5 Identification of Potential Water-based Receptors

Potential receptors of UGEE-related contamination are surface water and groundwater bodies, water supplies (abstractions) that source water from surface and groundwater resources, registered protected areas, and groundwater dependent terrestrial ecosystems (GWDTEs).

This section describes potential water-based receptors that are present in each of the case study areas, which depend on the surface and groundwater resources described in Sections 2 and 3. Surface and groundwater resources are inherently linked. Groundwater provides baseflow and supporting conditions for streams, lakes and GWDTEs which is especially important during prolonged dry weather conditions. Daly and Craig (2009) estimated that more than 30% of the annual average stream flow in Ireland can be derived from groundwater. In low-flow periods, this contribution can be significantly greater, exceeding 90% in certain aquifer types.

With regard to groundwater resources as receptors, there is no fixed depth which can be assigned to define when groundwater ceases to be a usable water resource. This issue is relevant in a UGEE context because of the risks of impact from hydraulic fracturing on groundwater quality. The UK Technical Advisory Group (UKTAG) on the Water Framework Directive (WFD) defined 400 m below ground level as a depth below which it may become increasingly difficult to obtain: a) adequate quantities of groundwater for supply purposes; and b) water that is of a quality that can be used for potable supply purposes. The 400 m depth limit was specified in context of WFD groundwater body delination purposes (to the EC), and should not be interpreted or regarded as a fixed limit for usable groundwater resources in either of the case study areas.

There are indications from past gas exploration wells drilled in the NCB that formation waters of variable salinity are present in bedrock formations at depth (see Section 2.11). This indicates that groundwater quality deteriorates with depth and that beyond a certain depth, the resource value of groundwater, e.g. as a usable source of water supply, is lost. Depths, configurations and circumstances of such water quality deterioration remain poorly understood, but would be expected to vary in three dimensions as a function of geological structures, stratigraphy and heterogeneity, degree of bedrock fracturing, and possible hydrogeological connections with shallow water resources.

5.1 Water Supply Abstractions

Both surface and groundwater resources are used for water supply purposes. As part of the UGEE JRP, relevant public bodies and private entities involved in public and private regulated supplies were contacted for information on existing sources of abstraction in both case study areas. As well, ground-truthing surveys were carried out to:

- Verify the information obtained;
- Improve the overall understanding of water users and related abstractions pressures; and
- Assist in the determination and specification of which water supplies would be suitable for potential baseline monitoring purposes.

Details of the ground-truthing survey are presented in Appendix G and findings are summarised below. The survey followed a three-tiered approach. Priority was given to inspect and document the suitability of public water supplies and group water schemes for sampling purposes. Second priority was assigned to industrial or commercially active supplies which are monitored as 'regulated supplies' by local authorities. Third priority was afforded to "other" private wells that supply farms, other facilities (which do not require monitoring or reporting by public bodies) and single houses.

Time constraints did not allow for all wells to be identified, but a substantially updated database of abstractions and understanding of groundwater use resulted from the survey work in both study areas.

5.1.1 Water supplies (abstractions) from groundwater

Verified groundwater abstractions from wells and springs are shown in Figure 5.1 and Figure 5.2 for the NCB and in Figure 5.3 for the CB.

In the NCB, groundwater is sourced for public supply, private regulated supply (e.g. group water schemes) and ‘other’ private supply (e.g. single homes, farms, industrial and commercial facilities). Public supply wells pump water from several of the rock formations of the Tyrone Group, whereas spring-sourced supplies are mostly linked with formations of the Leitrim Group. General information on wells and springs in the NCB are summarised in Table 5.1 and Table 5.2. Only public and private regulated supplies are included in the tables, but other private supplies that were identified from the ground-truthing survey are also shown on the maps (green symbols).

In the CB, there are no groundwater-based public or group water schemes within the UGEE licence boundary. The Lissacasey GWS is located immediately to the east of the licence boundary and elsewhere in the study area groundwater is an important source of water for industry/commerce, farms and single houses.

An overall summary of verified groundwater abstractions in the two study areas is presented in Table 5.3 and Figure 5.4. Regarding private wells serving single homes and farms, not all homes or farms could be visited during the ground-truthing survey, and thus not all potential abstractions could be verified. For this reason, the total number of abstractions in the lower abstraction categories (<50 m^3/d) is to be under-represented in Figure 5.4. Additionally, the data from the CB is believed to under-represent private regulated supplies as there were a small number of commercial enterprises which could not be verified following the initial inquiries that were made.

The largest groundwater abstraction in either of the two study areas is the Rockingham PWS which abstracts 2760 m^3/d on average. It is located marginally outside the UGEE licence area, but abstracts water from a limestone aquifer that is linked to the UGEE licence area in the NCB.

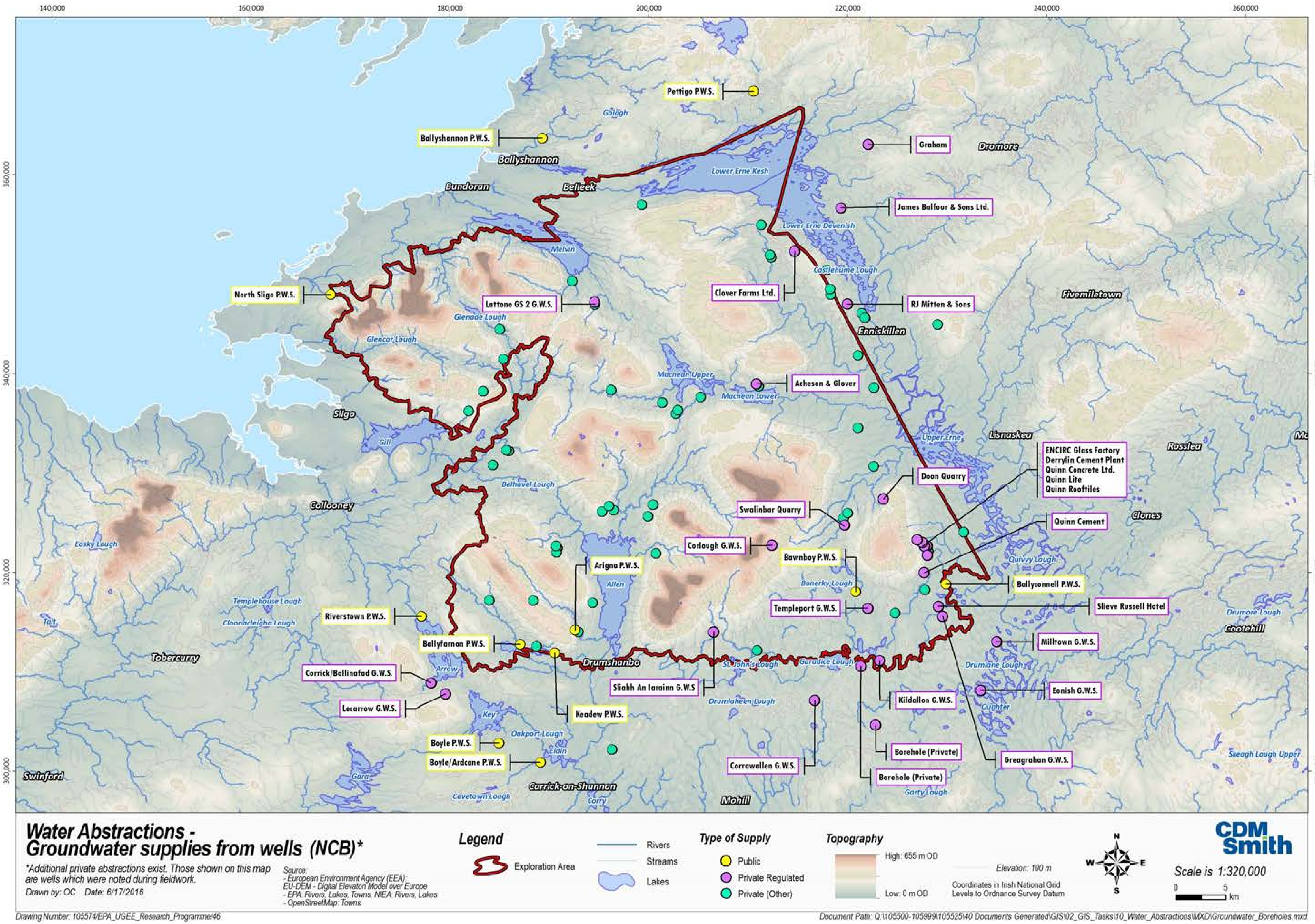


Figure 5.1. Groundwater abstractions from wells – NCB study area.

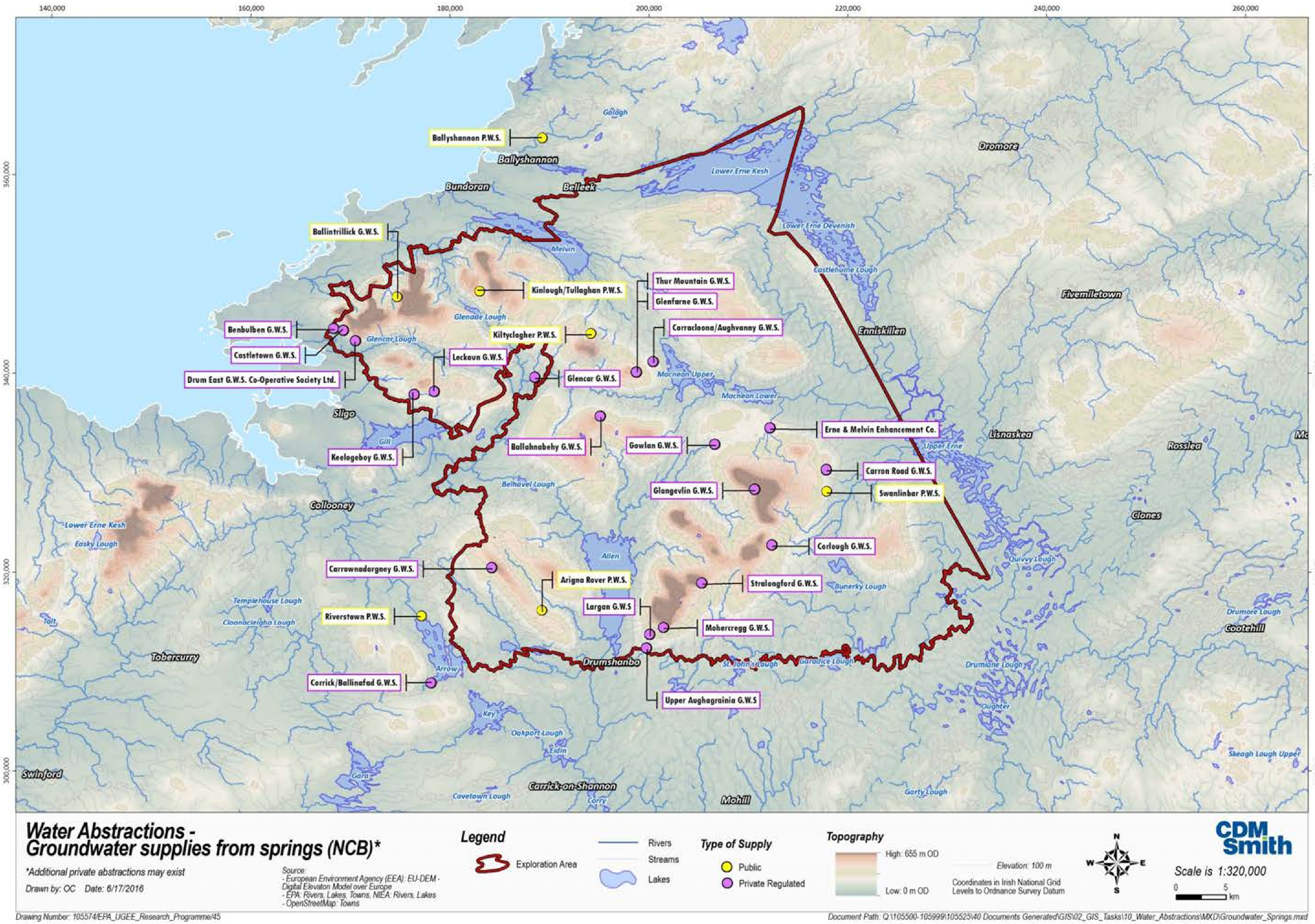


Figure 5.2. Groundwater abstractions from springs – NCB study area.

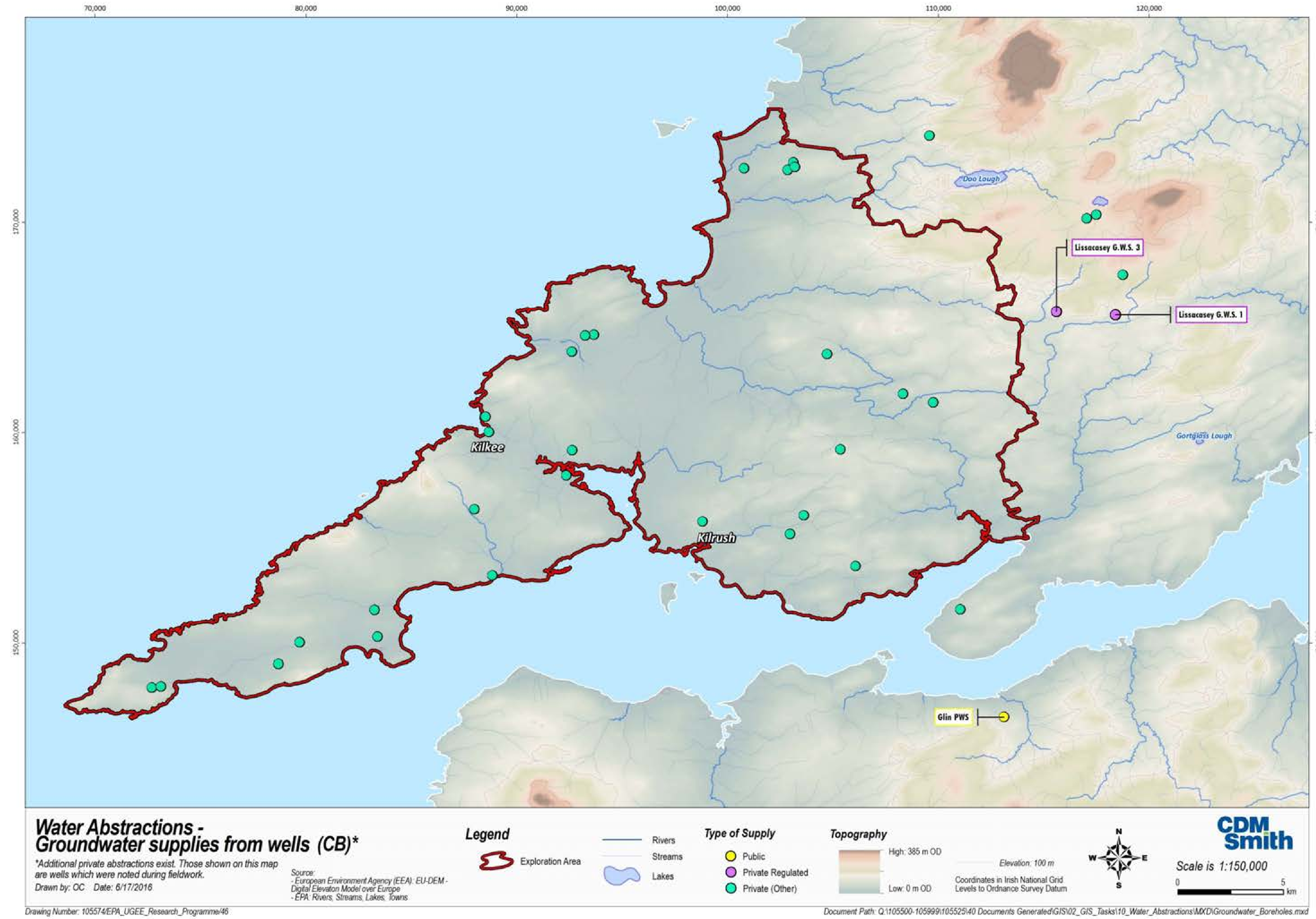


Figure 5.3. Groundwater abstractions – CB study area.

Table 5.1. Groundwater abstractions from wells – NCB study area

Supply name	Easting	Northing	County	Supply type	Supply code	Status	Est. abstraction (m^3/d)	Population served	Geological formation	Aquifer type
Bawnboy P.W.S.	220809	318039	Cavan	P.W.S.	0200PUB1007	Verified	360	50 houses	Dartry Lst	Rkc
Ballyfarnon P.W.S.	187068	312722	Roscommon	P.W.S.	2600PUB1009	Verified	120	200	Bricklieve Lst	Rkc
Rockingham Springs P.W.S. (Boyle P.W.S.)	184939	302850	Roscommon	P.W.S.	2600PUB1011/2600 PUB1023	Verified	2760	–	Oakport Lst	Rkc
Arigna P.W.S.	192609	314178	Roscommon	P.W.S.	2600PUB1005	Verified	[a]130–150	–	Gowlaun Shale	Pu
Keadew P.W.S.	190551	311856	Roscommon	P.W.S.	2600PUB1009	Verified	[a]120	–	Bricklieve Lst	Rkc
North Sligo P.W.S.	168008	347932	Sligo	P.W.S.	2700PUB2705	Verified	432	2000	Bundoran Shale	Ll
Ballyconnell P.W.S.	229878	318801	Cavan	P.W.S.	0200PUB0105	Verified	734	1220	Dartry Lst	Rkc
Boyle/Ardcane P.W.S.	189103	300887	Roscommon	P.W.S.	2600PUB1011	Verified	912	–	Ballymore Lst	Rkc
Pettigo P.W.S.	210536	368359	Donegal	P.W.S.	0600PUB1104	Verified	150	–	Ballyshannon Lst	Pl
ENCIRC Glass Factory	226999	323267	Fermanagh	[c]PR	AIL\2007\0001	Verified	400	Factory	Dartry Lst	2A
Slieve Russell Hotel	229129	316590	Cavan	PR	0200PRI0400	Verified	220	Hotel	Dartry Lst	Rkc
Sliabh An Iarainn G.W.S.	206537	313987	Leitrim	G.W.S.	–	Verified	480	–	Bricklieve Lst	Rkc
Lattone GS 2 (G.W.S.)	194558	347211	Leitrim	G.W.S.	–	Verified	0.4		Dartry Lst	Rkc
Quinn Cement	227683	319966	Cavan	PR	–	Verified	–		Dartry Lst	Rkc
Quinn Rooftiles	227515	322992	Fermanagh	PR	AIL\2008\0107	Verified	2–11	Factory	Dartry Lst	2A
Derrylin Cement Plant	228012	321739	Fermanagh	PR	AIL/2007/0129	Verified	183		Dartry Lst	2A
Kildallon G.W.S.	223220	311109	Cavan	G.W.S.	–	Verified	400	500 houses	Dartry Lst	Rkc
Acheson & Glover	210846	338952	Fermanagh	PR	AIL\2010\0003	Verified	Infrequent	Quarry	Knockmore Lst	2C

Supply name	Easting	Northing	County	Supply type	Supply code	Status	Est. abstraction (m^3/d)	Population served	Geological formation	Aquifer type
Swanlinbar Quarry	219703	324772	Cavan	PR	–	Verified	–	Quarry	Mudbank Lst	Ll
Doon Quarry	223597	327374	Fermanagh	PR	AIL/2008/0104	Verified	17	Quarry	Dartry Lst	2A
Quinn Concrete Ltd	227751	322635	Fermanagh	PR	AIL\2008\0106	Verified	11–50	–	Dartry Lst	2A
Quinn Lite	227998	322644	Fermanagh	PR	AIL\2008\0105	Verified	51–100	–	Dartry Lst	2A
Clover Farms Ltd	214700	352300	Fermanagh	PR	AIL\2008\0015	[b]Unverified	11–50	–	Bundoran Shale	2C
Greagrahan G.W.S.	229570	315580	Cavan	G.W.S.	–	[b]Unverified	–	–	Dartry Lst	Rkc
R.J. Mittens & Sons	219968	346997	Fermanagh	PR	AIL\2008\0037	[b]Unverified	450	–	Ballyshannon Lst	2A
Borehole (private)	221319	310535	Leitrim	PR	1700PRI1062	[b]Unverified	12	–	Dartry Lst	Rkc
Graham (private)	222052	363023	Fermanagh	PR	AIL\2008\0135	[b]Unverified	21	–	–	2A
James Balfour and Sons Ltd.	219320	356660	Fermanagh	PR	AIL\2008\0095	[b]Unverified	1152	–	Shanmullagh	2C
Milltown G.W.S.	234990	313000	Cavan	G.W.S.	0200PRI2030	Verified	300		Ballysteen	Rf
Eonish G.W.S.	233400	308100	Cavan	G.W.S.	–	[b]Unverified	–	–	Ballysteen	Ll
Borehole (private)	222822	304662	Leitrim	PR	1700PUB6000	[b]Unverified	111	–	Finnalaghta	Pl
Corrawallen G.W.S.	216700	307100	Leitrim	G.W.S.	1700PRI1140	Verified	41	–	Drumgesh Shale	Ll
Lecarrow G.W.S.	179575	307736	Sligo	G.W.S.	2700PRI0050	Verified	10	50	Boyle Sst	Ll
Corrick/Ballinafad G.W.S.	178107	308863	Sligo	G.W.S.	2700PRI1028	Verified	90	–	Bricklieve Lst	Rkc
Templeport G.W.S.	222028	316404	Cavan	G.W.S.	–	Verified	160–200		Dartry Lst	Rkc

[a]Borehole being made redundant in May/June 2015.

[b]Data obtained from pre-2010 registers; Confirmation of abstraction not available at time of publication.

[c]PR – private regulated

2 A, highly productive aquifer; 2B, low productive aquifer; 2C, low productivity aquifer.

Table 5.2. Groundwater abstractions from springs – NCB study area

Supply name	Easting	Northing	County	Supply type	Supply code	Status	Net abstraction (m^3/d)	Source	Geological formation	Aquifer type
Arigna Rover	189237	316144	Roscommon	P.W.S.	2600PUB1008	Verified	50	Spring	Lackagh Sst	PI
Ballaghnabehy	195111	335667	Leitrim	G.W.S.	1700PRI1031	Verified	[a]1.9	Spring	Briscloonagh Sst	PI
Ballintrillick	174687	347699	Sligo	P.W.S.	2700PRI1019	Verified	100	Spring	Benbulben Shale	LI
Benbulben	168320	344499	Sligo	G.W.S.	2700PRI1023	Verified	50–70	Spring	Mullaghmore Sst	Lm
Carrownadargney	184203	320458	Sligo	G.W.S.	2700PRI1027	Verified	28	Spring	Dergvone Shale	Pu
Castletown	169297	344304	Sligo	G.W.S.	2700PRI1026	Verified	20	Spring and stream	Benbulben Shale	LI
Corlough	212371	322732	Cavan	G.W.S.	0200PRI0291	Verified	[c]300	Spring and borehole	Gowlaun Shale	Pu
Corracloona/Aughvanny	200425	341172	Leitrim	G.W.S.	–	Verified	7	Spring	Glenade Sst	Lm
Erne & Melvin Enhancement Co.	212200	334500	Fermanagh	Private	AIL\2008\0021	Verified	5300 (all returned)	Spring	Knockmore Lst	2A
Glangevlin	210638	328338	Cavan	G.W.S.	0200PRI2018	Verified	350	Spring	Briscloonagh Sst	PI
Glenade/Tullaghan/Erriff	183021	348248	Leitrim	P.W.S.	1700PUB0017/1700PUB0018/17ABS010017	Verified	1100	Spring	Dartry Lst	Rkc
Glenfarne	198738	340100	Leitrim	G.W.S.	–	Verified	30	Spring	Briscloonagh Sst	PI
Keelogeboy	176433	337842	Sligo	G.W.S.	2700PRI1024	Verified	150	Spring	Dartry Lst	LI
Kiltyclogher spring	194177	343985	Leitrim	P.W.S.	1700PUB4500	Verified	60	Spring	Carraun Shale	PI

Supply name	Easting	Northing	County	Supply type	Supply code	Status	Net abstraction (m^3/d)	Source	Geological formation	Aquifer type
Largan	200075	313696	Leitrim	G.W.S.	–	Verified	[a]5.6	Spring	Dergvone Shale	Pu
Riverstown	177159	315584	Sligo	P.W.S.	2700PUB2708	Verified	[c]22.5	Spring and borehole	Bricklieve Lst	Rkc
Stralongford spring	205351	318909	Leitrim	G.W.S.	–	Verified	[a]4.1	Spring	Gowlaun Shale	Pu
Swanlinbar	217893	328131	Cavan	P.W.S.	0200PUB0117	Verified	170–220	Spring	Benbulben Shale	Pl
Ballyshannon	189289	363667	Donegal	P.W.S.	0600PUB1105	Verified	[e]1694	Spring and borehole	Ballyshannon Lst	Rk
Upper Aughagrainia	199766	312314	Leitrim	G.W.S.	–	Verified	44.3	Spring	Bellavally Shale	Ll
Mohercregg G.W.S	201478	314420	Leitrim	G.W.S.	1700PRI1086	Verified	39	Spring	Gowlaun Shale	Pu
Gowlan/Blacklion	206650	332850	Cavan	G.W.S.	0200PRI2019/0200PRI 0251	Verified	450	Spring	Dartry Lst	Rk
Glencar	188542	339598	Leitrim	G.W.S.	–	Verified	****	Spring	Ballyshannon Lst	Rkc
Thur Mountain Spring	198759	340104	Leitrim	G.W.S.	1700PRI1109	Verified	[a]3.2	Spring	Briscloonagh Sst	Pl
Corrick/Ballinafad	178107	308863	Sligo	G.W.S.	2700PRI1028	Verified	90	Spring	Bricklieve Lst	Rkc
Carron road G.W.S.	217854	330286	Fermanagh	G.W.S.	–	Verified	[a,f]3.2	Spring	Benbulben Shale	2B
Leckaun	178436	338154	Leitrim	G.W.S.	1700PRI1094	Unverified	40	Spring	Dartry Lst	Rkc
Drum East	170521	343239	Sligo	G.W.S.	2700PRI1032/ 2700PRI1030	Verified	4806 (all returned)	Spring	Knockmore Lst	Ll

[a]Estimated data based on 2.6 people/household in Leitrim (CSO 2011) using 0.122m^3/day water usage per person (ESRI 2014).

[b]Used average value of 6 houses to account for seasonal occupancy of holiday homes.

[c]Abstraction from combined spring and borehole source.

[d]Used value of 17.5 houses.

[e] The scheme consists of a lake source (Lough Unshin), a spring and two boreholes which are used to augment the spring supply at times of low flow. The total abstraction volume for all three sources is 1694.

2 A, highly productive aquifer; 2B, low productive aquifer; 2C, low productivity aquifer.

Table 5.3. Numbers of ground-truthed groundwater supplies in or near the UGEE licence areas

Type of supply	Public supply[a]	Private regulated supply[b]	Other private abstractions[c]
Northwest Carboniferous Basin			
Borehole	10	26	51
Spring	7	19	ND[d]
Borehole and Spring	1	1	ND
Mixed SW and GW	1	2	ND
Clare Basin			
Borehole	1[e]	1[f]	32[g]
Spring	0[e]	1[h]	ND[d]
Mixed SW and GW	0[e]	1	ND

[a]Public water supply – operated by IW (via local authorities) or NIW.

