulnerability) or Rk/E (regionally important aquifer with an extreme vulnerability). Groundwater protection responses are assigned to these zones for different potentially polluting activities.

Groundwater Source: A source of water supply which depends on groundwater, usually a well (dug well or borehole) or a spring, occasionally an infiltration gallery.

Groundwater Table: The uppermost level of saturation in an aquifer at which the pressure is atmospheric.

Karst: An area of limestone or other highly soluble rock, in which the landforms are of dominantly solutional origin, and in which the drainage is usually underground in solutionally enlarged fissures and conduits.

Karst Feature: Landscape feature which results from karstification (solution of limestone) such as a turlough, swallow hole, cave, etc.

Lacusterine: Pertaining to a lake.

Limestone: A sedimentary rock composed primarily of calcium carbonate. Some 10% to 15% of all sedimentary rocks are limestones. Limestone is usually organic, but it may also be inorganic.

Limestone Pavement: Bare limestone surface from which soil and loose rocks have been stripped – usually by relatively recent ice erosion during a glacial period.

Mean Annual Maximum Flow Maximum flow per annum for the full dataset presented as a mean value.

Mudstone: Argillaceous or clay-bearing sedimentary rock which is non-plastic and has a massive non-foliated appearance.

Peak River Flow The maximum flow attained for a particular river. Usually in m^3/s.

Perched Groundwater Table: When impermeable strata or lenses are present in the subsurface, the volume immediately above the impermeable unit can become saturated as the water is unable to percolate further down into the aquifer. The convex surface that this creates is a perched groundwater table.

Permeability: The ability of a medium to transmit fluids under a potential gradient (units = $L^3/t/L^2$ or L/t). Measure of a soil or rock's capacity to transmit water.

Piezometric Surface: (Potentiometric Surface) The surface representative of the level to which water will rise in a well cased to the impermeable layer above a confined aquifer. In unconfined aquifers, this surface corresponds with the groundwater table.

Point (Pollution) Source: Any discernible, confined, or discrete conveyance from which pollutants are or may be discharged, including (but not limited to) pipes, ditches, channels, tunnels, conduits, wells, containers, slatted sheds and animal rearing sheds.

Potential Evapotranspiration (PE): The term used to describe the process under conditions of unrestricted availability of water at the vegetation surface. In drier conditions, actual evapotranspiration is usually less than PE. The term potential evapotranspiration (PE) is used when the water supply available to the plant is not limited. If the water supply in the soil is limited, the actual evapotranspiration (AE) will be less than the potential value.

Potential Surface Runoff The theoretical calculation of runoff using rainfall and potential evapotranspiration. The actual surface run-off is less than the potential due to rainfall being lost to ground as recharge.

Porosity: The total of all void spaces present withina rock, but not all these spaces will be interconnected and thus able to contain and transmit fluids.

Precipitation: Any form of water, such as rain, snow, sleet, or hail, that falls to the earth's surface.

RAW Readily Available Water. Used in soil moisture balance calculations to determine the quantity of actual evapotranspiration.

Recharge: The addition of water to the zone of saturation; also, the amount of water added.

Return Period The frequency with which a certain event would be expected to occur on average over a long period of record.

Sandstone: A clastic rock composed of particles that range in diameter from 1/16 millimetre to 2 millimetres in diameter. Sandstones make up about 25% of all sedimentary rocks.

Saturated Zone: The zone below the water table in which all pores and fissures are full of water.

Shale: A rock formed from fine-grained clay-size sediment.

Siltstone: A typically layered and flaggy rock composed of two thirds silt-sized particles.

Source Protection Area (SPA): The catchment area around a groundwater source which contributes water to that source (Zone of Contribution), divided into two areas; the Inner Protection Area (SI) and the Outer Protection Area (SO).

The **SI** is designed to protect the source against the effects of human activities that may have an immediate effect on the source, in particular in relation to microbiological pollution. It is defined by a 100-day time of travel (TOT) from any point below the water table to the source.

The **SO** covers the remainder of the zone of contribution of the groundwater source.

Specific Run-off Runoff per unit area (m/yr)

Spring: A flow of water that occurs where the groundwater table intercepts the ground surface.

Storage: The volume of water held within a certain volume of saturated aquifer.