[b]Private regulated supply – monitored by local authorities or NIEA. Includes Public Group Water Schemes, Private Group Water Schemes and certain private supplies (e.g. food industry, hotels).

[c]Private “other” abstractions – small supplies, most of which are used for human consumption, includes commercial/industrial facilities, farms and several confirmed domestic wells for single homes. Not all domestic wells in the study areas have been located or visited.

[d]ND – no specific data are available. There would be additional supplies that fall within this category.

[e]There are no groundwater-sourced public water supplies in the CB licence area.

[f]The number of private regulated supplies in Co. Clare is likely incomplete.

[g]Not all farms in the two study areas have been visited, thus the number of wells is expected to be greater.

[h]Vandeler walled gardens – spring used for irrigation purposes only.

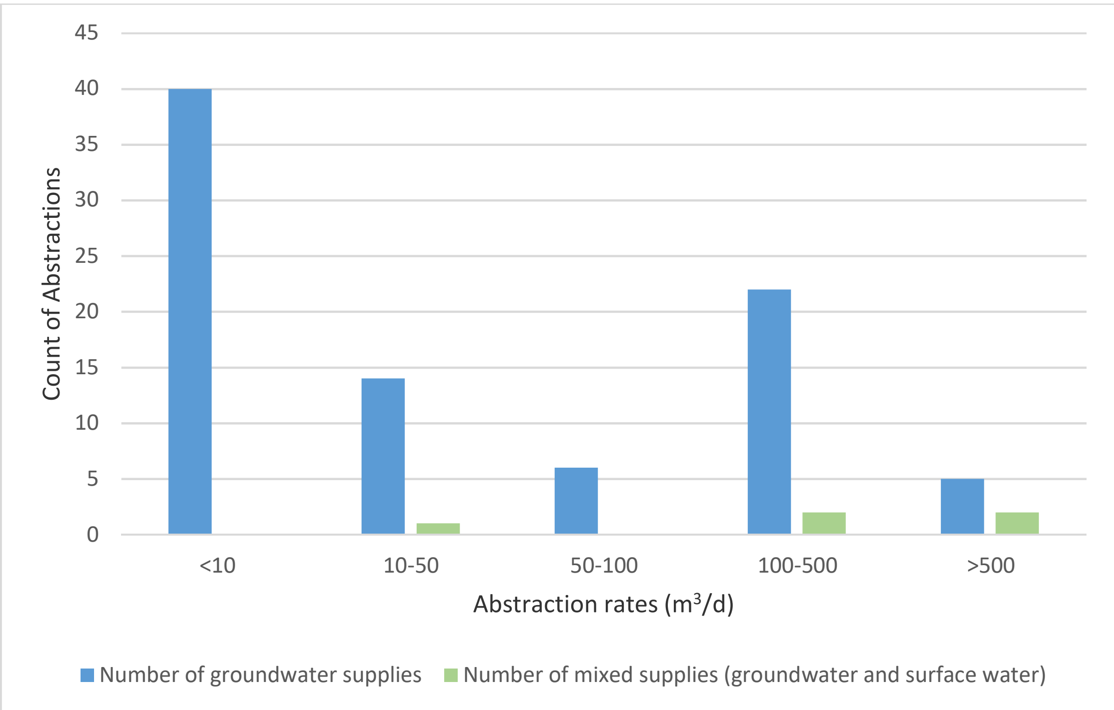


Figure 5.4. Ranges of estimated or known abstraction rates for verified groundwater sources.

5.1.2 Water supplies (abstractions) from surface water

River and lake abstractions are presented in Figure 5.5 and Figure 5.6 and in Table 5.4 to 5.6. An overall summary of verified surface water abstractions is provided in Table 5.7. The largest surface water abstractions which are directly in or at the margin of the UGEE licence area in the NCB are associated with Loughs Gill, Melvin and Erne (notably Bundoran, North Leitrim Regional and Killyhevlin/Belleek in Co. Fermanagh, respectively). Volumetrically, abstractions from lakes are significantly greater than abstractions from streams.

Figure 5.7 summarises the range of surface water abstraction rates from public and private regulated supplies that were verified for both study areas. The majority of abstractions are greater than 500 m^3/d, and the single largest abstraction is 44,000 m^3/d at Killyhevlin in the NCB. The single largest abstraction in the CB is approximately 12,000 m^3/d from Doo Lough, which is located near and east of the UGEE licence area, but is the principal source of water for public and group water schemes in western Co. Clare, including the UGEE licence area.

5.2 Water Framework Directive Register of Protected Areas

A Register of Protected Areas for water-dependent habitats and species is maintained by the EPA in Ireland (EPA, 2015) and by the NIEA in Northern Ireland (NIEA, 2014b). The Register of Protected Areas is compiled in accordance with Article 6 of the WFD. Annex IV of the Directive specifies the types of areas that must be included in the register. These areas are based on existing national and European Union (EU) legislation as described below.

5.2.1 Protected areas (waters used for the abstraction of drinking water)

Waters used for the abstraction of drinking water are designated protected areas under the Water Framework Directive (2000/60/EC). Their locations are indicated on Figure 5.8 and Figure 5.9. In Ireland, the WFD drinking water protected areas were assigned in 2005. They do not correspond with the current understanding of the locations of all surface water abstractions. The data collection effort on both groundwater and surface water abstraction points undertaken as part of the UGEE JRP is considered to be a more up to date reference on the location of drinking water sources.

In Northern Ireland, there are two drinking water protected areas within the NCB – Belleek (Belleek Water Treatment Works and Enniskillen (Killyhevlin Water Treatment Works).

5.3 Designated Sites and Areas

Designated sites are ecological protected areas at EU and national levels, as follows:

1. EU designated (Natura 2000) sites:
    - Special Areas of Conservation (SAC)
    - Special Protected Areas (SPAs)
2. National level designated sites:
    - Proposed Natural Heritage Areas (pNHA) and Natural Heritage Areas (NHA) in Ireland
    - Areas of Scientific Interest (ASSI) in Northern Ireland.

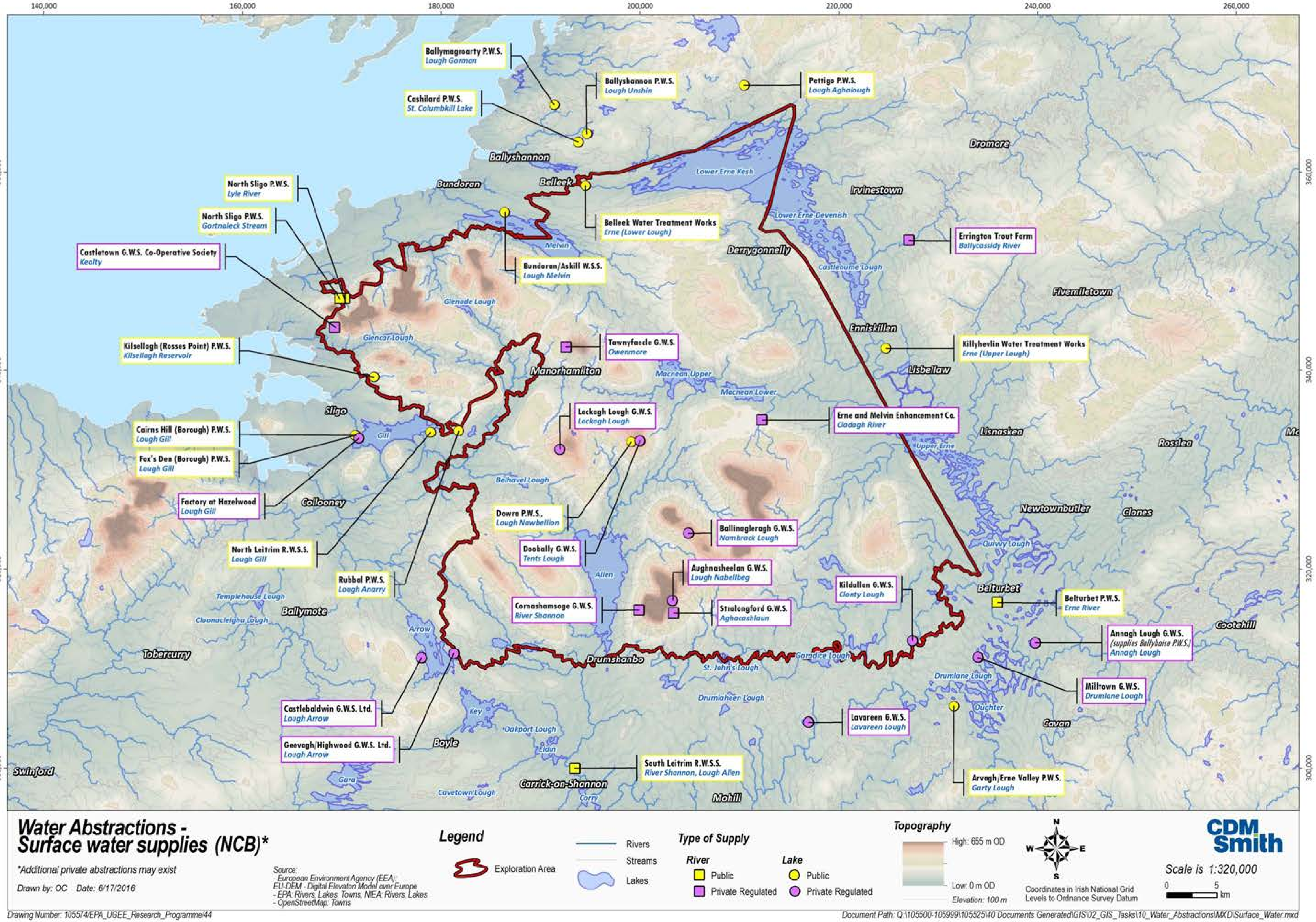


Figure 5.5. Surface Water Abstractions – NCB study area.

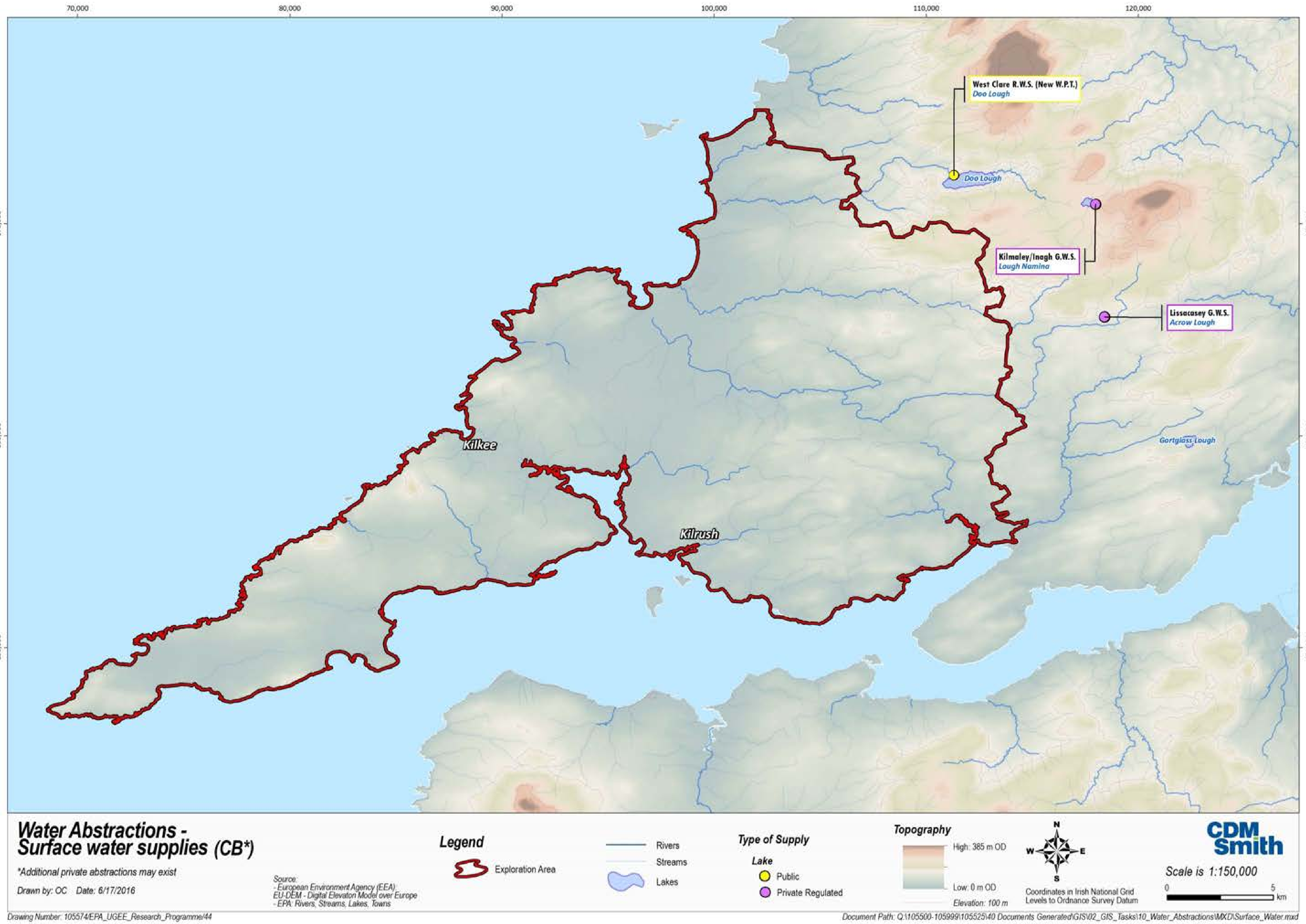


Figure 5.6. Surface Water Abstractions – CB study area.

Table 5.4. River abstractions – NCB study area

Supply name	Easting	Northing	County	Supply type	Supply code	Status	Net abstraction (m^3/day)	Geological formation	Waterbody
Belturbet P.W.S.	235953	316626	Cavan	P.W.S.	0200PUB0108	Verified	720	Drumgesh Shale	Erne
Castletown G.W.S. Co-Operative Society	169366	344332	Sligo	G.W.S.	2700PRI1026	Verified	44	Benbulben Shale	Kealty
Cornashamsoge	199920	315869	Leitrim	G.W.S.	1700PRI1202	Verified	20	Gowlaun Shale	Shannon
Erne & Melvin Enhancement Co.	212280	334980	Fermanagh	Private (industry)	AIL\2010\0014	Verified	4806 (all returned	Knockmore Lst	Cladagh River
Errington Trout Farm	227065	353138	Fermanagh	Private (industry)	AIL\2008\0065	Verified	1700	Ballinamallard	Ballycassidy River
Mullaghgarve/Aghacashel	203374	315572	Leitrim	G.W.S.	1700PRI1105	Verified	12	Dergvone Shale	Aghacashlaun
North Sligo P.W.S.	169822	347267	Sligo	P.W.S.	2700PUB2705	Verified	[a]1850	Mullaghmore Sst	Gortnaleck Stream
North Sligo P.W.S.	170273	347246	Sligo	P.W.S.	2700PUB2705	Verified	[a]	Benbulben Shale	Lyle River
[b]South Leitrim Regional Water Supply Scheme	193442	299976	Leitrim	P.W.S.	1700PUB1100	Verified	12000	Croghan Lst	Shannon/Lough Allen
Tawnyfaecle	192541	342343	Leitrim	G.W.S.	1700PRI1123	Verified	22	Ballyshannon Lst	Owenmore

[a]The total abstraction rate for North Sligo P.W.S. from the two rivers (Gortnaleck and Lyle) is approx. 1,850m^3/day. The abstraction rate of the individual rivers is not measured but the caretaker reports that the Gortnaleck rate is higher.

[b]Outside the exploration area but strong hydrological connection to the NCB.

Table 5.5. Lake abstractions – NCB study area

Supply name	Easting	Northing	County	Supply type	Supply code	Status	Abstraction rate (m^3/d)	Geological formation	Waterbody	Lake area (km^2)
Annagh Lough G.W.S. (supplies the Ballyhaise P.W.S.)	239780	312540	Cavan	G.W.S.	0200PRI0201/ 0200PUB1005	Verified	1455	Coronea	Annagh Lough	0.352
Kildallan G.W.S.	227428	312769	Cavan	G.W.S.	0200PRI2020/ 0200PRI0253	Verified	740	Dartry Lst	Clonty Lough	0.106
Milltown G.W.S.	234000	311100	Cavan	G.W.S.	0200PRI2023	Verified	250	Ballysteen, Drumgesh Shale	Drumlane Lough	0.639
Belleek Water Treatment Works – Lough Erne	194519	358651	Ferman agh	P.W.S.	W4722	Verified	2600	Benbulben Shale, Bundoran Shale, Ballyshannon Lst, Glencar Lst Mullaghmore Sst Slishwood Division	Erne (Lower Lough)	104
Killyhevlin water treatment works – Lough Erne	224747	342218	Ferman agh	P.W.S.	W4701	Verified	44,000	Ballysteen, Benbulben Shale, Bundoran Shale, Mullynagowan Sst, Ballyshannon Lst, Clogher Valley, Newtownbutler Limestone Member, Dartry Lst, Mudbank Lst	Erne (Upper Lough)	32.2
Arvagh/Erne Valley Scheme	231594	306190	Cavan	P.W.S.	0200PUB0101	Verified	2800	Coronea	Garty Lough	0.83
Kilsellagh (Rosses Point) P.W.S.	173256	339324	Sligo	P.W.S.	2700PUB2706	Verified	4594	Mullaghmore Sst	Kilsellagh Reservoir	0.042
Pettigo Pub P.W.S.	210487	368692	Donegal	P.W.S.	0600PUB1104	Verified	50	Slishwood Division	Lough Aghalough	0.14
Castlebaldwin G.W.S. Ltd.	178030	311040	Sligo	G.W.S.	2700PRI1025	Verified	432	Bricklieve Lst	Lough Arrow	12.47

Supply name	Easting	Northing	County	Supply type	Supply code	Status	Abstraction rate (m^3/d)	Geological formation	Waterbody	Lake area (km^2)
Geevagh/Highwood G.W.S. Ltd.	181274	311494	Sligo	G.W.S.	2700PRI1033	Verified	730	Bricklieve Lst	Lough Arrow	12.47
Fox's Den (Borough) P.W.S.	171347	333436	Sligo	P.W.S.	2700PUB2701	Verified	4196	Dartry Lst, Mudbank Lst, Serpentinite, Slishwood Division	Lough Gill	13.8
Cairns Hill (Borough) P.W.S.	171438	333438	Sligo	P.W.S.	2700PUB2711	Verified	5456	Dartry Lst, Mudbank Lst, Serpentinite, Slishwood Division,	Lough Gill	13.8
Factory at Hazelwood	171740	333170	Sligo	(Private)		Verified	1250	Dartry Lst, Mudbank Lst, Serpentinite, Slishwood Division,	Lough Gill	13.8
North Leitrim Regional Supply Scheme	178952	333730	Leitrim	P.W.S.	1700PUB0016	Verified	8000	Dartry Lst, Mudbank Lst, Serpentinite, Slishwood Division,	Lough Gill	13.8
Ballymagroarty P.W.S.	191370	366734	Donegal	P.W.S.	0600PRI3103	Verified	730	Ballyshannon Lst	Lough Gorman	0.075
Bundoran, Askill P.W.S.	186389	355962	Donegal	P.W.S.	0600PUB1108	Verified	7000	Benbulben Shale, Mullaghmore Sst	Lough Melvin	22.1
Dowra P.W.S.	199128	332760	Cavan	P.W.S.	0200PUB0111	Verified	60	Gowlaun Shale	Lough Nawbellion	0.05
Ballyshannon P.W.S.	194669	363816	Donegal	P.W.S.	0600PUB1105	Verified	[a]500	Bundoran Shale, Slishwood Division	Lough Unshin	0.272
Cashilard P.W.S.	193788	362964	Donegal	P.W.S.	0600PUB1106	Verified	158	Slishwood Division	St. Columbkill Lake	0.065
Doobally G.W.S.	200000	332900	Cavan	G.W.S.	0200PRI2015/ 0200PRI0234	Verified	75	Lackagh Sst	Tents Lough	0.042
Aughnasheelan G.W.S.	203279	316821	Leitrim	G.W.S.	1700PRI1080	Verified	83	Gowlaun Shale	Lough Nabellbeg	0.0122
Ballinagleragh G.W.S.	204874	323603	Leitrim	G.W.S.	1700PRI1058	Verified	141	Lackagh Sst	Nambrack Lough	0.0724

Supply name	Easting	Northing	County	Supply type	Supply code	Status	Abstraction rate (m^3/d)	Geological formation	Waterbody	Lake area (km^2)
Lackagh Lough G.W.S.	191944	332032	Leitrim	G.W.S.	1700PRI1102	[b]Unverified	236	Lackagh Sst	Lackagh Lough	0.067
Lavareen Lough G.W.S.	216972	304590	Leitrim	G.W.S.	1700PRI1056	Verified	10	Drumgesh Shale	Lavareen Lough	–
Lough Anarry, Rubbal G.W.S.	181753	333879	Leitrim	P.W.S.	1700PUB2000	[b]Unverified	135	Slishwood Division	Lough Anarry	0.111

[a]The scheme consists of a lake source (Lough Unshin), a spring and two boreholes which are used to augment the spring supply at times of low flow. The total abstraction volume for all three sources is 1694.

[b]Data obtained from 2009 register; data confirming current abstraction not available at time of publication.

Table 5.6. Lake abstractions – CB study area

Supply name	Easting	Northing	County	Supply type	Classification	Scheme code	Status	Abstraction rate (m^3/d)	Type	Geological formation	Waterbody	Lake area (km^2)
Lissycasey	118418	165605	Clare	G.W.S.	Private regulated	0300PRI2004	Verified	814 (lake used as backup or supplemental supply during high demand)	Lake and borehole	Central Clare Group	Acrow lough	0.06
West Clare Regional WS	111321	172287	Clare	P.W.S.	Public	0300PUB1066	Verified	12,000	Lake	Central Clare Group	Doo Lough	1.3
Kilmaley/Inagh	117999	170919	Clare	G.W.S.	Private regulated	0300PRI2010	Verified	1200	Lake	Central Clare Group	Lough Naminna	0.202

Table 5.7. Number of surface water supplies in or near the UGEE licence areas

Type of supply	Public supply[a]	Private regulated supply[b]	Other private abstractions[c]
Northwest Carboniferous Basin			
Lake	14	10	ND
River/stream	4	5	ND
Clare Basin			
Lake	1	2	ND
River/stream	0	ND	ND

[a]Public water supply operated by IW (via local authorities) or NIW

[b]Monitored by local authorities or NIEA. Includes Public Group Water Schemes, Private Group Water Schemes and Small Private Supplies

[c]Abstractions with potential use for human consumption –commercial/industrial activity (e.g. hotels). It does not includes some recorded domestic wells

[d]ND means no data is available. It does not imply that there are no supplies that fall within this category.

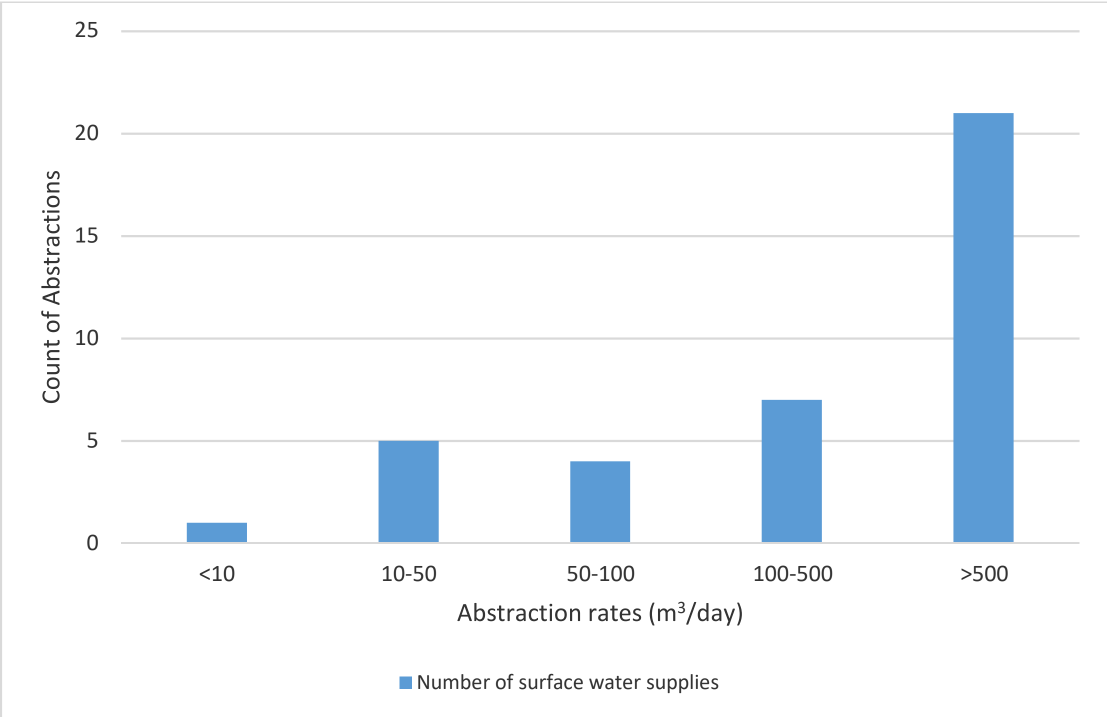


Figure 5.7. Summary of abstraction ranges for surface water sources.

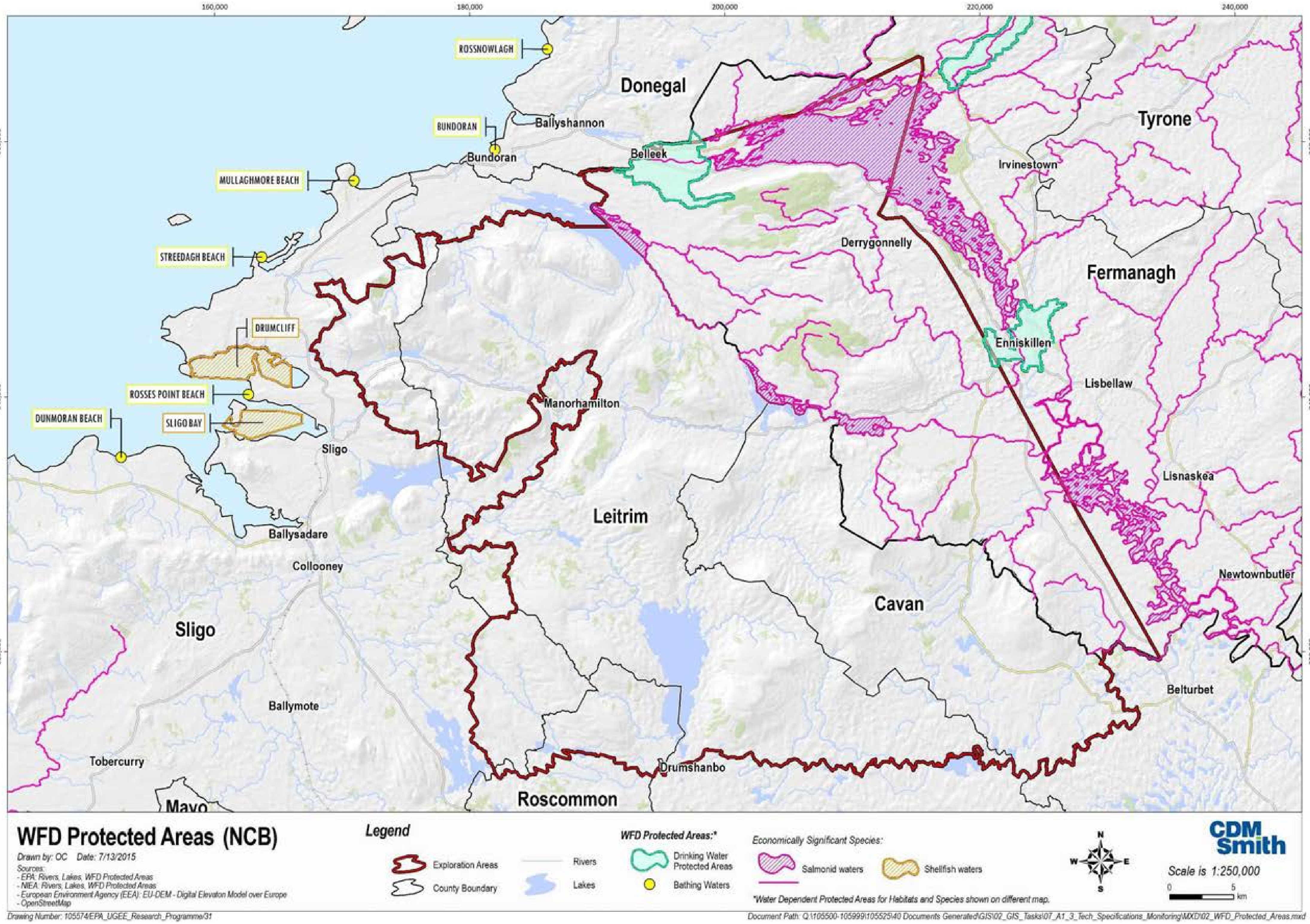


Figure 5.8. WFD Protected Areas – NCB study area.

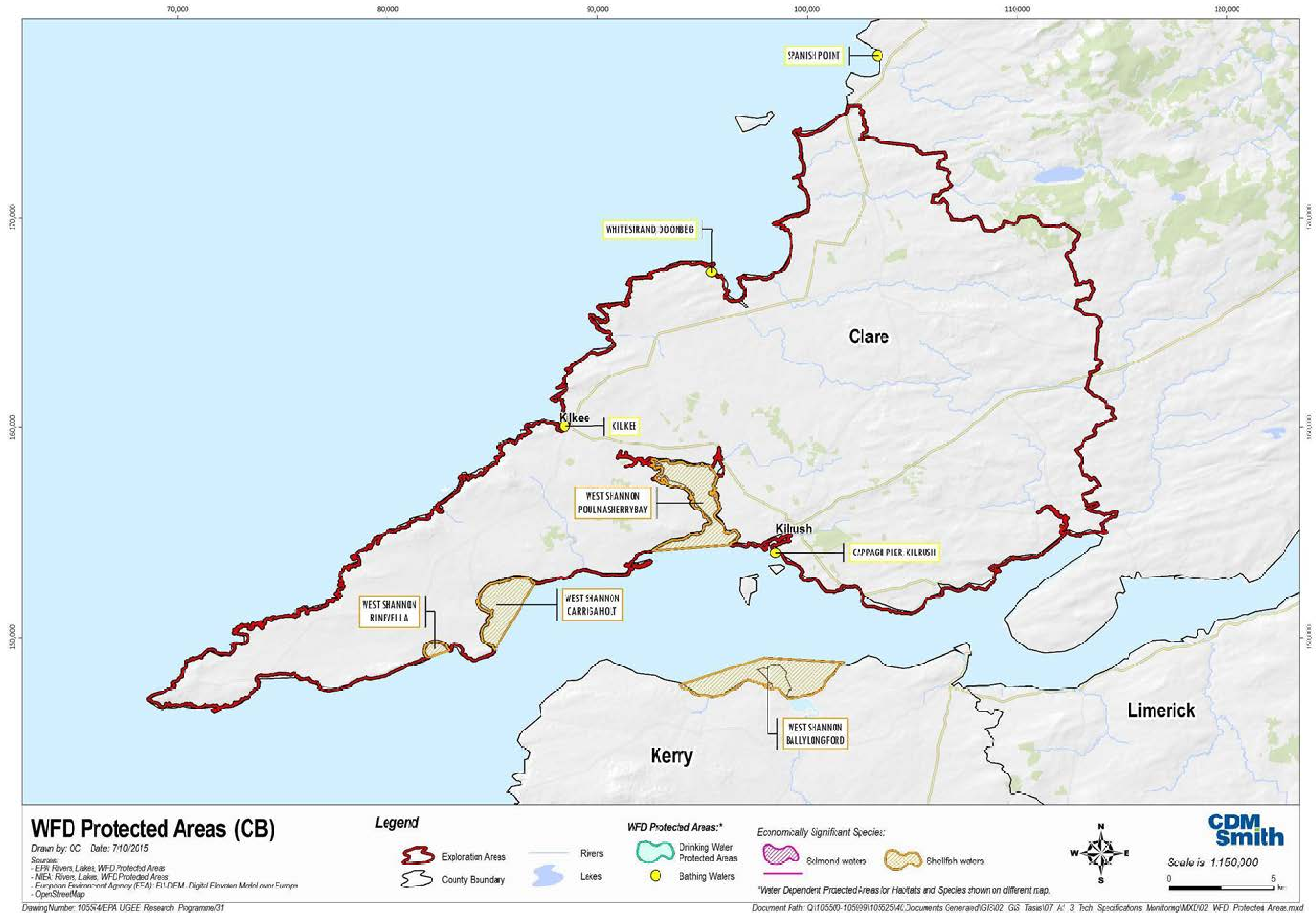


Figure 5.9. WFD Protected Areas – CB study area.

These are shown in Figure 5.10 and Figure 5.11 for the two case study areas, and those which are considered to be specifically water-dependent are identified in Figure 5.12 and Figure 5.13.

5.3.1 Natura 2000 Sites

Natura 2000 sites are nature conservation sites established under the EC Habitats Directive (92/43/EEC) and the Birds Directives (2009/147/EC). They incorporate Special Areas of Conservation (SACs) and Special Protected Areas (SPAs), as outlined below.

5.3.1.1 Special Areas of Conservation

SACs are protected sites under the EC Habitats Directive. Habitats which are named in Annexes I and II of the Directive include raised bogs, blanket bogs, turloughs, sand dunes, machairs, heaths, lakes, rivers, woodlands, estuaries and sea inlets. In Ireland, 25 species are afforded protection under the Directive, including salmon, otter and the freshwater pearl mussel (NPWS, 2014). Within the case study areas, SACs that are designated as Natura 2000 sites are listed in Table 5.8. They cover a total land area of approximately 326 km^2, equivalent to 12% of the UGEE licence area. Two of the SACs are cross-border SACs:

- Cuilcagh – Anierin Uplands (IE)/Cuilcagh Mountain (Northern Ireland) – Natura 2000 codes IE0000584/UK0016603
- Lough Melvin (IE/Northern Ireland) – Natura 2000 codes IE0000428/UK0030047

5.3.1.2 Special Protected Areas

SPAs are listed in Table 5.9, and are protected sites under the EC Birds Directive, which covers the protection of rare and vulnerable species of wild birds (as listed in Annex I of the directive), as well as regularly occurring migratory species. The SPAs cover a land area of approximately 19.2 km^2 within the case study areas, equivalent to less than 1 % of the total study area.

5.3.2 National level designations

5.3.2.1 Natural Heritage Areas

Natural Heritage Areas (NHAs) are areas in Ireland which are considered important for the habitats which are present or which hold species of plants and animals whose habitat needs protection. All NHAs that have been given legal protection are listed in Table 5.10 for the two case study areas, and all such areas are bogs. There are additional proposed NHAs (pNHAs), which were published on a non-statutory basis in 1995, and which have limited legal protection under Local Authority Development Plans. These sites are of significance at a national level as several pNHAs have overlapping designations as SACs and/or SPAs. NHAs can also be designated for areas of special geological interest.

5.3.2.2 Areas of Special Scientific Interest

Areas of Special Scientific Interest (ASSIs) are designated in Northern Ireland under the Environment Order (Northern Ireland) 2002. ASSIs are designated as areas of special scientific interest because of flora and/or fauna, or geological features. Several ASSIs have overlapping designations as SACs and/or SPAs. The ASSIs that are present in the NCB are listed in Table 5.11.

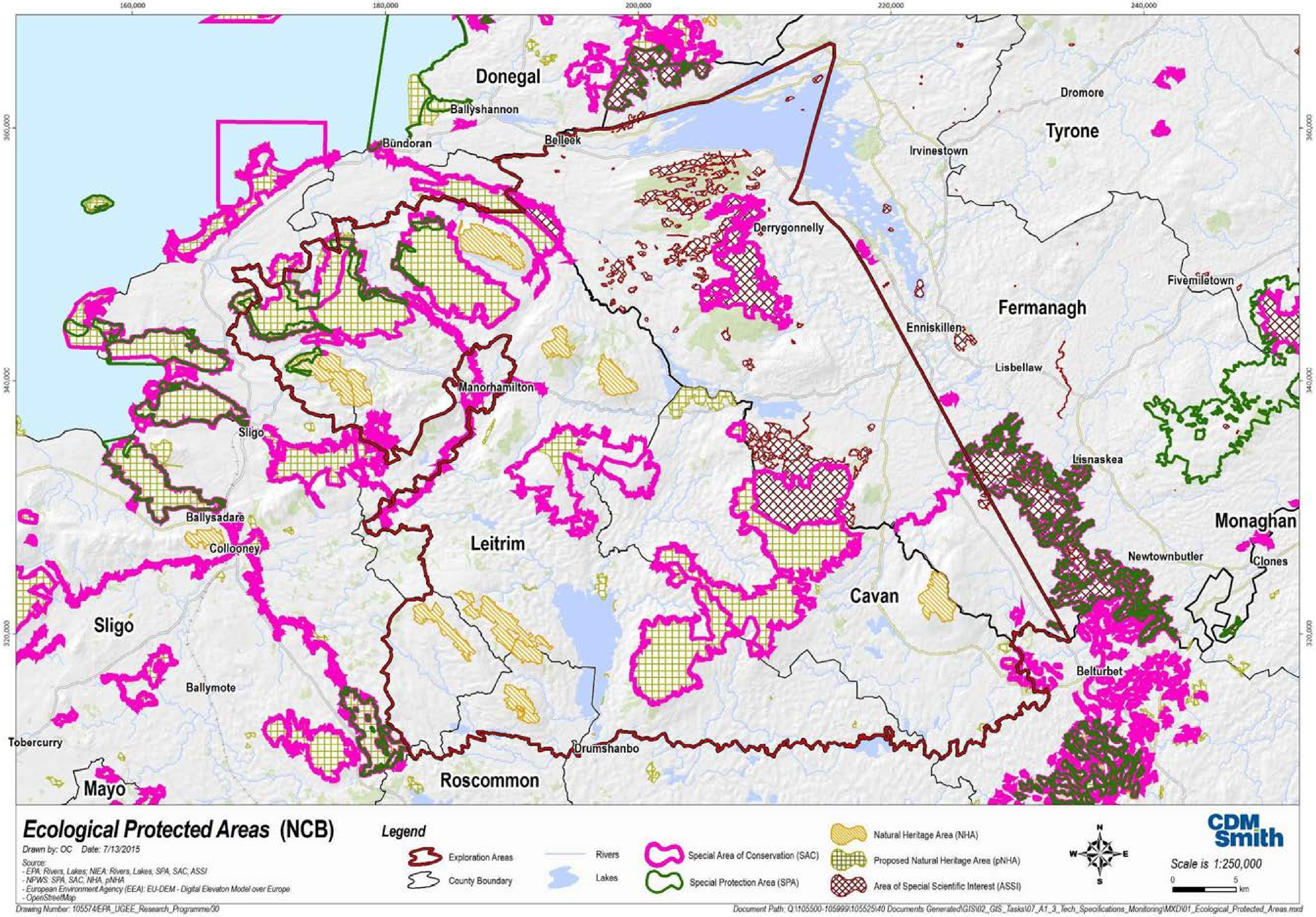


Figure 5.10. Ecological protected areas – NCB study area.

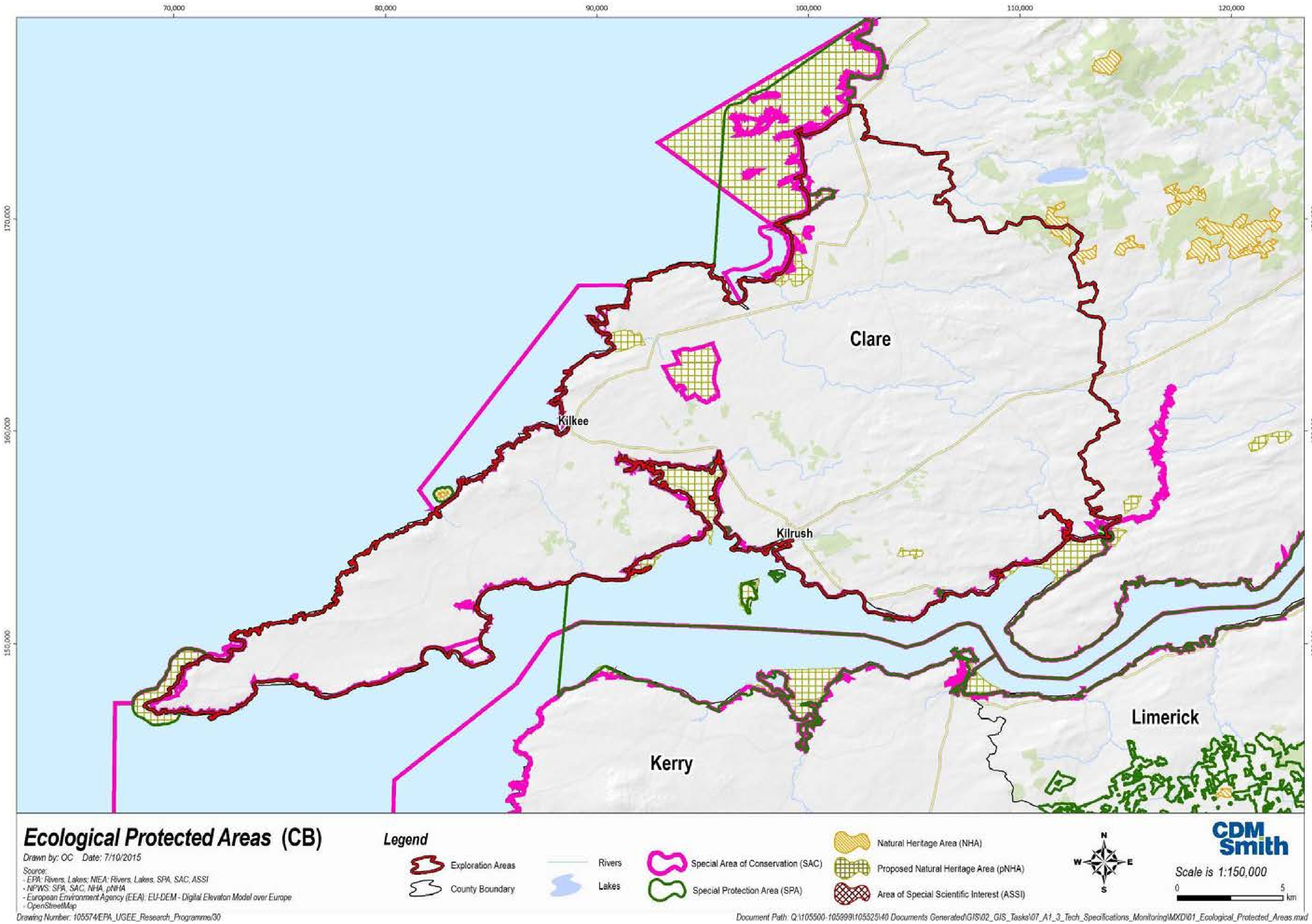


Figure 5.11. Ecological protected areas – CB study area.

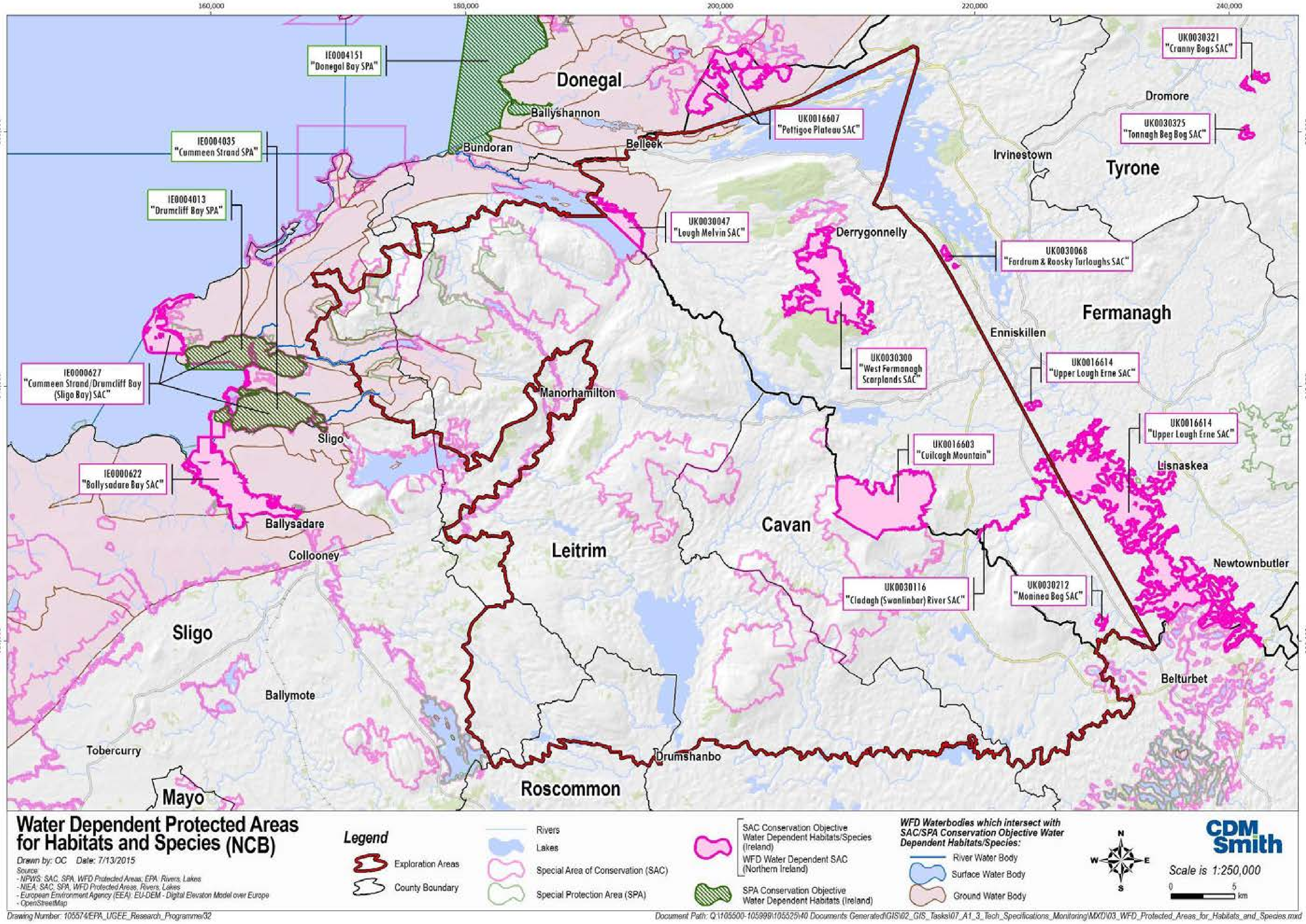


Figure 5.12. Water Dependent Protected Areas for Habitats and Species – NCB study area.

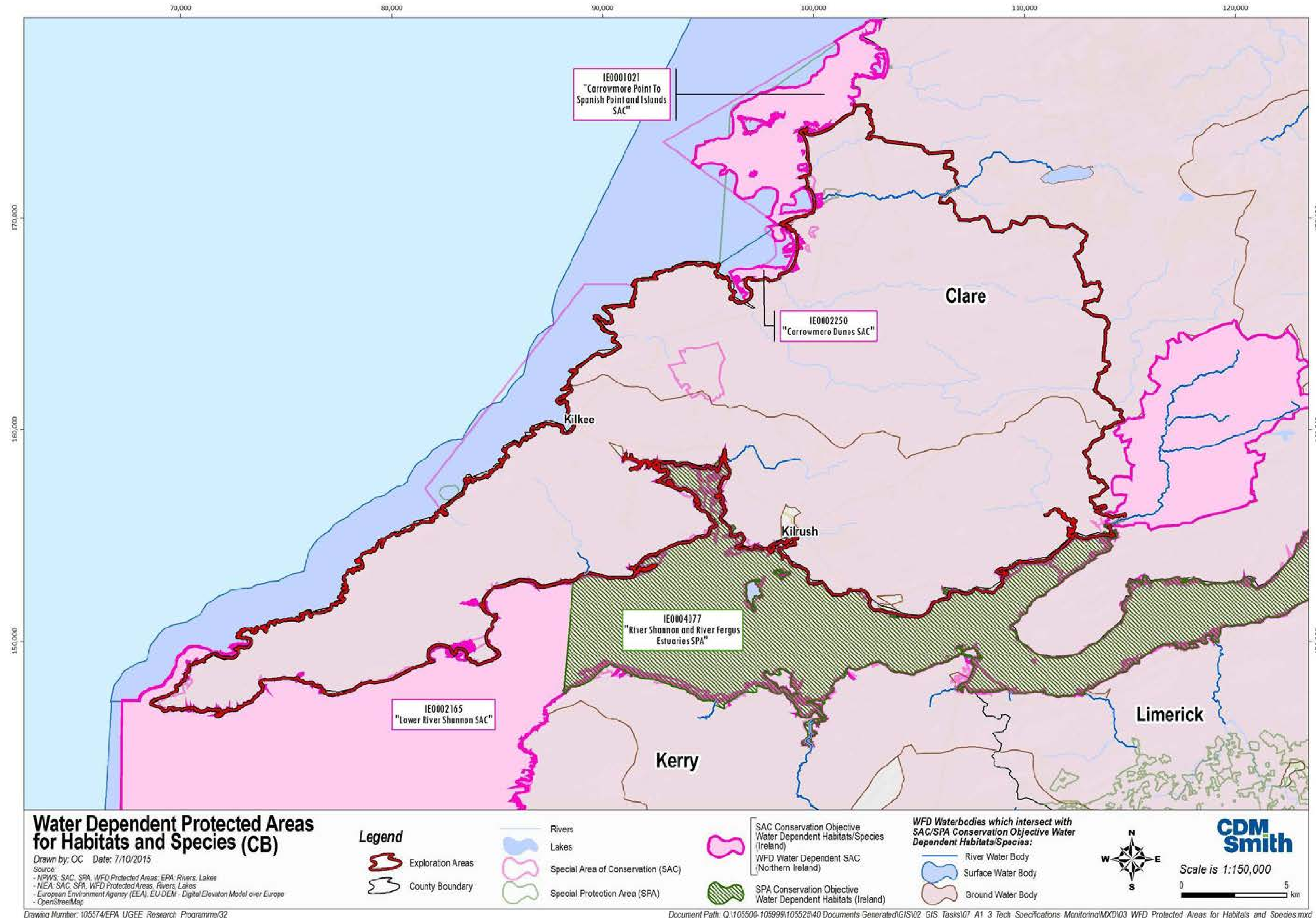


Figure 5.13. Water Dependent Protected Areas for Habitats and Species – CB study area.