Subsoil: The material between the topsoil and the bedrock.

Swallow Hole: A small steep depression caused in karst topography by the dissolution and collapse of subterranean caverns in carbonate formations.

TAW Total Available Water. Used in soil moisture balance calculations to determine the quantity of actual evapotranspiration.

Till: A glacial sediment composed of rounded rock fragments in a clay rich matrix.

Time of Travel (TOT): The time required for a contaminant to move in the saturated zone from a specific point to a well. It is the average linear velocity of flowing groundwater using Darcy's Law: V = k/ne . dh/dx, where: ne = effective porosity; k = permeability; dh/dx = groundwater gradient

Turlough: Seasonal lakes found in the lowland karsts of western Ireland. They often fill and empty via estavelles.

Unsaturated Zone: The zone between the land surface and the water table, in which pores and fissures are only partially filled with water. Also known as the vadose zone.

Vulnerability: A term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

Zone of Contribution (ZOC): The area surrounding a pumped well that encompasses all areas or features that supply groundwater recharge to the well. It is defined as the area required to support an abstraction from long-term groundwater recharge.

16.4.12 FIGURES

Figure 4 OPW Hydromewtric Output for November 2009 Flood Event on the River Shannon at Drumsna Gauge.

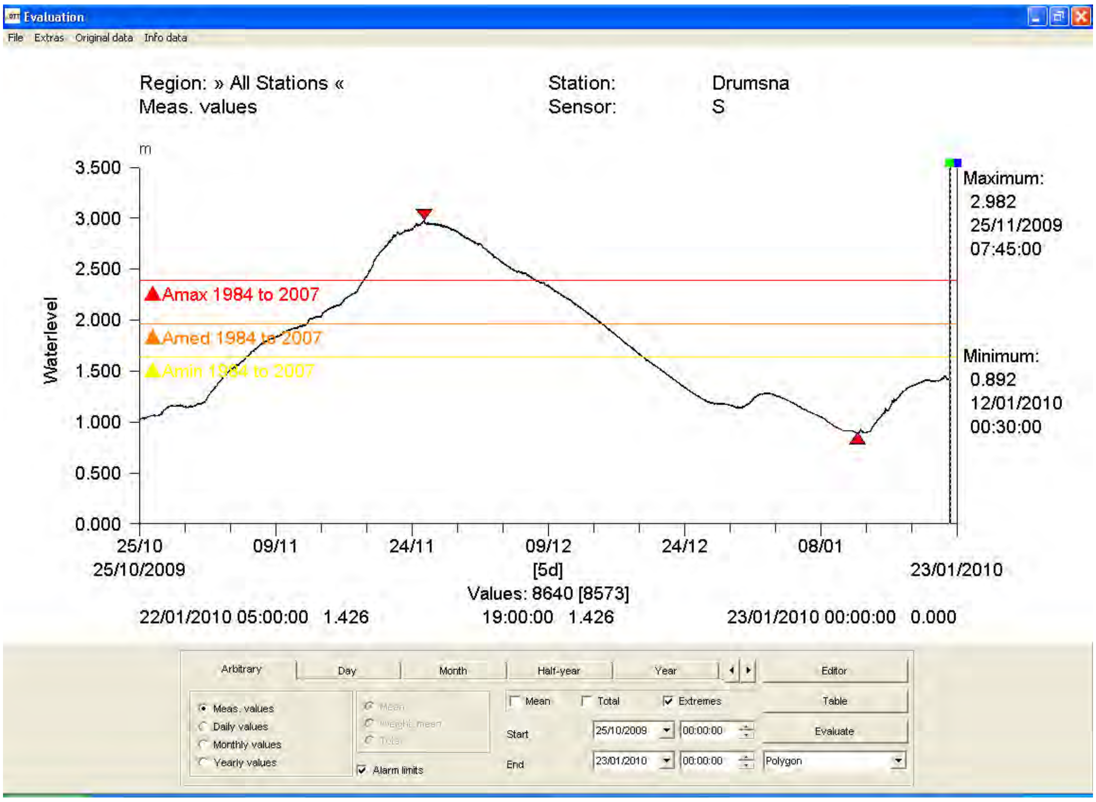

Figure 5 Bedrock Aquifers