Table 5.8. SACs within or adjoining the case study areas and their qualifying interests

Site name	Natura 2000 code	SAC selected for the following habitats	WFD Protected Area – 1st cycle	WFD Protected Area – 2nd cycle	Designated GWDTE	GWDTE habitat – qualifying interest	SAC selected for the following species
Ben Bulben, Gleniff And Glenade Complex	IE0000623	[3260] Floating River Vegetation [4030] Dry Heath [4060] Alpine and Subalpine Heaths [5130] Juniper Scrub [7220] Petrifying Springs* [8120] Calcareous Scree [8210] Calcareous Rocky Slopes	Y	N	N	Y	[1013] Geyer's Whorl Snail *(Vertigo geyeri)* [1355] Otter *(Lutra lutra)*
Lough Arrow	IE0001673	[3140] Hard Water Lakes	Y	N	N	N	
Lough Melvin	IE0000428	[3130] Oligotrophic to Mesotrophic Standing Waters	Y	N	N	N	[1106] Atlantic Salmon *(Salmo salar)* [1355] Otter *(Lutra lutra)*
Arroo Mountain	IE0001403	[4010] Wet Heath [7130] Blanket Bogs (Active)* [7220] Petrifying Springs* [8120] Calcareous Scree [8210] Calcareous Rocky Slopes	Y	N	N	Y	
Glenade Lough	IE0001919	[3150] Natural Eutrophic Lakes	Y	N	N	N	[1092] White-clawed Crayfish (*Austropotamobius pallipes)* [1833] Slender Naiad (*Najas flexilis)*

Site name	Natura 2000 code	SAC selected for the following habitats	WFD Protected Area – 1st cycle	WFD Protected Area – 2nd cycle	Designated GWDTE	GWDTE habitat – qualifying interest	SAC selected for the following species
Lough Gill	IE0001976	[3150] Natural Eutrophic Lakes [91A0] Old Oak Woodlands [91E0] Alluvial Forests*	Y	N	N	Y	[1092] White-clawed Crayfish *(Austropotamobius pallipes)* [1095] Sea Lamprey *(Petromyzon marinus)* [1096] Brook Lamprey *(Lampetra planeri)* [1099] River Lamprey (*Lampetra fluviatilis)* [1106] Atlantic Salmon *(Salmo salar)* [1355] Otter *(Lutra lutra)*
Boleybrack Mountain	IE0002032	[3160] Dystrophic Lakes [4010] Wet Heath [4030] Dry Heath [6410] Molinia Meadows [7130] Blanket Bogs (Active)*	Y	N	N	Y	
Cuilcagh-Anierin Uplands (IE); Cuilcagh Mountain (NI). (Note – cross-border SAC)	IE0000584/ UK0016603	[3130] Oligotrophic to Mesotrophic Standing Waters [3160] Dystrophic Lakes [4010] Wet Heath [4030] Dry Heath [6230] Species-rich Nardus Grassland* [7130] Blanket Bogs (Active)* [8220] Siliceous Rocky Slopes	Y	N	N	Y	
Corratirrim	IE0000979	[8240] Limestone Pavement*	Y	N	N	N	
Lough Oughter And Associated Loughs	IE0000007	[3150] Natural Eutrophic Lakes [91D0] Bog Woodland*	Y	N	N	N	[1355] Otter *(Lutra lutra)*

Site name	Natura 2000 code	SAC selected for the following habitats	WFD Protected Area – 1st cycle	WFD Protected Area – 2nd cycle	Designated GWDTE	GWDTE habitat – qualifying interest	SAC selected for the following species
Lower River Shannon	IE0002165	[1110] Sandbanks [1130] Estuaries [1140] Tidal Mudflats and Sandflats [1150] Coastal Lagoons* [1160] Large Shallow Inlets and Bays [1170] Reefs [1220] Perennial Vegetation of Stony Banks [1230] Vegetated Sea Cliffs [1310] Salicornia Mud [1330] Atlantic Salt Meadows [1410] Mediterranean Salt Meadows [3260] Floating River Vegetation [6410] Molinia Meadows [91E0] Alluvial Forests*	Y	Y	N	Y	[1029] Freshwater Pearl Mussel *(Margaritifera margaritifera)* [1095] Sea Lamprey *(Petromyzon marinus)* [1096] Brook Lamprey *(Lampetra planeri)* [1099] River Lamprey *(Lampetra fluviatilis*) [1106] Atlantic Salmon (*Salmo salar)* [1349] Bottle-nosed Dolphin (*Tursiops truncatus*) [1355] Otter (*Lutra lutra*)
Carrowmore Point To Spanish Point And Islands	IE0001021	[1150] Coastal Lagoons* [1170] Reefs [1220] Perennial Vegetation of Stony Banks [7220] Petrifying Springs*	Y	N	N	Y	
Carrowmore Dunes	IE0002250	[1170] Reefs [2110] Embryonic Shifting Dunes [2120] Marram Dunes (White Dunes) [2130] Fixed Dunes (Grey Dunes)*	Y	N	N	Y	[1014] Narrow-mouthed Whorl Snail (*Vertigo angustior*)
Kilkee Reefs	IE0002264	[1160] Large Shallow Inlets and Bays [1170] Reefs [8330] Sea Caves	Y	N	N	N	

Site name	Natura 2000 code	SAC selected for the following habitats	WFD Protected Area – 1st cycle	WFD Protected Area – 2nd cycle	Designated GWDTE	GWDTE habitat – qualifying interest	SAC selected for the following species
Tullaher Lough And Bog	IE0002343	[7110] Raised Bog (Active)* [7120] Degraded Raised Bog [7140] Transition Mires [7150] Rhynchosporion Vegetation	Y	N	N	Y	
Cummeen Strand/Drumcliff Bay (Sligo Bay) (Note – outside of study area but downstream & within Rosses Point GWB)	IE000627	[1130] Estuaries [1140] Tidal Mudflats and Sandflats [2110] Embryonic Shifting Dunes [2120] Marram Dunes (White Dunes) [2130] Fixed Dunes (Grey Dunes)* [5130] Juniper Scrub [7220] Petrifying Springs*	Y	Y	Y	Y	[1014] Narrow-mouthed Whorl Snail (Vertigo angustior) [1095] Sea Lamprey (Petromyzon marinus) [1099] River Lamprey (Lampetra fluviatilis) [1365] Common (Harbour) Seal (Phoca vitulina)
Largalinny	UK0030045	91A0 Old sessile oak woods with Ilex and Blechnum in the British Isles	N	N	Y	N	
Monawilkin	UK0016619	6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (* important orchid sites) 91A0 Old sessile oak woods with Ilex and Blechnum in the British Isles	N	N	N	N	
Lough Melvin (Note – cross-border SAC)	IE0000428/ UK0030047	3130 Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea* 6410 Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) 91A0 Old sessile oak woods with Ilex and Blechnum in the British Isles	Y	Y	Y	N	1106 Atlantic salmon (*Salmo salar)*

Site name	Natura 2000 code	SAC selected for the following habitats	WFD Protected Area – 1st cycle	WFD Protected Area – 2nd cycle	Designated GWDTE	GWDTE habitat – qualifying interest	SAC selected for the following species
West Fermanagh Scarplands	UK0030300	6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (* important orchid sites) 6410 Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) 8240 Limestone pavements (* Priority feature) 9180 Tilio-Acerion forests of slopes, screes and ravines (* Priority feature) 3150 Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* – type vegetation 4010 Northern Atlantic wet heaths with *Erica tetralix* 7130 Blanket bogs (* if active bog) (* Priority feature) 7220 Petrifying springs with tufa formation (Cratoneurion) (* Priority feature) 7230 Alkaline fens	Y	Y	Y	Y	
Cladagh (Swanlinbar) River	UK0030116	3260 Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation	Y	Y	N	N	1029 Freshwater pearl mussel Margaritifera

Site name	Natura 2000 code	SAC selected for the following habitats	WFD Protected Area – 1st cycle	WFD Protected Area – 2nd cycle	Designated GWDTE	GWDTE habitat – qualifying interest	SAC selected for the following species
Cuilcagh Mountain	UK0016603	7130 Blanket bogs (* if active bog) (* Priority feature) 3160 Natural dystrophic lakes and ponds 4010 Northern Atlantic wet heaths with Erica tetralix 4030 European dry heaths 4060 Alpine and Boreal heaths 8110 Siliceous scree of the montane to snow levels (*Androsacetalia alpinae* and *Galeopsietalia ladani)* 8220 Siliceous rocky slopes with chasmophytic vegetation	Y	Y	Y	Y	
Moninea Bog	UK0030212	7110 Active raised bogs (* Priority feature)	Y	Y	Y	Y	
Upper Lough Erne (Within the Erne SWB and Enniskillen GWB)	UK0016614	3150 Natural eutrophic lakes with Magnopotamion or Hydrocharition – type vegetation 91A0 Old sessile oak woods with Ilex and Blechnum in the British Isles 91E0 Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*)	Y	Y	Y	Y	1355 Otter (*Lutra lutra)*
Fardrum and Roosky Turloughs (Within the Erne SWB and Enniskillen GWB)	UK0030068	3180 Turloughs * Priority feature	Y	Y	Y	Y	

NI, Northern Ireland.

Table 5.9. SPAs within or adjoining the case study areas and their qualifying interests

Site name	Natura 2000 code	Features of interest	WFD Protected Area – 1st cycle	WFD Protected Area – 2nd cycle
Mid-Clare Coast SPA	004182	Cormorant (*Phalacrocorax carbo*) [A017] Ringed Plover (*Charadrius hiaticula*) [A137] Sanderling (*Calidris alba*) [A144] Purple Sandpiper (*Calidris maritima*) [A148] Dunlin (*Calidris alpina*) [A149] Turnstone (*Arenaria interpres*) [A169] Barnacle Goose (*Branta leucopsis*) [A396] Wetlands & Waterbirds [A999]	Y	N
River Shannon and River Fergus Estuaries SPA	004077	Cormorant (*Phalacrocorax carbo*) [A017] Whooper Swan (*Cygnus cygnus*) [A038] Light-bellied Brent Goose (*Branta bernicla hrota*) [A046] Shelduck (*Tadorna tadorna*) [A048] Wigeon (*Anas penelope*) [A050] Teal (*Anas crecca*) [A052]Pintail (*Anas acuta*) [A054] Shoveler (*Anas clypeata*) [A056] Scaup (*Aythya marila)* [A062] Ringed Plover (*Charadrius hiaticula*) [A137] Golden Plover (*Pluvialis apricaria*) [A140] Grey Plover (*Pluvialis squatarola*) [A141] Lapwing (*Vanellus vanellus*) [A142] Knot (*Calidris canutus*) [A143] Dunlin (*Calidris alpina*) [A149] Black-tailed Godwit (*Limosa limosa*) [A156] Bar-tailed Godwit (*Limosa lapponica*) [A157] Curlew (*Numenius arquata*) [A160] Redshank (*Tringa totanus*) [A162] Greenshank (*Tringa nebularia*) [A164] Black-headed Gull (*Chroicocephalus ridibundus*) [A179] Wetlands & Waterbirds [A999]	Y	Y

Site name	Natura 2000 code	Features of interest	WFD Protected Area – 1st cycle	WFD Protected Area – 2nd cycle
Loop Head SPA	004119	Kittiwake (*Rissa tridactyla*) [A188] Guillemot (*Uria aalge*) [A199]	Y	N
Sligo/Leitrim Uplands SPA	004187	Peregrine (*Falco peregrinus*) [A103] Chough (*Pyrrhocorax pyrrhocorax*) [A346]	Y	N
Lough Arrow SPA	004050	Little Grebe (*Tachybaptus ruficollis*) [A004] Tufted Duck (*Aythya fuligula*) [A061] Wetlands & Waterbirds [A999]	Y	N
Cummeen Strand SPA (Note – outside of study area but downstream)	004035	Light-bellied Brent Goose (Branta bernicla hrota) [A046] Oystercatcher (Haematopus ostralegus) [A130] Redshank (Tringa totanus) [A162] Wetland and Waterbirds [A999]	Y	Y
Drumcliff Bay SPA (Note – outside of study area but downstream)	004013	Sanderling (Calidris alba) [A144] Bar-tailed Godwit (Limosa lapponica) [A157] Wetland and Waterbirds [A999]	Y	Y
Upper Lough Erne	UK9020071	*Cygnus* A038	Y	Y

Table 5.10. NHAs and proposed NHAs within the two study areas

Site code	Site name	Designation
002400	Cragnashingaun Bogs NHA	NHA
000009	Slieve Rushen Bog NHA	NHA
002430	Aghavoghil Bog NHA	NHA
002384	Dough/Thur Mountains NHA	NHA
002435	Crockauns/Keelogyboy Bogs NHA	NHA
002321	Corry Mountain Bog NHA	NHA
002321	Corry Mountain Bog NHA	NHA
000617	Kilronan Mountain Bog NHA	NHA
002435	Crockauns/Keelogyboy Bogs NHA	NHA
002415	Carrane Hill Bog NHA	NHA
001021	Carrowmore Point To SPAnish Point And Islands	pNHA
001007	White Strand/Carrowmore Marsh	pNHA
000200	Farrihy Lough	pNHA
000070	Tullaher Lough And Bog NHA	pNHA
000065	Poulnasherry Bay	pNHA
000027	Clonderalaw Bay	pNHA
001025	St. Senan's Lough	pNHA
000045	Loop Head	pNHA
000986	Lough Macnean Upper	pNHA
000979	Corratirrim	pNHA
000584	Cuilcagh – Anierin Uplands	pNHA
000976	Blackrock's Cross	pNHA
000974	Annagh Lough (Ballyconnell)	pNHA
000007	Lough Oughter And Associated Loughs	pNHA
000977	Clonty Lough	pNHA
000428	Lough Melvin	pNHA
001415	Kinlough Wood	pNHA
001403	Arroo Mountain	pNHA
000623	Ben Bulben, Gleniff And Glenade Complex	pNHA
001919	Glenade Lough	pNHA
001404	Bonet River	pNHA
001418	O'Donnell's Rock Wood	pNHA
001976	Lough Gill	pNHA
002032	Boleybrack Mountain	pNHA
000426	Kilgarriff Marsh	pNHA
001419	Owengar Wood	pNHA
000427	Lough Allen, South End and Parts	pNHA
001409	Cromlin Bridge Wood	pNHA
001407	Corduff Lough	pNHA
001413	Garadice Lough Wood	pNHA
001673	Lough Arrow	pNHA

Table 5.11. Areas of Special Scientific Interest in the NCB study area

Site reference	Site name	Site reference	site name
ASSI119	Magheramenagh	ASSI236	Lenaghan Wood
ASSI020	Drumlisaleen	ASSI235	Lurgan River Wood
ASSI019	Lergan	ASSI248	Lough Aleater
ASSI191	The Cliffs of Magho	ASSI247	Lough Scolban
ASSI018	Moneendogue	ASSI263	Cruninish Island
ASSI108	Braade	ASSI264	Hare Island
ASSI016	Beagh Big	ASSI297	Knocknashangan
ASSI111	Largalinny	ASSI299	Ross
ASSI168	Glennasheevar	ASSI298	Blackslee
ASSI017	Garvros	ASSI322	Drumbegger
ASSI013	Monawilkin	ASSI324	Keadew
ASSI139	Ground Bridge	ASSI319	Gravel Ridge Island
ASSI140	Lough Melvin	ASSI332	Tower More
ASSI190	Tullysranadeega	ASSI331	Glen East
ASSI201	West Fermanagh Scarplands	ASSI353	Lough Anierin
ASSI001	Carrickbrawn	ASSI359	Lough Naman Bog and Lake
ASSI144	Boho	ASSI380	Lough Formal
ASSI120	Bellanaleck	ASSI375	Marlbank
ASSI070	Tattenamona Bog	ASSI384	Scribbagh
ASSI207	Kilnameel	ASSI270	Lough Navar Scarps and Lakes
ASSI048	Corraslough Point	ASSI376	Florence Court
ASSI093	Upper Lough Erne – Belleisle	ASSI385	Stranacally
ASSI166	Knockninny Hill	ASSI366	Gortalughany
ASSI200	Cladagh (Swanlinbar) River	ASSI394	Tonnagh Quarry
ASSI069	Cuilcagh Mountain	ASSI393	Lough Alaban
ASSI094	Upper Lough Erne – Trannish	ASSI271	Big Dog Scarps and Lakes
ASSI015	Moninea Bog	ASSI403	Rushy Hill
ASSI076	Killymackan Lough	ASSI400	Frevagh
ASSI242	Conagher	ASSI402	Drumcully
ASSI244	Mullynaskeagh		

5.3.3 *Areas designated to protect economically significant species*

Areas designated to protect economically significant species were established under European directives which aimed to protect shellfish (79/923/EEC) and freshwater fish (78/659/EEC). Locations of salmonid waters are included in Figure 5.8 and Figure 5.9. In the NCB, Ireland has comparatively fewer rivers and lakes designated as salmonid waters than Northern Ireland.

5.3.4 *Bathing waters*

Bathing waters are designated under the amended Bathing Water Directive (2006/7/EC), and are also included on Figure 5.8 and Figure 5.9.

5.3.5 *Nutrient sensitive areas*

Nutrient sensitive areas comprise nitrate vulnerable zones and polluted waters designated under the Nitrates Directive (91/676/EEC) and areas designated as sensitive areas under the Urban Waste

Water Treatment Directive (91/271/EEC). Nitrate is not a particular contaminant of concern in a UGEE context, thus nitrate sensitive areas were not considered further in this study.

5.3.6 Areas designated for the protection of habitats or species

Areas designated for the protection of habitats or species are areas previously designated for habitats or species where maintaining or improving the WFD status of water is important for their protection. They comprise the water-dependent habitats of Natura 2000 sites and the Registers of Protected Areas that include SACs and SPAs listed in Table 5.8 and Table 5.9. During the first cycle of WFD River Basin Management Plans (2009–2014) in Ireland, 44 of the habitats that are listed under Annex I of the EC Habitats Directive were determined to be water-dependent (Ó'Riain *et al.* 2005; Mayes and Codling, 2009). These are identified in the "WFD Protected Area – 1st cycle" column in Table 5.8 and Table 5.9.

In 2015, the EPA and NPWS revised the designation of which SACs and SPAs are water-dependent for the second cycle of the River Basin Management Plans (2015–2021). Water-dependent habitats were prioritised based on conservation objectives of the habitats and species, and are noted as "WFD Protected Area – 2nd cycle" in Table 5.8 and shown in Figure 5.8 and Figure 5.9.

In Northern Ireland, there are additional areas designated as WFD protected areas for habitats and species, however, the boundaries around particular habitats have not been delineated. The difference in designation between Ireland and Northern Ireland has meant that some cross-border Natura 2000 sites are not completely designated as a WFD protected area, such as the Lough Melvin SAC shown in Figure 5.12.

5.4 Groundwater Dependent Terrestrial Ecosystems

Some SACs are designated as GWDTEs. These are wetlands where the associated ecology depends on groundwater for supporting conditions, including groundwater levels, flow or discharge and/or chemistry (e.g. nutrient fluxes, alkalinity). Figure 5.14 and Figure 5.15 show the designated GWDTEs associated with each study area. The delineation of GWDTEs under the WFD is carried out by each member state, and methods employed in Ireland and Northern Ireland are summarised below.

5.4.1 Ireland designated GWDTEs

In Ireland, GWDTEs were designated by the EPA and the NPWS (EPA, 2014b). GWDTEs contain habitats that are listed under Annex I and species that are listed under Annex II of the EU Habitats Directive. GWDTEs can be protected as SACs. Only GWDTEs that were considered to be at risk of failing WFD environmental objectives were originally included on the Register of SACs in Ireland. None were located within the UGEE licence areas. However, one petrifying spring (Ballincar) is located within the Cumeen Strand/Drumcliffe Bay (Sligo Bay) SAC, approximately 4.5 km downstream of the NCB licence area. Additional GWDTEs (with qualifying interests as SACs) have been identified and designated by the NPWS during the second WFD River Basin Management Cycle. None are located within the two UGEE licence areas.

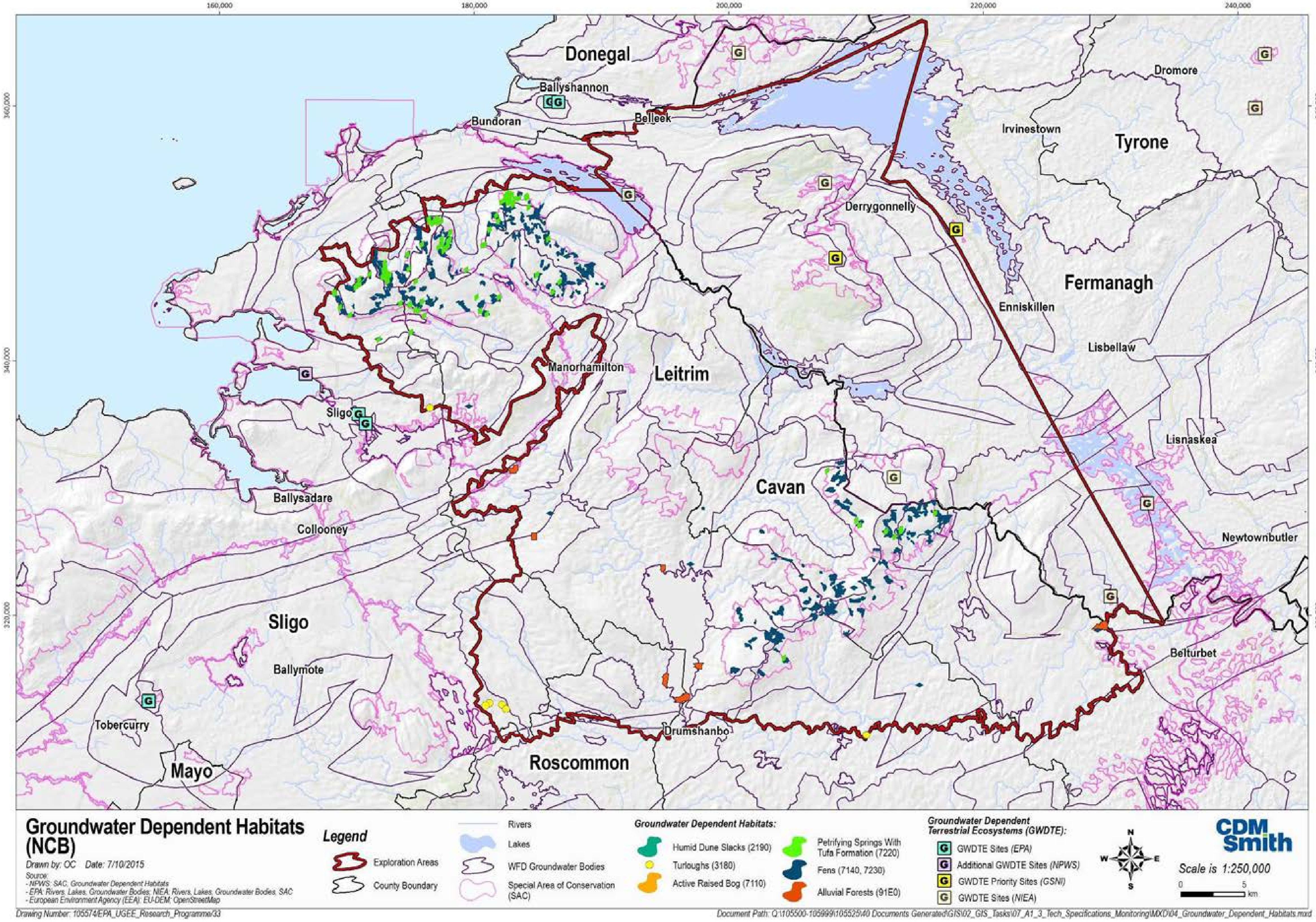


Figure 5.14. GWDTEs – NCB study area.

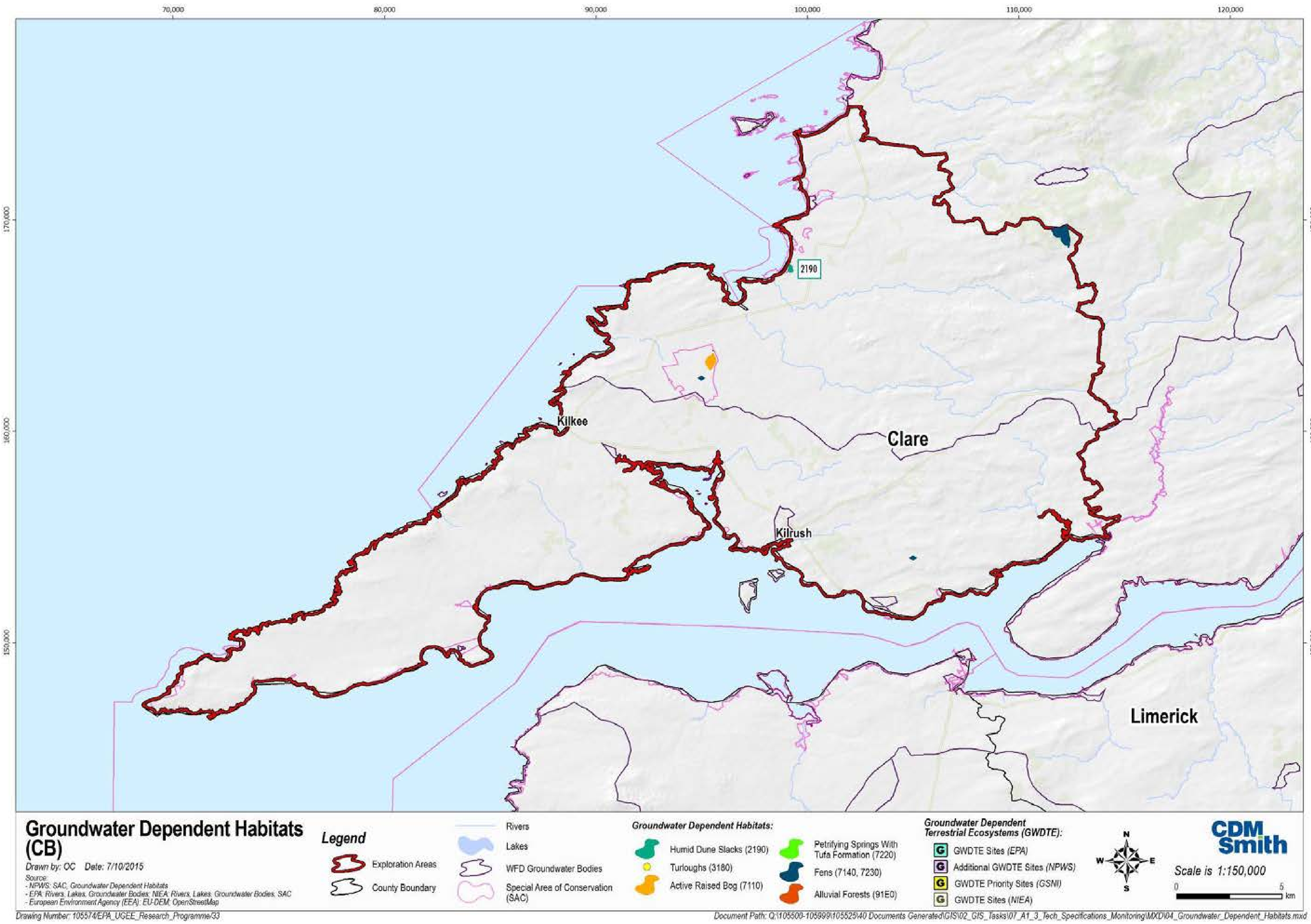


Figure 5.15. GWDTEs – CB study area.

5.4.2 Northern Ireland designated GWDTEs

In Northern Ireland, GWDTEs were identified from ecological and hydrogeological assessment. The National Vegetation Classification (NVC) was used to categorise the dependence of SACs and SPAs on groundwater as high, moderate or low. Those considered to be high were assigned as GWDTEs (MacDonald *et al.*, 2005). Six GWDTEs were identified by the NIEA (2014b) in the Lough Allen Basin: Largalinny, Lough Melvin, West Fermanagh Scarplands, Cuilcagh Mountain, Moninea Bog, Upper Lough Erne and Fardrum and Rooskey Turloughs. These are included in Table 5.8 and Figure 5.14), and they include active blanket and raised bogs, petrifying springs, alluvial forests and alkaline fens. Two have been prioritised by the GSNI based on further assessment:

- West Fermanagh Scarplands SAC – several petrifying springs associated with the Dartry and Glencar limestones; and
- Fardrum and Rooskey Turloughs SAC – associated with the Ballyshannon Limestone Formation. They are considered to be "at risk" of failing WFD environmental objectives on the basis of elevated nitrate concentrations in related groundwater bodies.

5.4.3 Undesignated GWDTEs

A recent research project of GWDTEs in Ireland, undertaken by Kimberley and Coxon (2013), identified 11 different habitat types, see Table 5.12, as those habitat types which can be considered '*most groundwater dependent*'.

Table 5.12. List of groundwater-dependent terrestrial ecosystem types

Annex I habitat type	Natura 2000 code
Alkaline fen	7230
[a]Calcareous fen with Cladium mariscus and Carex davalliana	7210
[a]Petrifying springs with tufa formation (Cratoneurion)	7220
Transition mire (quaking bogs)	7140
[a]Active raised bog	7110
[a]Turloughs	3180
Blanket bog ([a]if active) (FLUSHES ONLY)[b]	7130
Northern Atlantic wet heaths with Erica tetralix (FLUSHES ONLY)[b]	4010
[a]Alluvial forests with Alnus glutinosa and Fraxinus excelsior	91EO
Machair ([a]in Ireland)	21AO
Humid dune slacks	2190

[a]Indicates a priority habitat for conservation.

[b]Identifies Annex I habitat types where the focus is on flushed areas only

These habitat types were checked against the qualifying interests of the SACs and SPAs listed in Table 5.8 and Table 5.9 to determine whether any of the 11 habitat types were present in the designated SACs and SPAs. Based on this check, 9 of the 17 SACs that were not designated as GWDTEs on the WFD Register of Protected Areas were flagged as having Annex I habitat type attributes (i.e. qualifying interests).

5.4.3.1 Identification of undesignated GWDTEs

In 2013, the NPWS and Joint Nature Conservation Committee (JNCC) published a report on the conservation status of all habitats and species listed in the annexes of the Habitats Directive as required under Article 17 of the Directive. In Ireland, habitat surveys have been undertaken since the last Article 17 report published in 2007, and the updated mapping in Ireland has been obtained from the NPWS. In Northern Ireland, locations of habitats were obtained from the "Individual Habitat Reports – 3rd UK Habitats Directive Reporting" available on the JNCC website (JNCC, 2013).

A summary of the updated mapping is highlighted in Table 5.13.

Table 5.13. Summary of updated GWDTE mapping

Type (Natura 2000 code)	Ireland study areas	Northern Ireland study area
Turloughs (3180)	Six turloughs are recorded by NPWS. See Figure 5.16. Ballinlig, Black Lough, Lough Agh and White Lough are located near Lough Arrow (thus, associated with the Bricklieve karst). Lough Anelteen is just north of Lough Gill (thus, Dartry karst) and Edentinny Ballinamore is located southwest of Ballinmore town (also Bricklieve karst). There are no turloughs in the CB study area.	Fardrum and Roosky Turloughs SAC near Lough Erne
Alluvial forests (91EO)	Six areas of alluvial forests are mapped. None are named. All are in the NCB. Four are located along the margins of Lough Allen, and are outside of SACs. One is mapped along a stream at Killavoggy. Another is mapped along Annagh Lough near Ballyconnell. There are no alluvial forests mapped in the CB study area.	Mature alluvial forests (JNCC, 2013) are mapped within the Upper Lough Erne SAC
Calcareous fens: Alkaline fens (7230) and Cladium fens (7210)	Mapped within three SACs in the NCB study area: a) Ben Bulben, Gleniff and Glenade Complex, b) Arroo Mountain and c) Cuilcagh – Anierin Uplands. See Figure 5.17.	Alkaline fens are widespread in the West Fermanagh Scarplands SAC. Cladium fens are only known in few locations where they occur in small stands associated with alkaline fens. None are believed to be present in the UGEE licence area (JNCC, 2013).
Transition Mire (Quaking Bogs) (7140)	None are mapped but may be present in a variety of locations, both in Ireland and NI, and both in fen situations in lowlands and within the blanket bog landscape (JNCC, 2013).	
Petrifying springs with tufa formations (7220)	Frequent in three SACs: a) Ben Bulben, Gleniff And Glenade Complex, b) Arroo Mountain and c) Cuilcagh – Anierin Uplands. In particular petrifying springs occurring on the Ben Bulben Range are considered by NPWS (2013b) to constitute a distinct group of high conservation value. The overall conservation status is described as inadequate due to general pressures such as grazing, pollution and drainage and abstractions (NPWS, 2013b). There are no petrifying springs in the CB study area.	Present in the West Fermanagh Scarplands and is recorded from the Marlbank ASSI (JNCC, 2013).

Type (Natura 2000 code)	Ireland study areas	Northern Ireland study area
Flushes in Blanket Bog (7130) and Wet Heath (4010)	Wet heaths and blanket bogs are mapped by the NPWS, however areas of flushes are not identified. In addition, not all flushes are significantly groundwater dependent (Kimberly and Coxon, 2013).	No information on the location of wet heath and blanket bog flushes was found in JNCC reports.
Active raised bog (7110)	Tullaher Lough and Bog SAC in the CB study area. None mapped in the NCB study area.	Most of County Fermanagh such as Moninea Bog SAC but the boundaries are not delineated
Humid Dune Slacks (2190) and Machair (21AO)	Carrowmore Dunes SAC in the CB study area. There are no machair habitats mapped in either study area.	None.

NI, Northern Ireland.

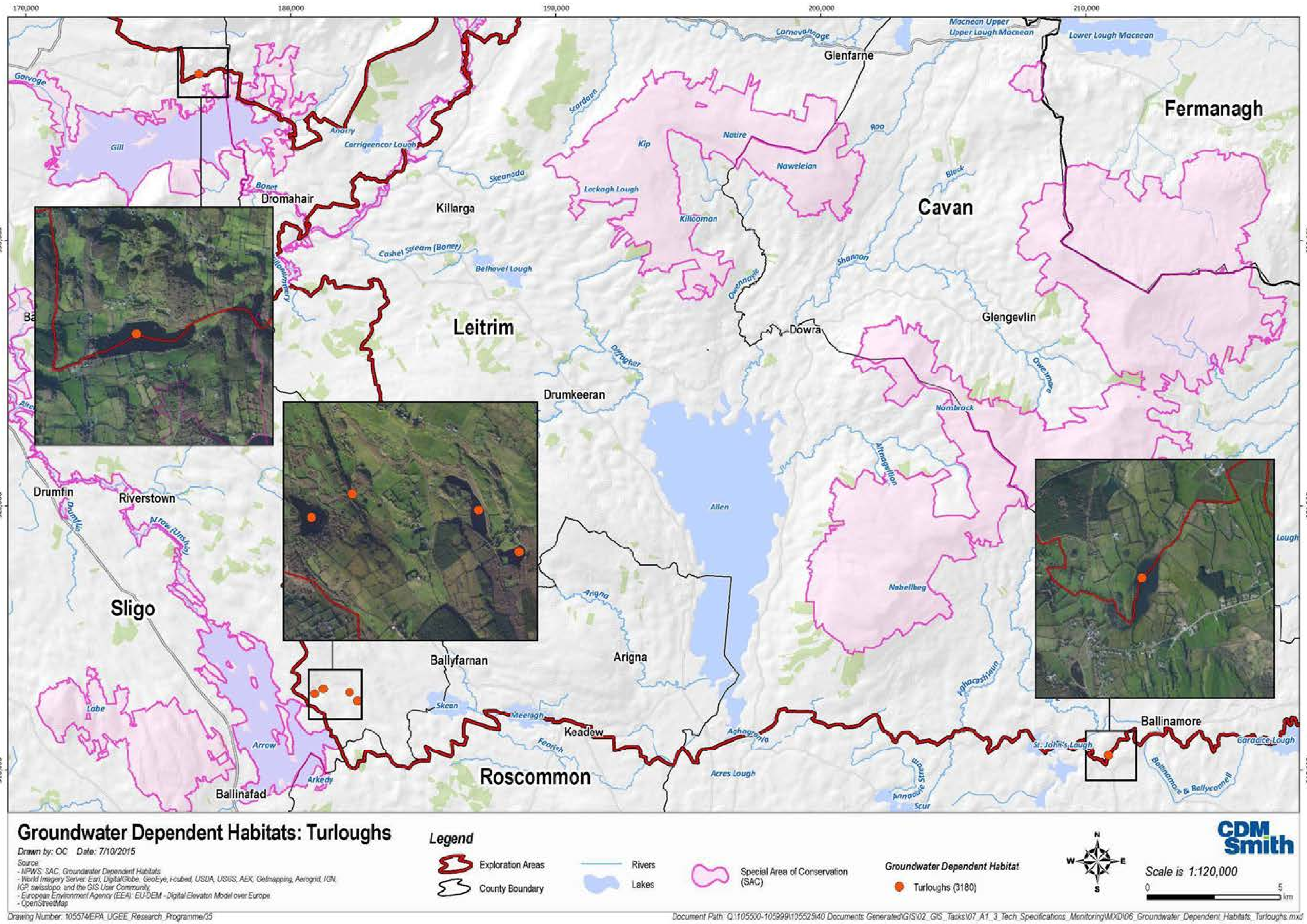


Figure 5.16. Turlough Locations – NCB study area in Ireland.

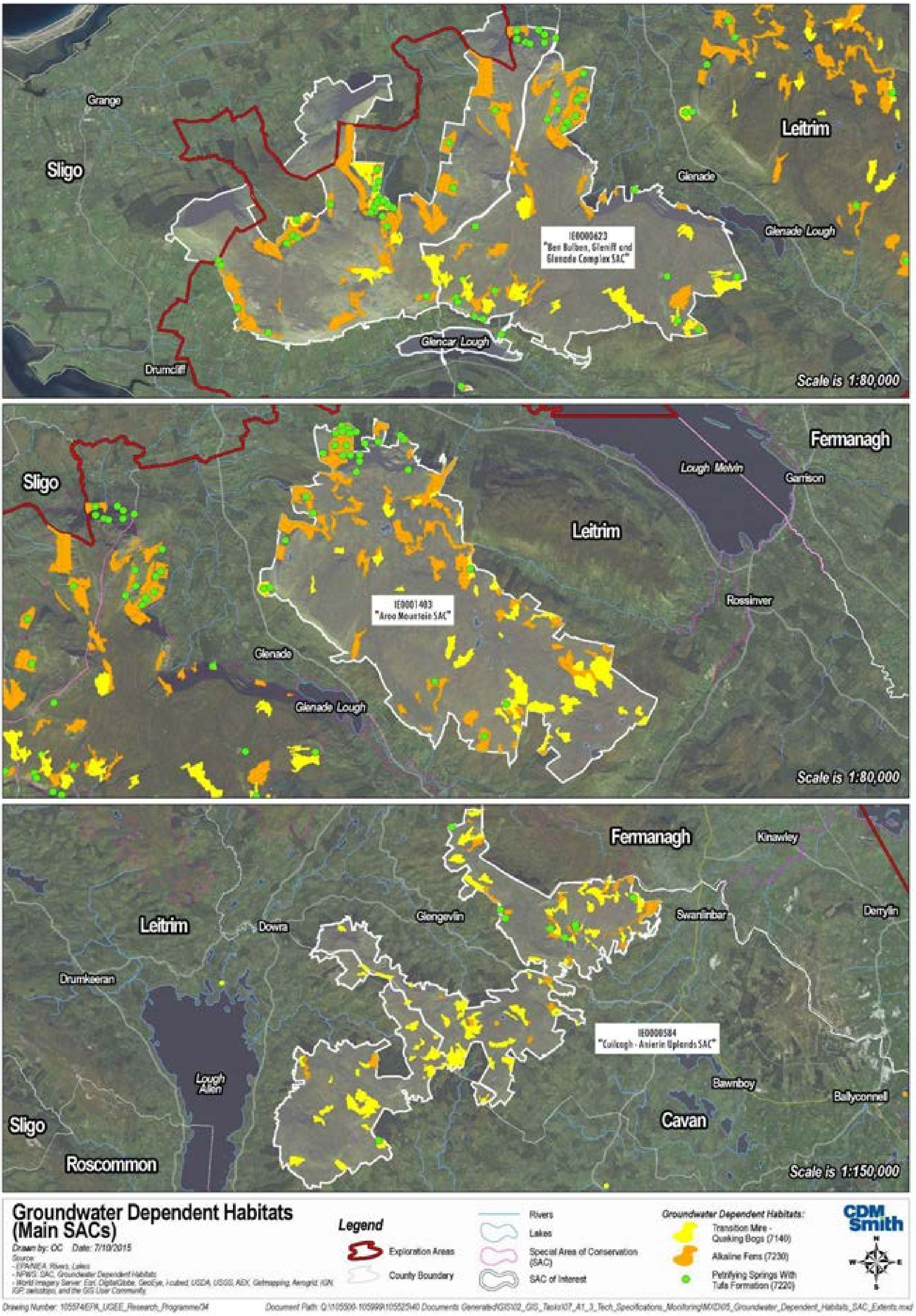


Figure 5.17. Groundwater Dependent Habitats in Three SACs – NCB study area in Ireland.

6 Existing Environmental Monitoring and Pressures

6.1 Overview

Existing environmental pressures on water resources and aquatic ecosystems within the two case study areas derive from land uses, waste management practices and specific economic activities. The most recent, publically available land use maps are included as Figures 6.1 to 6.3. Environmental pressures are catchment- and location-specific. With regard to water quality, they result from both diffuse and point sources of pollution. With regard to water quantity, they relate to abstractions and other regulatory schemes.

Degrees of impact are assessed and quantified from monitoring data and surveys or mapping of environmental pressure indicators. The latter are described by activities and features such as wastewater discharges (treatment plants and septic tank systems), agricultural practices (e.g. landspreading, farmyards), forestry, and industry (e.g. mines, quarries).

Environmental impacts can also be assessed and quantified from visual observations. Impacts can be direct or indirect. An example of a direct impact would be the drying out of a stream section due to over-abstraction of surface water and/or groundwater. An example of an indirect impact would be increased sediment runoff as a result of construction activity, which can cause reduced visibility and oxygen deficiency in streams. Any number of impacts can be caused by anthropogenic influences in a catchment, and these can be of a short-term or long-term nature. The assessment of long-term impacts require monitoring data to identify and track patterns and trends.

The summary of existing environmental pressures presented in the current report reflects the most recent published information sourced from the EPA and NIEA with regard to WFD status classification of water bodies. Pressures that are relevant to the case study areas are outlined in the following sections followed by a summary of existing monitoring initiatives of waters and associated ecosystems in both Ireland and Northern Ireland.

6.1.1 Agriculture

Both the EPA and NIEA have identified widespread contamination of rural water supplies from agricultural sources, and the two principal water quality issues are:

- Enrichment of nutrients (phosphorus and nitrogen) to streams, lakes and groundwater. Nutrient compounds can originate from a range of sources, including runoff from farmyards, fertiliser applications (e.g. landspreading) and leaks from manure stores. Nutrients accelerate plant growth which affects water quality and disturbs aquatic biota through the process of eutrophication which is controlled by phosphorus enrichment in fresh water environments.
- Pollution from organic matter, involving discharges of wastewater, animal slurry/manure and silage effluent. The breakdown of organic material uses the oxygen that aquatic plants and animals need to survive. Both suspended solids and ammonia can cause fish kills. Slurry discharges can also contaminate drinking water with bacteria, parasites and viruses.

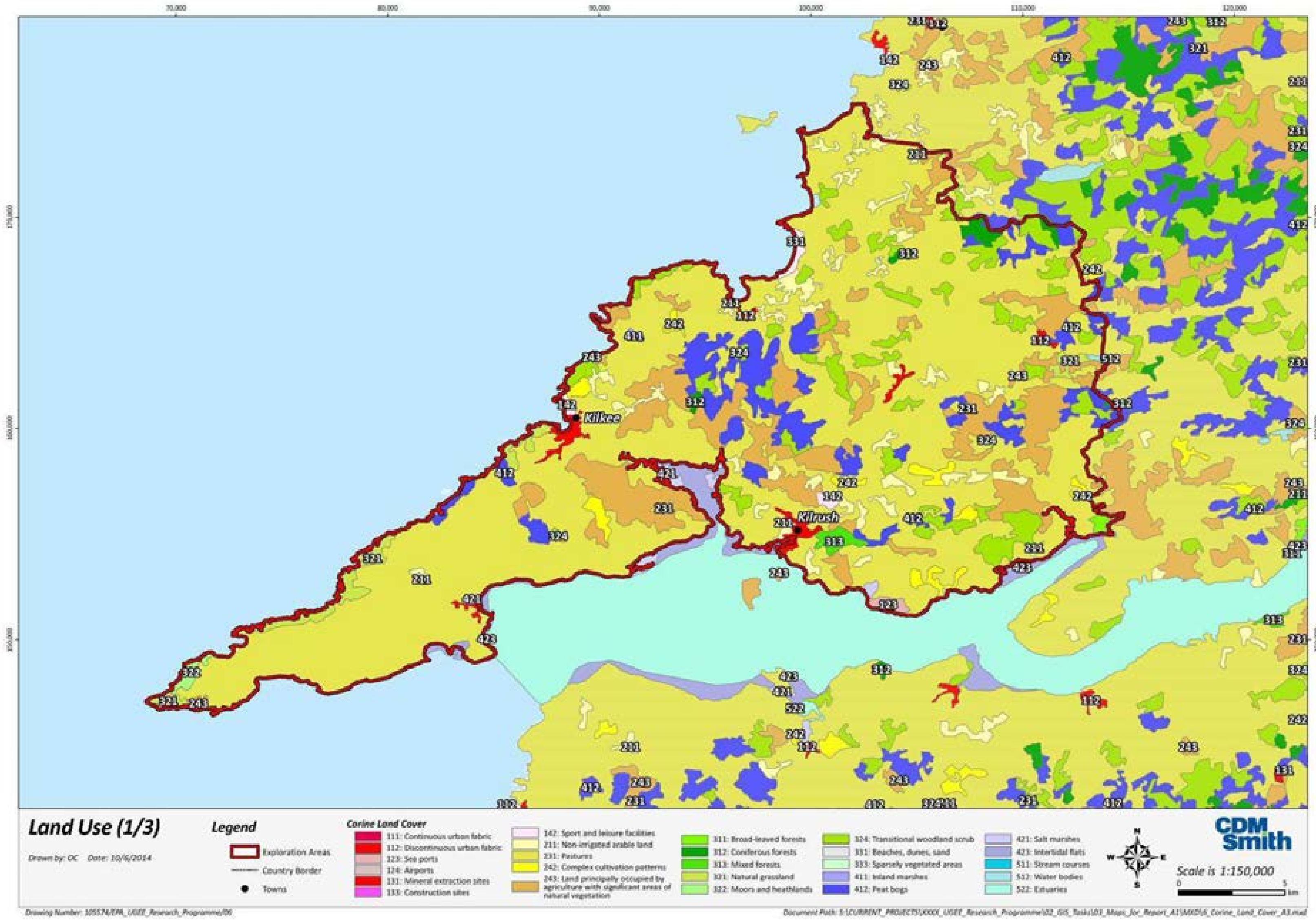


Figure 6.1. Corine (2006) land use – CB study area.

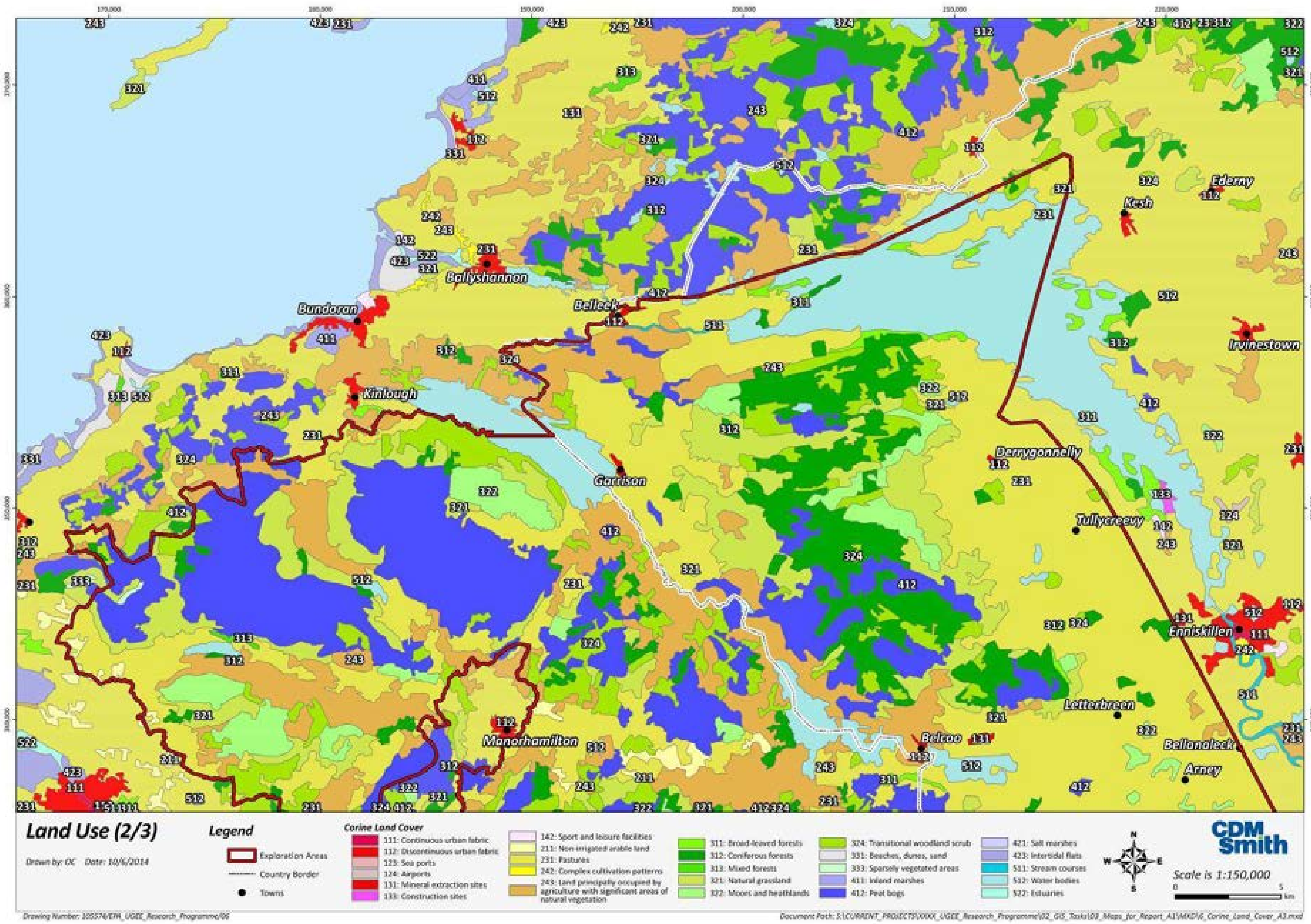


Figure 6.2. Corine (2006) land use – NCB study area – Part 1.

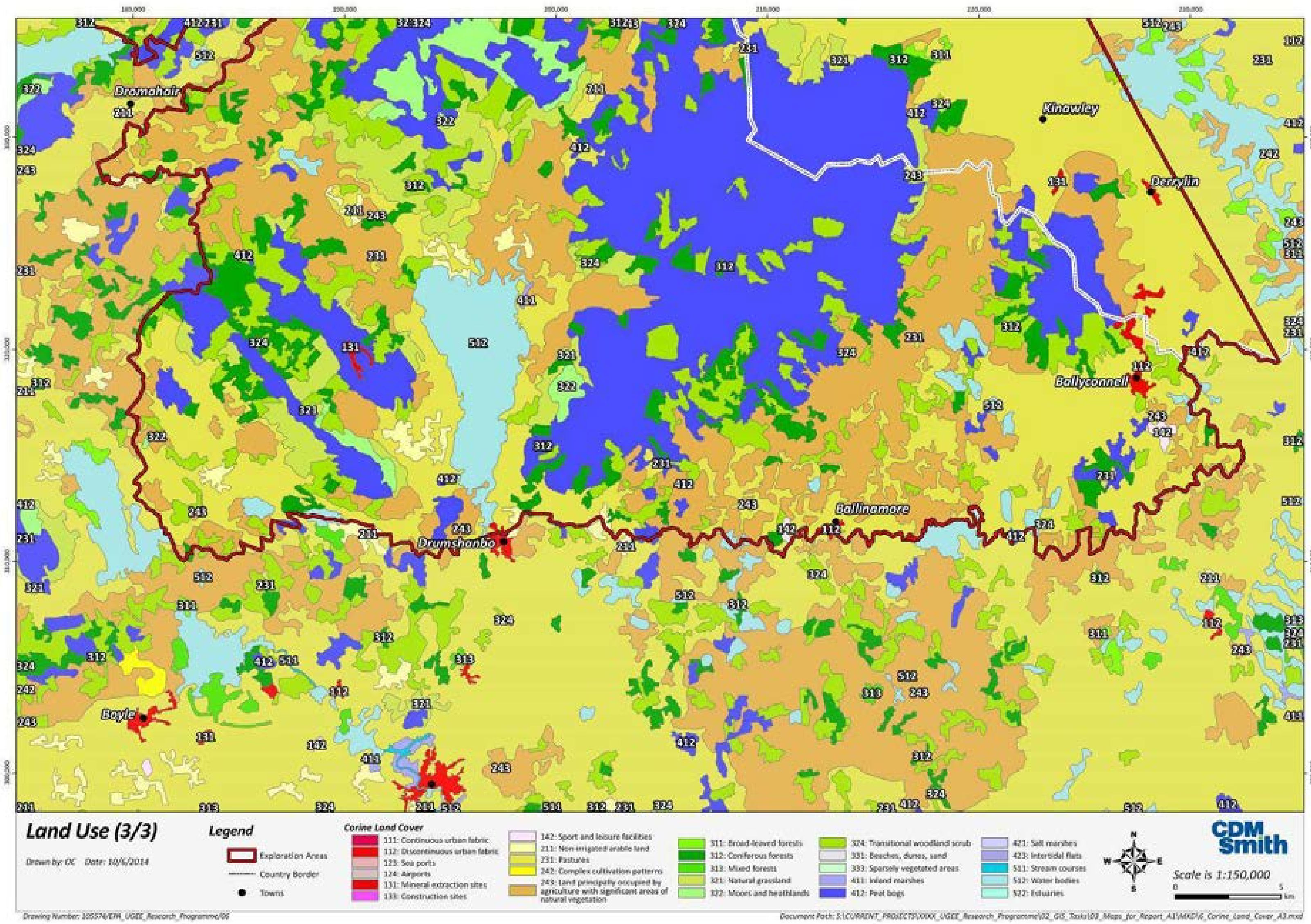


Figure 6.3. Corine (2006) land use – NCB study area – Part 2.

A third identified and potential threat from agriculture is the use of pesticides, which is described under Priority Substances in Section 6.1.4. The knowledge about potential impacts of pesticides is limited, largely due to the analytical challenges of targeting specific compounds contained in pesticides, which can vary over short periods of time.

6.1.2 Wastewater discharges

Within the case study areas, there are wastewater treatment plants associated with towns that discharge treated effluents to local waterways under license. Depending on their design and/or level of maintenance, wastewater treatment plants can become overloaded during rainstorms with resulting discharges of partially treated wastewater to streams, lakes and groundwater.

In rural areas, houses and businesses are not connected to public sewer systems and rely on onsite wastewater treatment systems (OSWTS) such as conventional septic tanks or proprietary secondary treatment systems, often via soil percolation to groundwater. OSWTSs often perform inadequately as a result of poor installation or maintenance practices. As well, in poorly drained areas, infiltration capacities are limited and effluent seepage may exfiltrate from the subsurface to flood grounds and/or run off into streams without the intended or required treatment. In poorly drained catchments, OSWTSs will frequently discharge effluent directly to streams from overflow pipes, especially when the capacity to percolate to groundwater is exceeded, thus contributing to impact on surface water quality.

6.1.3 Forestry

Forest cover is slowly growing in scale in both Ireland and Northern Ireland, in line with policy. Forestry can have both positive and negative impacts on the environment. The negative impacts are largely caused by poor management and planting on unsuitable soils. Documented water quality problems associated with afforestation are mostly a legacy of old practices, which are or have been amended subsequently, but potential water quality problems can still result from:

- Acidification – forest canopies capture sulphur and nitrogen compounds from the atmosphere. Rain becomes more acidic as it passes through the canopies to the ground below, and can impact on the chemical balance of receiving waters;
- Nutrient enrichment – forestry activities can introduce extra nutrients which, in naturally nutrient-poor areas, can lead to algal growths and eutrophication as mentioned above.
- Sedimentation – road-making and stream-crossing can cause erosion and sedimentation on susceptible soils. Mobilised sediments can reduce water quality and damage ecologically sensitive areas.
- Surface runoff pattern changes – clearfelling of forests can lead to a change in surface runoff patterns and increase sediment transport to streams and lakes.
- Pesticide contamination – inappropriate or incorrect application of pesticides may result in contamination of waters, via runoff or infiltration.
- Increased fluxes of dissolved organic carbon when draining organic soils.

6.1.4 Priority substances

Priority substances are contained in everyday products and used in households (for example medicines and cleaning products) and industry, but also in forestry, agriculture, small businesses, mines, construction sites and water treatment works. There are numerous ways by which dangerous substances can enter waters. These include regulated, unregulated or accidental releases, as follows:

- Industrial and municipal effluents;
- Discharges from wastewater systems;
- Pesticide applications to agricultural land, forestry, livestock, recreational areas, roads, paths, railways, sheep dips, or gardens;
- Use of chemicals in aquaculture to control diseases;
- Seepage from un-lined waste disposal sites or contaminated sites;
- Intermittent combined sewer overflow spills from urban systems; and
- Accidental misuse or otherwise inappropriate disposal of priority substance products, including spills.

6.1.5 Abstractions

Abstractions are generally not considered to be a significant environmental pressure in the two study areas. An overview of potential abstractions associated with UGEE activity and associated environmental risks is presented in Section 7.

6.2 Existing Environmental Monitoring

Existing environmental monitoring that is specific to the water resources of the two case study areas includes:

1. Water Framework Directive monitoring;
2. Drinking Water Quality monitoring;
3. Hydrometric monitoring; and
4. Monitoring of associated aquatic ecosystems.

6.2.1 Water Framework Directive monitoring

The EU Water Framework Directive (WFD) (2000/60/EC) requires all EU Member States to adopt an integrated ecosystem-based holistic approach for water management, in which all waters and their dependent ecosystems are considered as being inter-linked and inter-dependent.

For the first cycle of WFD implementation (2009–2014), the island of Ireland (Ecoregion 17 in the WFD) was divided into 8 RBDs, see Figure 6.4. The UGEE licence area in the NCB lies within several of the defined RBDs, whereas the UGEE licence area in the CB lies entirely within the Shannon International RBD.

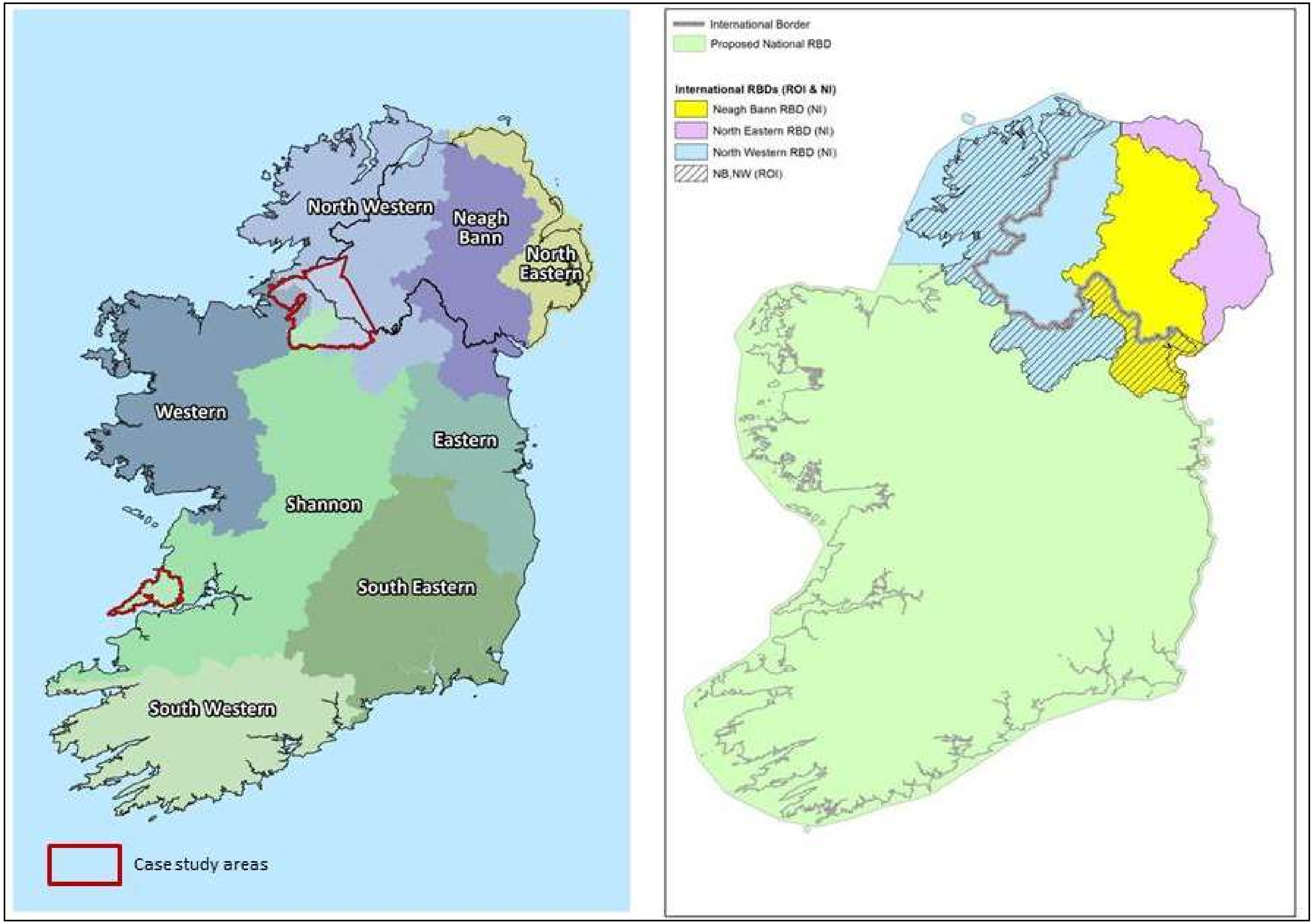


Figure 6.4. Current (left) and proposed (right) revised river basin districts.

As part of a review of governance structures in Ireland (DECLG, 2014), the number and boundaries of RBDs and underlying administrative areas were amended for the second cycle of WFD implementation (2015–2021), whereby a single (i.e. national) administrative area has been established in Ireland comprising the Eastern, South Eastern, South Western, and Western RBDs, as well as the portions of the North Western, Shannon and Neagh Bann International RBDs that are located within Ireland.

Since 2006, both the EPA and NIEA have designed and implemented WFD-compliant monitoring programmes across the river basin districts (RBDs) which aim to:

(a) Enable a comprehensive assessment of water quality and quantity for groundwater and surface water, and ecology for surface water; and

(b) Classify the chemical and quantitative 'status' of water bodies, following guidelines and requirements of reporting to the EC.

The WFD monitoring networks for water quality consists of three different monitoring programmes: surveillance, operational and investigative. The *surveillance* monitoring programme is designed to be representative of general status, providing data on long term trends and validating risk assessments which are undertaken as part of the WFD reporting requirements. The surveillance monitoring network contains sub-networks ('subnets') which are designed to fulfil one or more of the specific objectives of surveillance monitoring, such as monitoring of 'high' status water bodies which can be used as reference cases against which other water bodies are compared. Sampling for physico-chemical parameters is carried out every 3 months at a minimum, whereas monitoring of biological or hydromorphological quality elements (in surface waters only) should be carried out at least once during the surveillance monitoring period, which is tied to 6-year river basin management plan cycles.

Operational monitoring is intended to determine water body status, identify pollutant trends and assess the effectiveness of programmes of measures to reduce pollutant loading to water bodies and measures in order to maintain 'high' or 'good' water body status.

Operational monitoring is also used if surveillance monitoring has identified a water body to be at risk of failing to meet its environmental objectives and water bodies into which priority list substances are discharged. The frequency of operational monitoring for any parameter is determined on a case-by case basis so as to provide sufficient data for a reliable assessment of impact and effectiveness of mitigation measures.

Investigative monitoring is applied where the reason for status failure is unknown, to ascertain the magnitude and impacts of pollution, and to establish the factors causing water bodies to fail to achieve their environmental objectives.

The data collated form the basis for the classification of the water body status, which is carried out by the EPA and NIEA in Ireland and Northern Ireland, respectively. To enable consistency across the EU, the classification scheme is harmonised so that comparable reporting is achieved.

6.2.1.1 Streams and rivers

Streams and rivers are monitored for water quality at stations depicted in Figures 6.5 to 6.7. Details of analytical monitoring suites for each type of water body are provided in Appendix H.

There are a total of 94 WFD monitoring stations within the two case study areas, as summarised in Table 6.1. The majority of these are in the NCB, and are associated with operational monitoring. Table 6.2 lists the major river catchments and the number of physico-chemical monitoring stations in each catchment. Larger catchments, as well as catchments with varying physiographies, contain several monitoring stations. The Erne and the Shannon Upper are the largest catchments overall, and contain the largest number of monitoring points, respectively.

Several smaller catchments lack monitoring stations. Examples are the Annageeragh and Aughaveemagh catchments in the CB study area and the Duff and Bradoge catchments in the NCB study area. There are also several unnamed coastal river catchments in the CB study area which are not monitored. Such catchments are represented in the WFD reporting by the grouping of water bodies which was considered by both the EPA and the NIEA in the design of the WFD monitoring networks in 2006, whereby data from one catchment with similar physiographic attributes and environmental pressures is used to reflect conditions in other catchments in the same group. This principle was also used in the design of the WFD groundwater monitoring networks.

Physico-chemical parameters that are analysed for in streams and rivers are summarised in Table 6.3. In Ireland, operational monitoring is carried out on main-stem river sites 4 times per year with the aim of supporting the Programme of Measures for diffuse and point source pressures. For specific studies such as forestry impact or freshwater fish directive sites, the operational monitoring is carried out at a frequency of 12 times per year. For the surveillance monitoring network, the general parameters are monitored 12 times per year in every year of the six-year RBD plan cycle. The priority substances are also monitored 12 times per year, but only for one year of the RBD plan cycle.

In Northern Ireland, monitoring of rivers is carried out at least 4 times per year. The monitoring of ‘general quality assessment (GQA) parameters’ may be carried out more frequently, sometimes monthly. At a select number of sites that are considered to be at risk of not meeting environmental objectives, additional analysis is carried out, the frequency of which varies but which typically ranges from 4 to 7 times per year. A selected list of semi-volatile hydrocarbons are regularly analysed, including anthracene, bentazone, benzo(a)pyrene, fluoranthene, and naphthalene (see Appendix H).

6.2.1.2 Lakes

There are 34 WFD-reported lake water bodies, all are in the NCB, and the largest is Lough Erne. Twenty-nine of the lakes are located within Ireland, of which 17 are monitored by the EPA and local authorities. Five lakes are located in Northern Ireland and are monitored by the NIEA. Three lakes (Lough Melvin; Upper and Lower Lough Macnean) are cross-border lakes, and are monitored by both the EPA and NIEA. Some of the lakes are monitored at multiple stations, thus the total number of monitoring points in Table 6.1 exceeds the total number of monitored lakes in the study area.

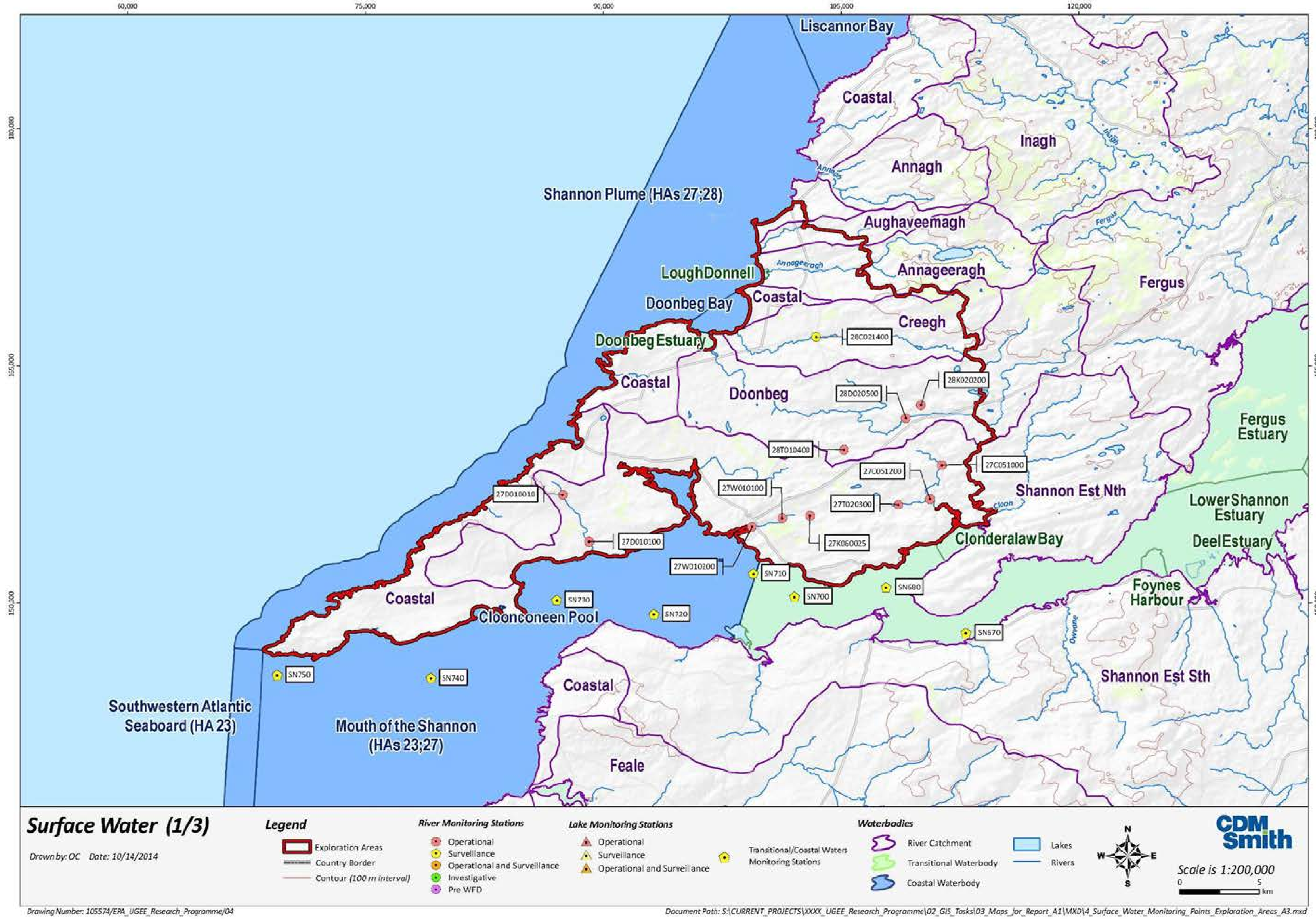


Figure 6.5. WFD surface water monitoring stations – CB study area.

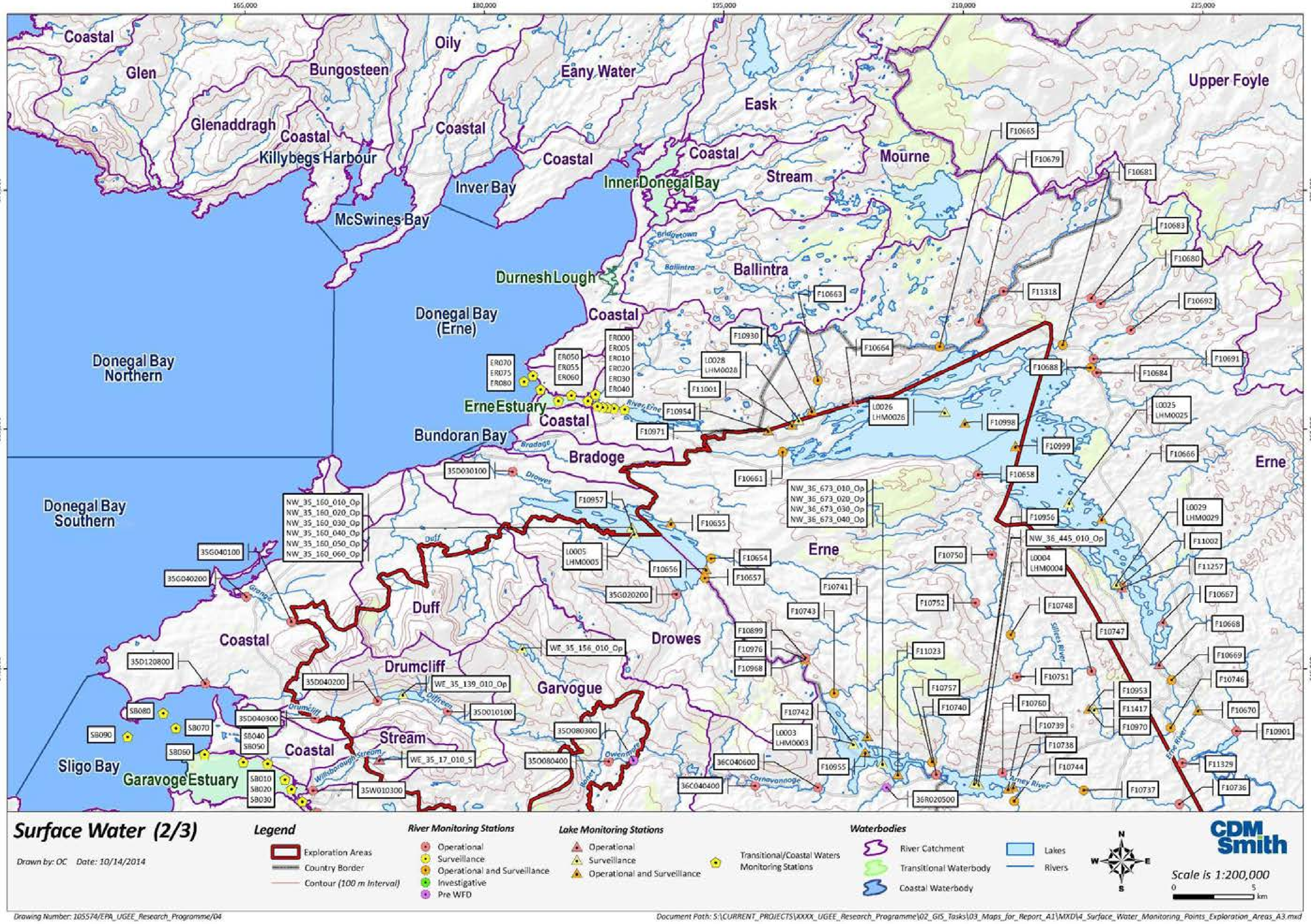


Figure 6.6. WFD surface water monitoring stations – NCB study area – Part 1.

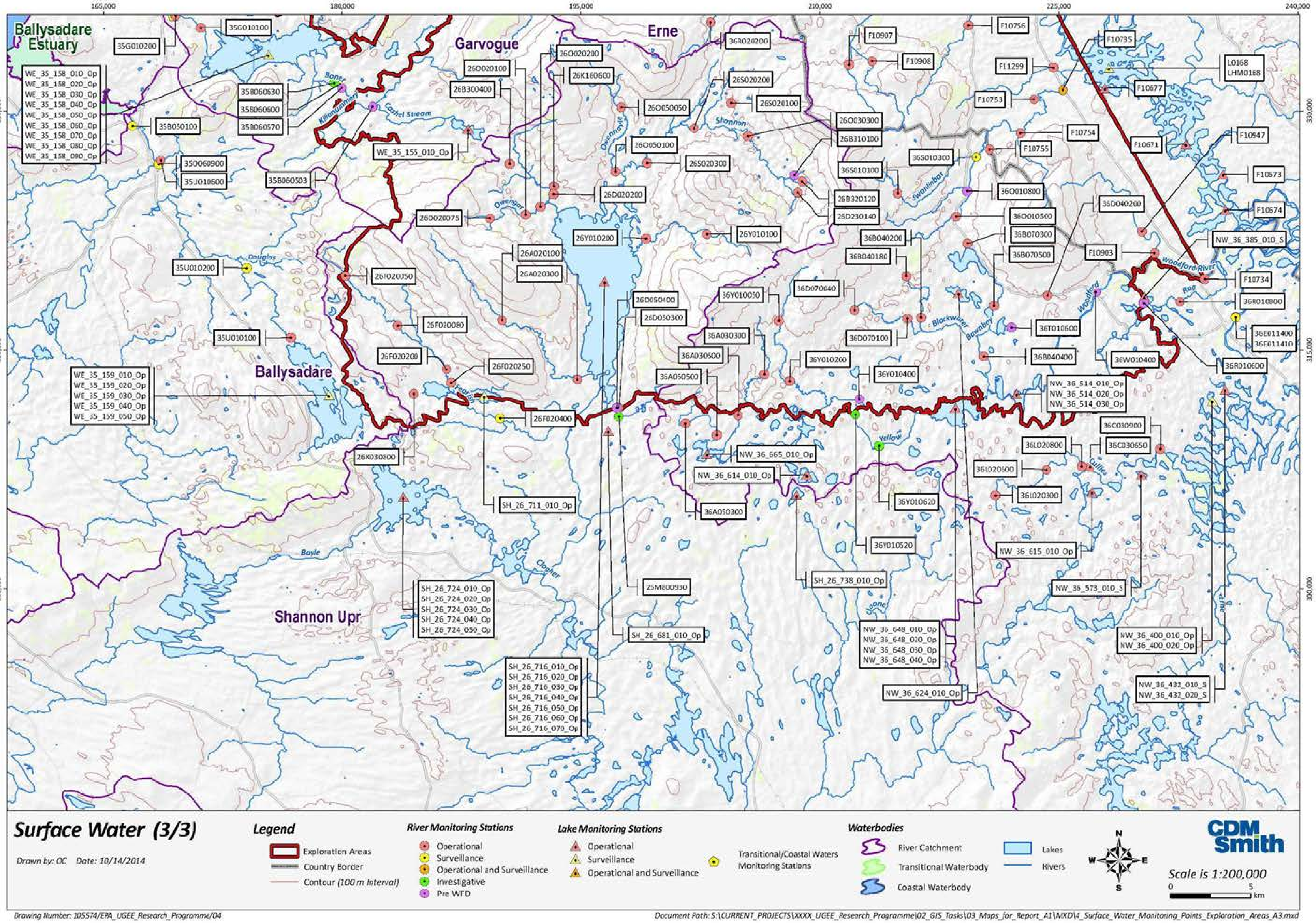


Figure 6.7. WFD surface water monitoring stations – NCB study area – Part 2.

Table 6.1. Summary of WFD monitoring points – rivers and lakes

	Ireland		Northern Ireland	Total
	Clare Basin	Northwest Carboniferous Basin	Northwest Carboniferous Basin	
Lakes	**–**	**21**	**24**	**45**
Operational	–	13		13
Surveillance	–	8	10	18
Surveillance and Operational	–	–	14	14
Rivers	**12**	**54**	**28**	**94**
Operational	11	44	19	74
Surveillance	1	1	–	2
Surveillance and Operational	–	–	9	9
Pre-WFD	–	9	–	9

Table 6.2. Number of river physico-chemical monitoring points per catchment

Catchment name	Catchment EU code	Area of catchment within study areas (km^2)	Percentage of catchment within study areas	Number of river physico-chemical monitoring points[a]
Erne	IE_NWIRBD_36_123	4500	41.4%	78
Shannon Upper	IE_SHIRBD_26_155a	3750	16.8%	28
Ballysadare	IE_WERBD_35_116	645	24.9%	5
Garvogue	IE_WERBD_35_117	397	100%	8
Shannon Estuary North	IE_SHIRBD_27_155e	327	60.3%	8
Drowes	IE_NWIRBD_35_121	160	100%	3
Doonbeg	IE_SHIRBD_28_154	147	66.3%	3
Duff	IE_NWIRBD_35_120	86.8	100%	0
Annageeragh	IE_SHIRBD_28_152	66.0	35.2%	0
Creegh	IE_SHIRBD_28_153	64.1	88.2%	1
Drumcliff	IE_WERBD_35_119	62.6	100%	1
Aughaveemagh	IE_SHIRBD_28_151	18.3	37.6%	0
Bradoge	IE_NWIRBD_36_122	17.4	100%	0
Stream	IE_WERBD_35_118	18.3	100%	1
Coastal	IE_WERBD_35_x5	111	100%	0
Coastal	IE_SHIRBD_27_d4_27	77.7	99.2%	0
Coastal	IE_SHIRBD_28_d4_28	27.6	99.0%	0
Coastal	IE_WERBD_35_w5	21.7	100%	0
Coastal	IE_SHIRBD_28_f4	9.57	29.4%	0
Coastal	IE_SHIRBD_28_e4	6.35	99.4%	0

[a]Some of the monitoring stations are located downstream just outside the study area

Table 6.3. WFD monitoring parameters for rivers

Parameters	Ireland			Northern Ireland
	Operational monitoring	Surveillance monitoring	Other surveillance (subnet) monitoring	
Temperature	Y	Y		Y
Dissolved Oxygen	Y	Y		Y
pH	Y	Y		Y
Salinity			Y	
Electrical Conductivity	Y	Y		Y
Hardness	Y	Y		Y
Colour	Y	Y		
Alkalinity	Y	Y		Y
o-Phosphate (Unfiltered Molybdate Reactive Phosphate)	Y	Y		
Soluble phosphorus				Y
Total Phosphorus			Y	
Total Nitrogen			Y	
Total Oxidised Nitrogen	Y	Y		
Nitrate	Y	Y		Y
Nitrite	Y	Y		Y
Ammonium	Y	Y		Y
Non-ionised Ammonia			Y	Y
Chloride	Y	Y		
Turbidity			Y	
Total suspended solids			Y	Y
Biochemical oxygen demand (BOD)	Y	Y		Y
2 6-Dichlorobenzamide			Y	
Copper – unspecified			Y	Y
Dichlobenil			Y	
Dissolved Organic Carbon			Y	
E. Coli			Y	
Enterococci (Intestinal)			Y	
Faecal coliforms			Y	
Fats, Oils & Greases			Y	
Fluoride			Y	
Malathion			Y	
Potassium – unspecified			Y	
Sodium – unspecified			Y	
Zinc – filtered			Y	Y
Pesticide suite[a]			Y	
Metals suite[a]			Y	
VOC suite[a]			Y	
PAH suite[a]			Y	Y

[a]For detailed list of specialist suites see Appendix H.

Surveillance monitoring on lakes is carried out on a monthly basis each year, and the list of parameters included are shown in Table 6.4. At operational monitoring sites, the same parameters are often analysed for in both Ireland and Northern Ireland, and the frequency of sampling ranges from 1 to 6 times per annum. For some operational monitoring sites in Ireland, the physico-chemical monitoring is generally carried out monthly during the same year that biological monitoring takes place.

Table 6.4. WFD surveillance monitoring parameters for lakes

Parameters	Ireland		Northern Ireland
	Acid lakes	Non-acid lakes	
Alkalinity	Y	Y	Y
Ammonia (total)	Y	Y	Y
Ammonia (non-ionised)			Y
Calcium	Y		
Chloride	Y		
Chlorophyll	Y	Y	
Conductivity	Y	Y	Y
Dissolved Oxygen	Y	Y	Y
Magnesium	Y		
pH	Y	Y	Y
Potassium	Y		
Silica	Y	Y	
Sodium	Y		
Sulphate	Y		
Total Oxidised Nitrogen	Y	Y	
Nitrate	Y	Y	Y
Nitrite	Y	Y	Y
Total phosphorus	Y	Y	
Soluble phosphorus			Y
True Colour	Y	Y	
Biological Oxygen Demand			Y
Total Hardness			Y
Suspended solids			Y
Temperature	Y	Y	Y
Zinc (total)[a]			Y
Copper (Dissolved)[a]			Y
Pesticide suite[b]	Y	Y	
Metals Suite[b]	Y	Y	
VOC suite[b]	Y	Y	
PAH suite[b]	Y	Y	Y

[a]Total zinc and dissolved copper are monitored at irregular frequencies ranging from 0 to 12 times per annum.

[b]For detailed list of specialist suites, see Appendix H.

6.2.1.3 Transitional and coastal

There are 10 transitional water bodies associated with the two study areas. Most are in the CB study area, and although there are no transitional water bodies directly within the NCB study area boundaries, 6 transitional waters are located downstream of the NCB study area, including the Erne Estuary, Garavoge Estuary and Ballysadare Estuary (within Sligo Bay). These are monitored at a total of 31 locations.

Surveillance monitoring on transitional and coastal waters is carried out 3 to 5 times per year. A listing of monitoring parameters is shown in Table 6.5. Priority substances are generally not monitored for; however, in Ireland, the Marine Institute monitors the concentrations of certain priority hazardous substances in a range of fin-fish species landed at Irish ports and also in shellfish from selected sites around the Irish coast (EPA, 2010a).

Table 6.5. WFD monitoring parameters for transitional and coastal waters

Parameter	Monitored
Salinity	Y
Temperature	Y
Dissolved Oxygen	Y
pH	Y
Ammonia (NH_3)	Y
Total Oxidised Nitrogen	Y
Total Phosphorus	Y
Biochemical Oxygen Demand	Y
Chlorophyll	Y

6.2.1.4 Groundwater

Figures 6.8 to 6.10 depict the associated WFD groundwater monitoring networks, superimposed on GSI's and GSNI's classification of aquifer types in Ireland and Northern Ireland, respectively. There are no WFD monitoring sites within the UGEE licence area in the CB. The nearest relevant WFD sampling point is 'Glin', which is within the CB but outside the UGEE license area, to the south of the Shannon Estuary

In the NCB, there are 11 groundwater quality monitoring points, 4 in Ireland and 7 in Northern Ireland. There are an additional 4 wells used for water level monitoring, 2 in Ireland and 2 in Northern Ireland. Finally, one spring (Manorhamilton in Ireland) is monitored for discharge volumes/rates. All of the WFD monitoring in the NCB are associated with karstified limestone aquifers. Groundwater quality samples are collected 3 to 4 times a year for the parameters listed in Table 6.6. Selected pesticides, volatile organic compounds and hydrocarbons are monitored 2 to 4 times in each 6-year river basin cycle.

6.3 Drinking Water Quality Monitoring

The EU Drinking Water Directive (Council Directive 98/83/EC) relates to the quality of water intended for human consumption. Its main objective is to protect human health from adverse effects of contamination of drinking water. The Directive applies to all supplies serving more than 50 people or supplying more than 10 m^3/day. The minimum requirements for monitoring are detailed in Annex II of the Directive, and abstraction rates determine the frequency and range of parameters to be tested.

Different analyses are required for 'check' and 'audit' monitoring under the Directive (EPA, 2010b), as listed in Table 6.7. The 'check' parameters must generally be analysed on a quarterly basis, whereas the extended suite of analysis called the 'audit parameters' is generally monitored annually.

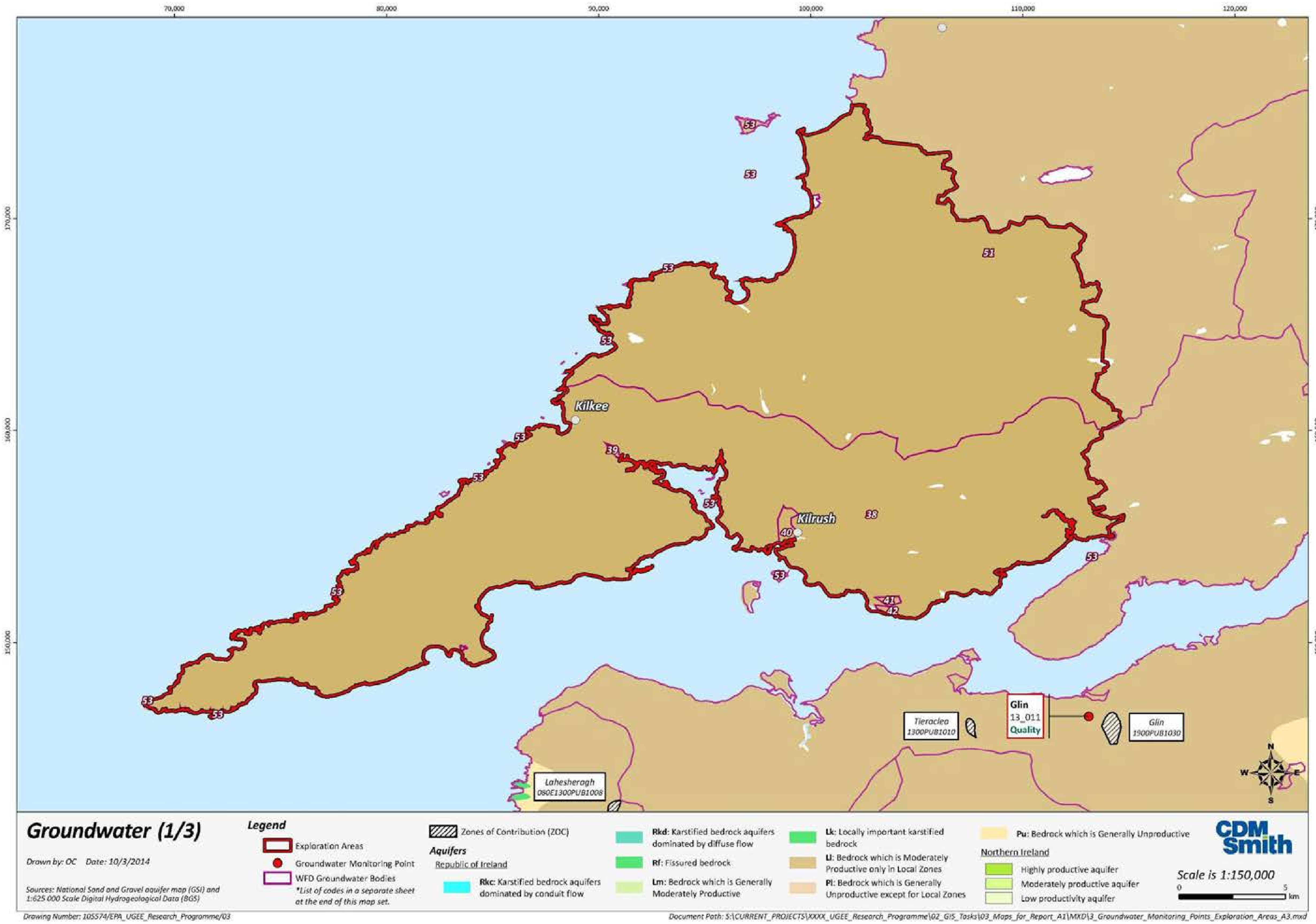


Figure 6.8. WFD groundwater monitoring stations – CB study area.

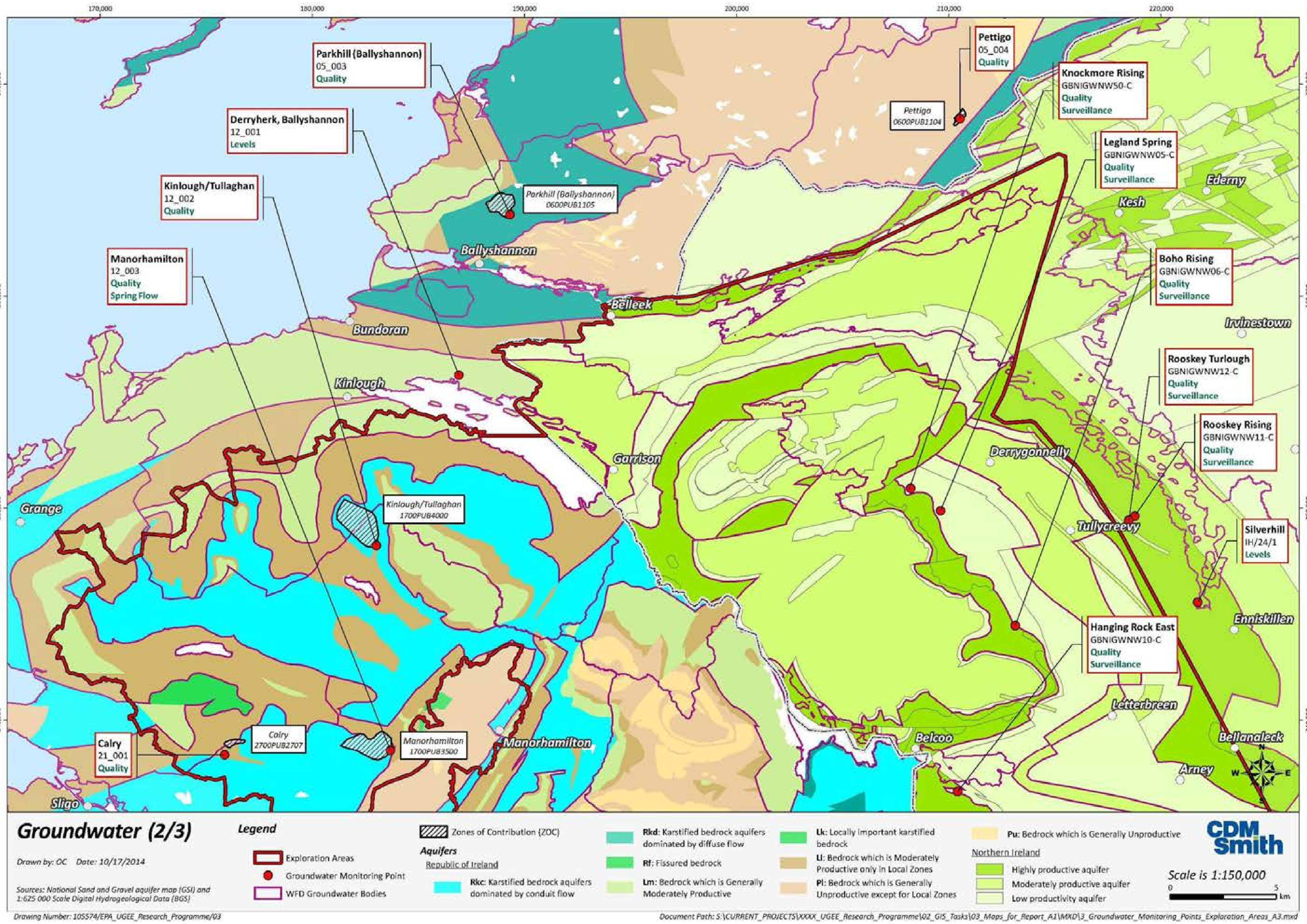


Figure 6.9. WFD groundwater monitoring stations – NCB study area – Part 1.

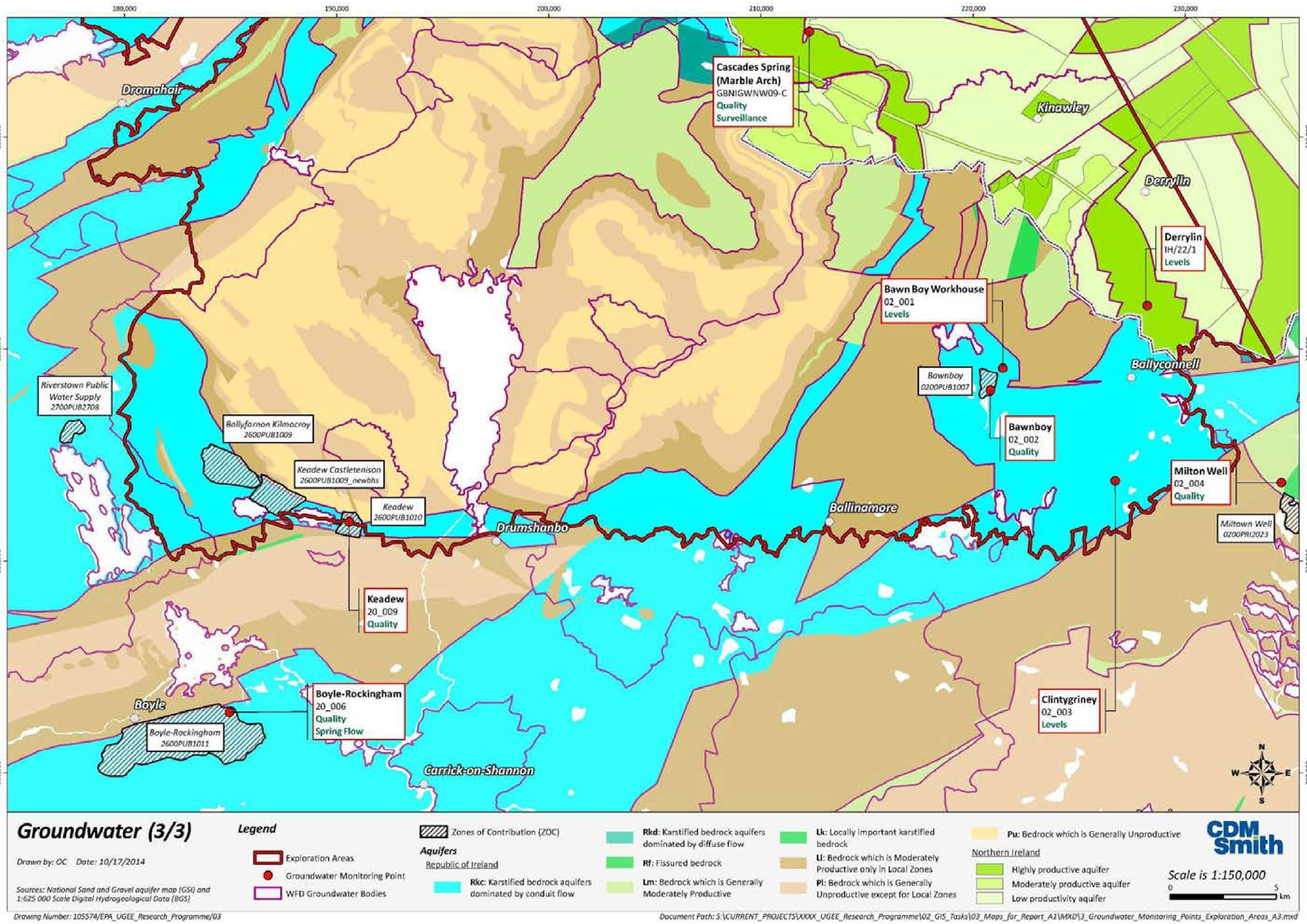


Figure 6.10. WFD groundwater monitoring stations – NCB study area – Part 2.

Table 6.6. WFD monitoring parameters for groundwater

Parameters	Ireland	Northern Ireland
pH	Y	Y
Temperature	Y	Y
Dissolved Oxygen	Y	Y
Total Coliforms	Y	Y
Faecal Coliforms	Y	Y
Alkalinity	Y	Y
Total Hardness	Y	Y
Colour	Y	Y
Turbidity	Y	Y
Ammonium	Y	Y
Nitrite	Y	Y
Nitrate	Y	Y
Total Phosphorus	Y	Y
Molybdate Reactive Phosphorus	Y	Y
Filtered Molybdate Reactive Phosphorus	Y	–
Total Organic Carbon	Y	–
Silica	Y	Y
Chloride	Y	Y
Fluoride	Y	Y
Sulphate	Y	Y
Sodium	Y	Y
Potassium	Y	Y
Magnesium	Y	Y
Calcium	Y	Y
Iron	Y	Y
Manganese	Y	Y
Boron	Y	Y
Aluminium	Y	Y
Chromium	Y	Y
Nickel	Y	Y
Copper	Y	Y
Zinc	Y	Y
Arsenic	Y	Y
Cadmium	Y	Y
Antimony	Y	Y
Barium	Y	Y
Lead	Y	Y
Uranium	Y	Y
Mercury	Y	Y
Cobalt	Y	Y
Molybdenum	Y	Y
Strontium	Y	Y
Silver	Y	Y
Beryllium	Y	–
Pesticides suite[a]	Y	Y
VOCs suite[a]	Y	Y
PAH suite[a]	Y	–

[a]For detailed list of specialist suites see Appendix H.

Table 6.7. Summary of check and audit monitoring parameters

Parameter	Check	Audit
Escherichia coli (E. coli)	Y	Y
Enterococci		Y
Antimony		Y
Arsenic		Y
Benzene		Y
Benzo (a)pyrene		Y
Boron		Y
Bromate		Y
Cadmium		Y
Chromium		Y
Copper		Y
Cyanide		Y
1,2-Dichloroethane		Y
Fluoride		Y
Lead		Y
Mercury		Y
Nickel		Y
Nitrate		Y
Nitrite	Y	Y
Pesticides		Y
Pesticides – Total		Y
Polycyclic aromatic hydrocarbons		Y
Selenium		Y
Tetrachloroethene and Trichloroethene		Y
Trihalomethanes – Total		Y
Aluminium	Y	Y
Ammonium	Y	Y
Chloride		Y
Clostridium perfringens	Y	Y
Colour	Y	Y
Conductivity	Y	Y
Hydrogen ion concentration	Y	Y
Iron	Y	Y
Manganese		Y
Odour	Y	Y
Sulphate		Y
Sodium		Y
Taste	Y	Y
Colony count 22˚C		Y
Coliform bacteria	Y	Y
Total organic carbon (TOC)		Y
Turbidity	Y	Y
Tritium		Y
Total indicative dose		Y

The Water Supply (Water Quality) Regulations (Northern Ireland) 2007 (as amended) in Northern Ireland and the European Communities (Drinking Water) (No. 2) Regulations 2007 (S.I. 278 of 2007) in Ireland both require that water is sampled at treatment works and consumers' taps for compliance checks. There is no requirement, however, to sample raw water, although some authorities do so at public supplies.

In Ireland, Irish Water has assumed responsibility for the monitoring of drinking water quality at public supplies. Local authorities remain responsible for monitoring of group water schemes and regulated small private supplies. Similarly, Northern Ireland Water is responsible for monitoring public water supplies in Northern Ireland, and the Drinking Water Inspectorate of the NIEA is responsible for monitoring of registered private supplies (> 10 m^3/day).

6.3.1 Location of abstractions for drinking water supply

For the purposes of the UGEE JRP, Irish Water (IW) and Northern Ireland Water (NIW) were contacted for information on locations, sources of water, and average abstraction rates of public and private regulated water supplies (e.g. group water schemes) within the case study areas. Both IW and NIW submitted available data. In Ireland, IW also referred the request onto the relevant local authorities for additional information.

Table 6.8 summarises the information received on monitored drinking water supplies (abstractions), which was subsequently the subject of the ground-truthing survey which is referenced in Section 5. Private or domestic wells which abstract less than 10 m^3/d do not require monitoring or reporting by public bodies in Ireland or Northern Ireland. The NIEA (2014a) estimates that up to 1200 private, unregulated supplies to single houses exist in Northern Ireland which do not require monitoring. The equivalent number in Ireland is significantly higher as most rural houses and farms are supplied by wells.

6.4 Hydrometric Monitoring

Hydrometric monitoring involves measurement of:

- Surface water flows and levels;
- Spring discharges;
- Groundwater levels.

Table 6.8. Estimated numbers of monitored drinking water supplies in or near the UGEE licence areas

Type of supply	Public supply	Private regulated supply[a]	Other private abstractions[b]
Northwest Carboniferous Basin			
Surface Water – River	4	8	ND[c]
Surface Water – Lake	14	10	ND[c]
Surface Water – Unknown	0	ND[c]	2
Groundwater	16	35	6
Clare Basin			
Surface Water – River	0	ND[c]	ND[c]
Surface Water – Lake	1	2	ND[c]
Groundwater	1	*3*	*4*

[a]Monitored by local authorities;

[b]Estimated number of monitored private abstractions >10 m3/d. Total numbers are likely greater than those identified as part of this stud, and would require further survey and ground-truthing work.

[c]ND means no data is available. It does not imply that there are no supplies that fall within this category.

The data are used to characterise hydro(geo)logical behaviour, derive historical statistics, and identify and monitor trends. All metrics associated tell a particular story and quantitative monitoring is accordingly an important element of water resources monitoring. In the context of the WFD, hydrometrics are also used to classify the quantitative status of water bodies for EC reporting purposes, As such, hydrometric monitoring data flag potential problem areas where water is being used unsustainably or where risk of impacts on aquatic ecosystems exists.

6.4.1 Surface water flow and level monitoring

In Ireland, a Register of Hydrometric Stations is maintained by the EPA, and stations are operated mainly by the EPA and the Office of Public Works (OPW). The Rivers Agency operates and maintains a similar register of hydrometric gauging stations in the Northern Ireland. There are 28 active stream gauging stations within the NCB with stream flow recorders. A further 5 are equipped with staff gauges for water level recording.

As indicated in the CB study area, there is just one hydrometric gauging station on the Doonbeg River. There are no lakes and, therefore, no lake level monitoring stations within the UGEE licence area.

The geology associated with each catchment is indicated in Appendix I. In Ireland catchments, the earliest stream records date back to the 1940s and 50s. In Northern Ireland, the majority of the records begin in the 1970s (Rivers Agency pers. comms. 2014), the majority of stations are associated with the Lough Erne drainage system. All catchments greater than 100 km^2 have at least one hydrometric gauge installed. There are a further 7 staff gauges on rivers where water levels are recorded and flows are estimated periodically but which are not equipped with continuous data recorders (of either water levels or flow). There are an additional set of 12 digital water level recorders on lakes. There is one active tidal gauge at Rosses Point in Donegal Bay. In the CB study area, there is just one hydrometric gauging station on the Doonbeg River. There are no lakes and, therefore, no lake level monitoring stations within the UGEE licence area.

The geology associated with each catchment is indicated in Appendix I. In Ireland catchments, the earliest stream records date back to the 1940s and 50s. In Northern Ireland, the majority of the records begin in the 1970s (http://nrfa.ceh.ac.uk/data/search).

Table 6.9. Number of active hydrometric stations associated with the UGEE licence areas

Licence area	Catchment name	Catchment EU code	Total catchment area	Percentage of catchment within licence area	Number of active hydrometric monitoring points[a]
NCB	Ballysadare	IE_WERBD_35_116	645.17	1.3%	3
NCB	Bradoge	IE_NWIRBD_36_122	17.39	0.3%	0
NCB	Coastal	IE_WERBD_35_w5	21.68	11.2%	1
NCB	Coastal	IE_WERBD_35_x5	111.44	10.7%	0
NCB	Drowes	IE_NWIRBD_35_121	160.13	73.5%	8
NCB	Drumcliff	IE_WERBD_35_119	62.62	93.4%	0
NCB	Duff	IE_NWIRBD_35_120	86.83	60.1%	0
NCB	Erne	IE_NWIRBD_36_123	4493.62	26.6%	27
NCB	Garvogue	IE_WERBD_35_117	396.61	61.7%	6
NCB	Shannon Upr	IE_SHIRBD_26_155a	3747.00	13.3%	8
NCB	Stream	IE_WERBD_35_118	18.29	64.5%	0
CB	Annageeragh	IE_SHIRBD_28_152	66.02	35.2%	0
CB	Aughaveemagh	IE_SHIRBD_28_151	18.32	37.6%	0
CB	Coastal	IE_SHIRBD_27_d4_27	77.74	99.2%	0
CB	Coastal	IE_SHIRBD_28_d4_28	27.60	99.0%	0
CB	Coastal	IE_SHIRBD_28_e4	6.35	99.4%	0
CB	Coastal	IE_SHIRBD_28_f4	9.57	29.4%	0
CB	Creegh	IE_SHIRBD_28_153	64.06	88.2%	0
CB	Doonbeg	IE_SHIRBD_28_154	146.82	66.3%	1
CB	Shannon Est Nth	IE_SHIRBD_27_155e	327.41	60.3%	0

[a]Some of the monitoring stations are located immediately downstream of the license areas, but are nonetheless relevant to the catchments in the licence area.

6.4.2 Groundwater level and discharge monitoring

As indicated in Figures 6.8 to 6.10, four boreholes are monitored for groundwater levels in the NCB for WFD purposes. Two are in Ireland, Bawn Boy Workhouse (02_001) and Clintygrigney Morton Well (02_003), and two are in Northern Ireland, Derrylin (IH/22/1) and Silverhill (IH/24/1). All are associated with karstified limestone aquifers in the Newtown-Ballyconnell (IEGBNI_NW_G_031) Enniskillen (UKGBNI4NW038) groundwater bodies. Discharges and levels are monitored only at one karst spring, Manorhamilton (12_003), which is located in the Carrowmore East (IE_WE_G_0042) groundwater body.

6.4.3 Monitoring of associated ecosystems

Article 17 of the Habitats Directive requires that the conservation status for habitat types and species are reported to the EC every six years. Monitoring of conservation status is required under Article 11 for all habitats (as listed in Annex I) and species (as listed in Annex II, IV and V).

Four parameters for habitats and species are assessed, as indicated in **Table 6.10.** Each parameter is classified as being “favourable” (good), “unfavourable – inadequate” (poor), “unfavourable – bad” (bad) or “unknown” when there are insufficient data. If one parameter is classed as poor, then the overall conservation status for the habitat or species is also designated as poor.

Table 6.10. Parameters assessed for conservation status of habitats and species

Habitat	Species
1. Range 2. Area 3. Structure & Functions 4. Future Prospects	1. Range 2. Population 3. Area of Suitable Habitat 4. Future Prospects

The first status assessments in Ireland were carried out in 2007 on the basis of best available information. In 2013, new additional information was developed as part of specific detailed monitoring programmes carried out by the NPWS on several habitats and species (NPWS, 2013a). Regular inspections of sites with special attention to the Annex I habitats by NPWS staff are ongoing, and are being carried out to identify trends, changes or threats, should they arise (NPWS, 2009). The NPWS liaises with the EPA and local authorities to determine the quality and quantity of waters associated with water-dependent habitats, to ensure that sampling frequency is adequate for detecting changes in the conservation status of habitats (NPWS, 2009). Table 6.11 outlines the existing water quality monitoring associated with SACs in the case study areas, and Table 6.12 outlines the same for SPAs.

6.5 WFD Water Body Status

Environmental pressures are assessed by the EPA and NIEA under existing WFD reporting requirements. The assessment involves the review of monitoring data against specific ‘tests’ (UKTAG, 2009, 2012a,b; EPA, 2010c) which result in the classification of the quantitative and qualitative status of each water body. The assessment is reported every six years, in line with the preparation of river basin management plans.

Table 6.11. Water quality monitoring – WFD protected area SACs in the case study areas

Site name	Natura 2000 code	Description of monitoring
Ben Bulben, Gleniff And Glenade Complex	IE0000623	Upland area – Some streams from upland areas are monitored.
Lough Arrow	IE0001673	The lake is monitored
Lough Melvin	IE0000428	The lake is monitored
Arroo Mountain	IE0001403	Upland area – Some streams from upland areas are monitored.
Glenade Lough	IE0001919	The lake is monitored
Lough Gill	IE0001976	The lake is monitored as well as several rivers that discharge to it from the study area.
Boleybrack Mountain	IE0002032	Upland area – Some streams from upland areas are monitored.
Cuilcagh – Anierin Uplands	IE0000584	Upland area – Some streams from upland areas are monitored.
Corratirrim	IE0000979	No monitoring
Lough Oughter And Associated Loughs	IE0000007	There is a dense network of rivers and lakes. The Rag River is monitored, as is Cullinaghan Lough.
Lower River Shannon	IE0002165	A transitional water body with 9+ monitoring locations.
Carrowmore Point To Spanish Point And Islands	IE0001021	(Offshore) No monitoring
Carrowmore Dunes	IE0002250	One monitoring point of a stream discharging to the SAC (Creegh River)
Kilkee Reefs	IE0002264	(Offshore) No monitoring
Tullaher Lough And Bog	IE0002343	No monitoring
Lough Melvin	UK0030047	The lake is monitored
West Fermanagh Scarplands	UK0030300	There are two groundwater monitoring locations present. Two rivers that flow from the SAC are also monitored.
Cladagh (Swanlinbar) River	UK0030116	The river is monitored.
Cuilcagh Mountain	UK0016603	Upland area – Some streams from upland areas are monitored.
Moninea Bog	UK0030212	No monitoring
Upper Lough Erne	UK0016614	The lake is monitored as well as several rivers that discharge to it from the study area.

Table 6.12. Water quality monitoring – WFD protected area SPAs in the case study areas

Site name	Natura 2000 code	Description of monitoring
Mid-Clare Coast SPA	004182	No monitoring
River Shannon and River Fergus Estuaries SPA	004077	A transitional water body with 9+ monitoring locations.
Loop Head SPA	004119	There is one transitional monitoring location (approximately 700 m away)
Sligo/Leitrim Uplands SPA	004187	There is some monitoring of rivers that flow from the SAC
Lough Arrow SPA	004050	The lake is monitored
Upper Lough Erne	UK9020071	The lake is monitored

As obtained from the EPA (2014c) and the NIEA (2014c), the WFD water body status reported in 2009 for surface water and groundwater bodies are shown in Figures 6.11 to 6.16 for the two case study areas. The following sections present the status for each water body type, emphasising conclusions about existing environmental pressures. Both the EPA and NIEA are re-assessing the systems and methods of extrapolating and updating water body status in preparation of the second cycle of WFD implementation (2015–2021).

6.5.1 River water bodies

Several river water bodies in both study areas failed to meet the 'at least good status' objective of the WFD in 2009. In the CB study area, see Figure 6.17, approximately 60% of the classified river water bodies are at less than good status, compared to approximately 30% in the NCB study area, see Figure 6.18. However, the NCB study area is much larger, contains a much greater number of water bodies, and includes one water body at 'bad status'.

River water bodies failed to reach 'good' status primarily on the basis of biological indicators, in particular the quality of macroinvertebrate colonies, which are judged from 'Q-scores' in Ireland and the 'Biological Monitoring Working Party (BMWP) biotic score system' in Northern Ireland. In WFD terms, the surface water ecological classification combines three factors: 1) biology; 2) supporting water quality (physico-chemical quality); and 3) supporting physical condition (hydrology and morphology). The biological classification system describes the extent to which human activity has altered ecological communities by comparing the condition of aquatic flora and fauna with known, undisturbed or pristine conditions. In both study areas, none of the river water bodies failed to reach at least 'good' status on the basis of abstraction pressures.

The main cause of the 'moderate' and 'poor' status of river water bodies in the study areas is the composition and abundance of benthic invertebrate fauna. In Ireland, this is mainly attributed to organic (nutrient, e.g. phosphorus) enrichment and oxygen conditions (EPA, 2011b), but there are other pressures which may also contribute. Specific reasons for the reduced quality of macroinvertebrate colonies in affected catchments and water bodies have not been ascertained and would require further consultation with the EPA and/or NIEA.

Of those water bodies that are of 'moderate' or 'poor' status on the basis of macroinvertebrate quality, all passed the WFD status tests for general physico-chemical conditions, as indicated by PO_4, NO_3, NH_3, and BOD. In Ireland, hydromorphological features were assessed to indicate a departure from reference conditions; however, they were not used to provide assessments of status lower than 'high' or 'good' (EPA, 2010c). It is considered that if hydromorphological pressures were significant, they would have an impact on the macroinvertebrate quality element (EPA, 2010c).

A test for specific pollutants for supporting the biological elements was carried out by the NIEA for some water bodies within the NCB study area in Northern Ireland, whereby the concentrations of specific pollutants were compared with relevant environmental quality standards (EQS). Only one river in Northern Ireland, the Cladagh River, failed on a specific pollutant (zinc), and was classified as being at 'moderate' ecological status overall.

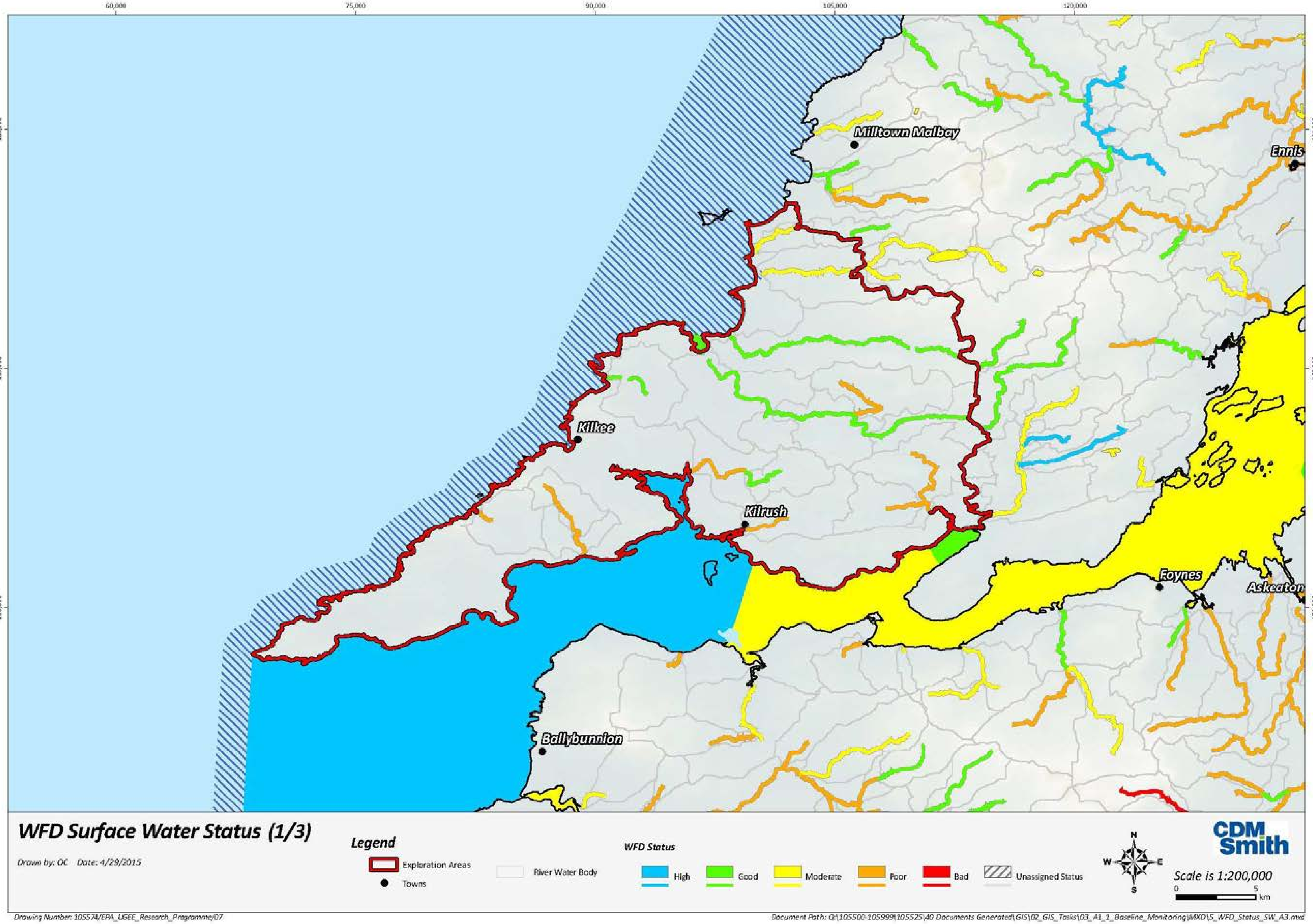


Figure 6.11. WFD surface water body status – CB study area.

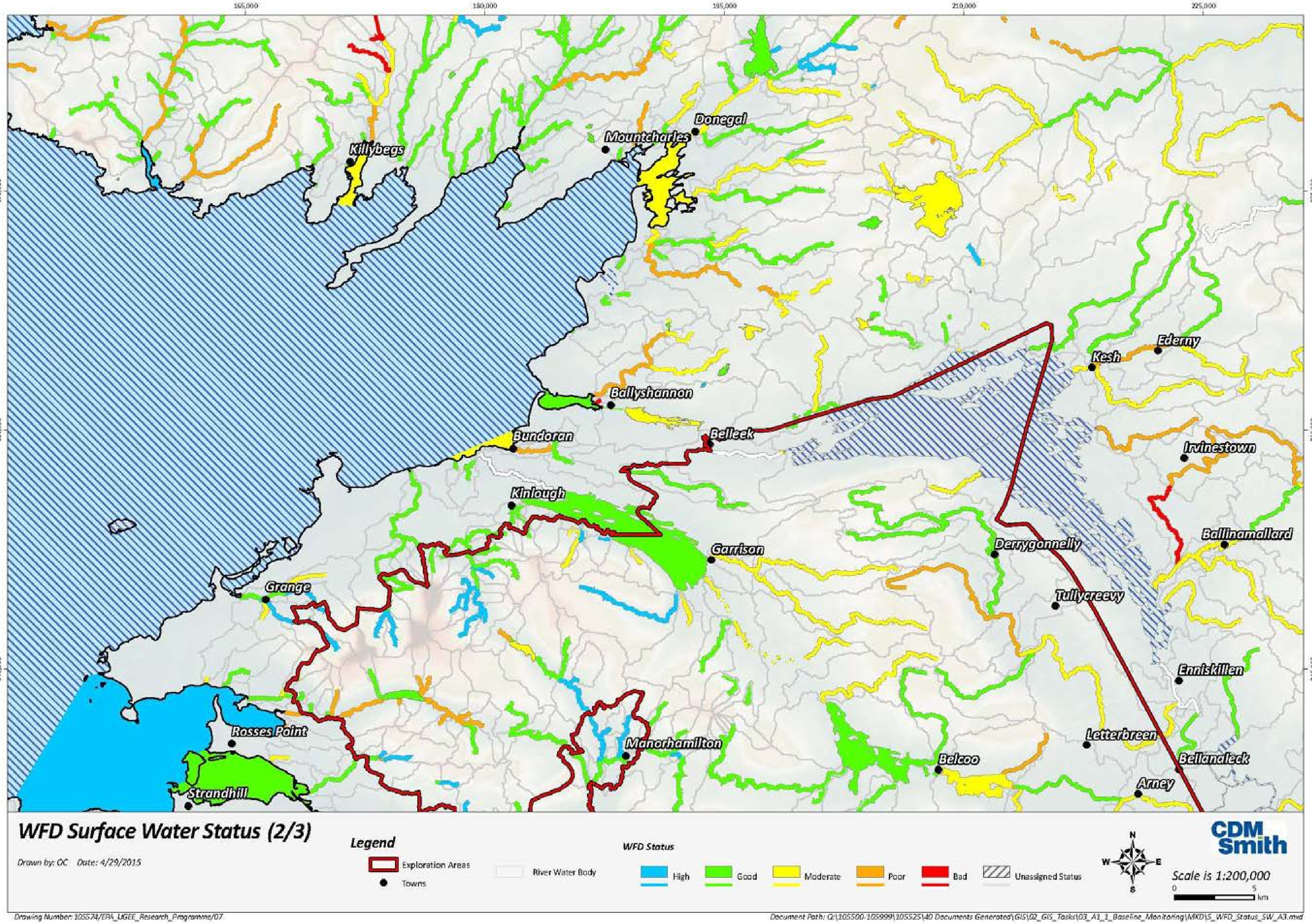


Figure 6.12. WFD surface water body status – NCB study area – Part 1.

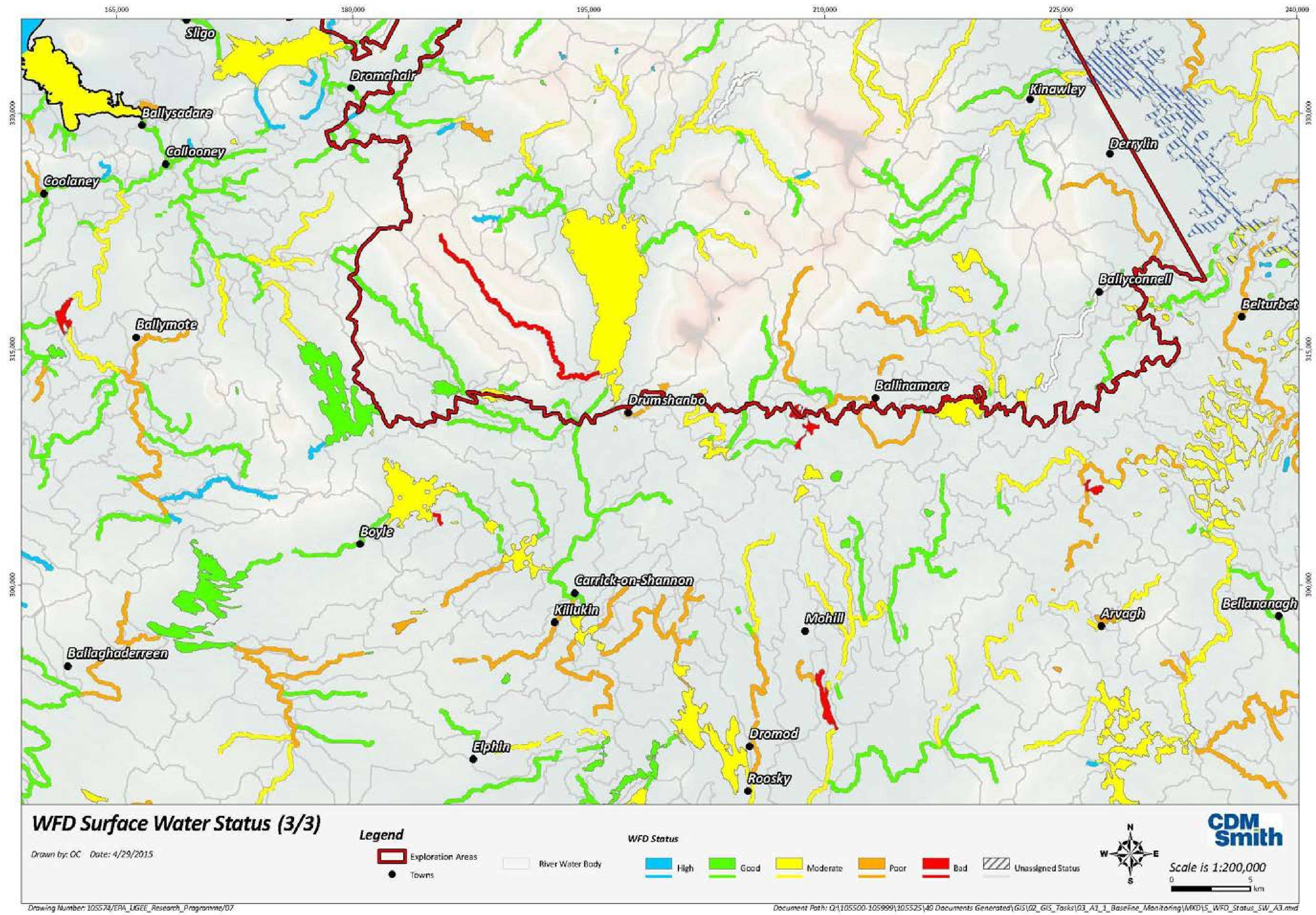


Figure 6.13. WFD surface water body status – NCB study area – Part 2.

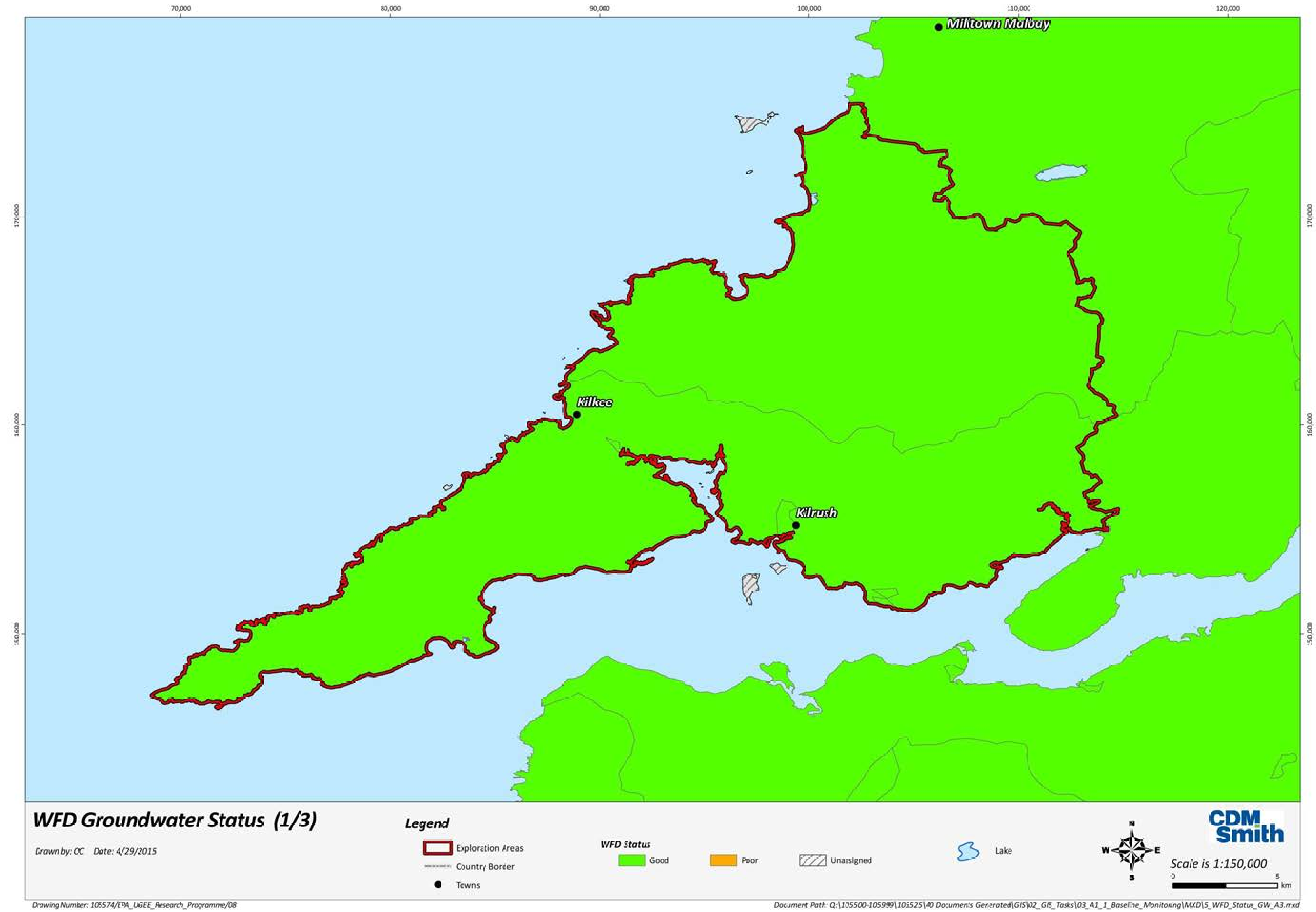


Figure 6.14. WFD groundwater body status – CB study area.

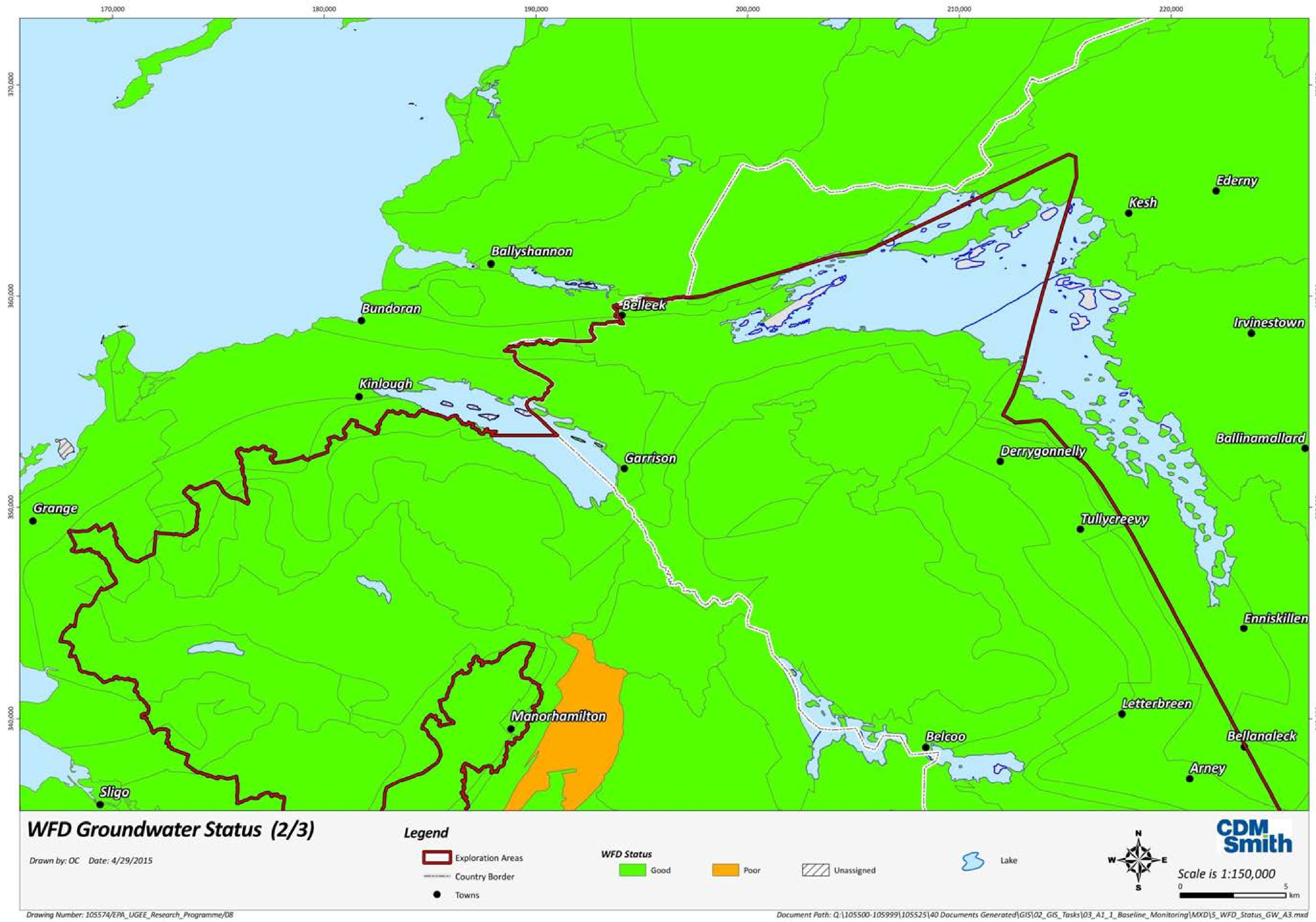


Figure 6.15. WFD groundwater body status – NCB study area – Part 1.

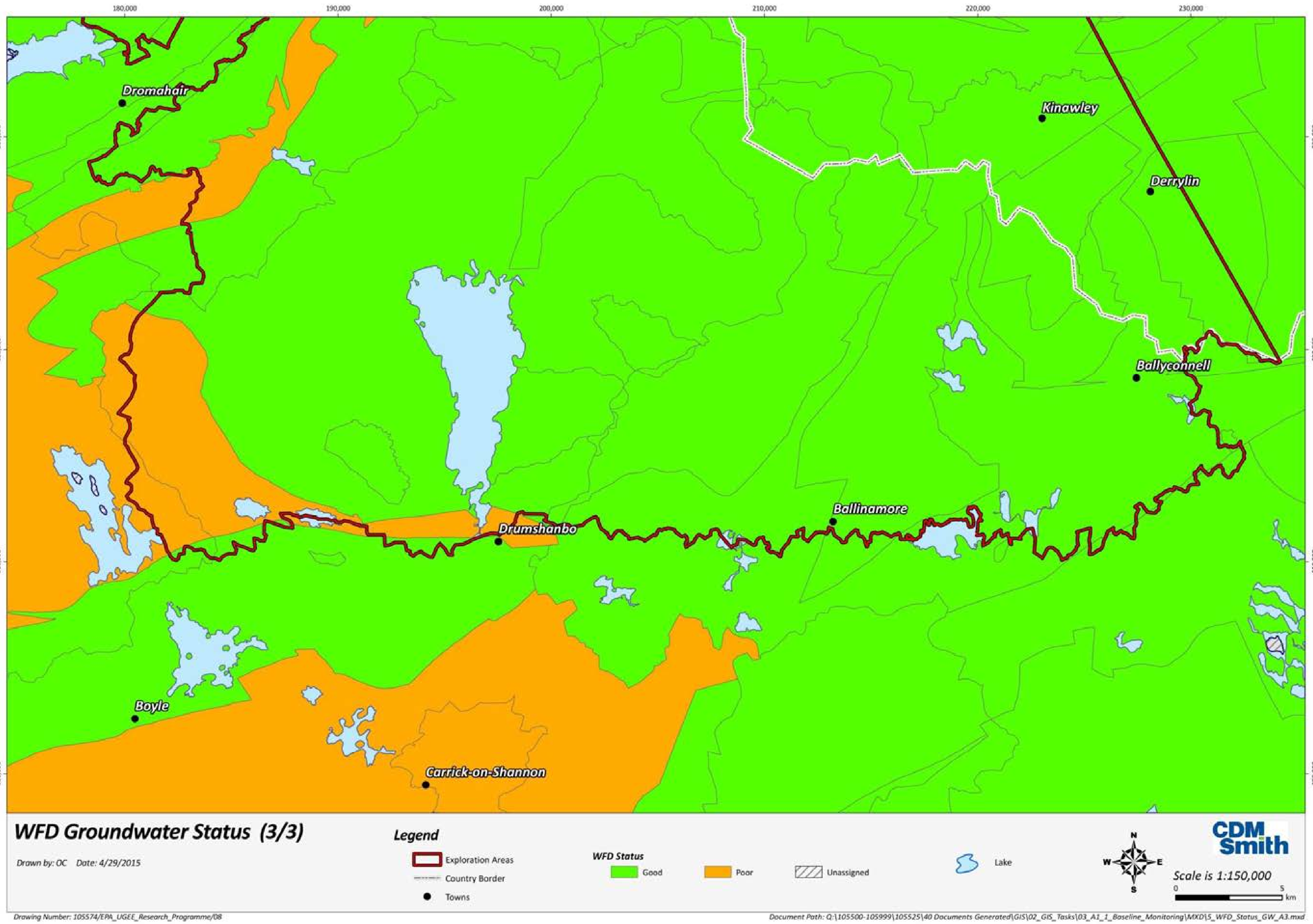


Figure 6.16 WFD groundwater body status – NCB study area – Part 2.

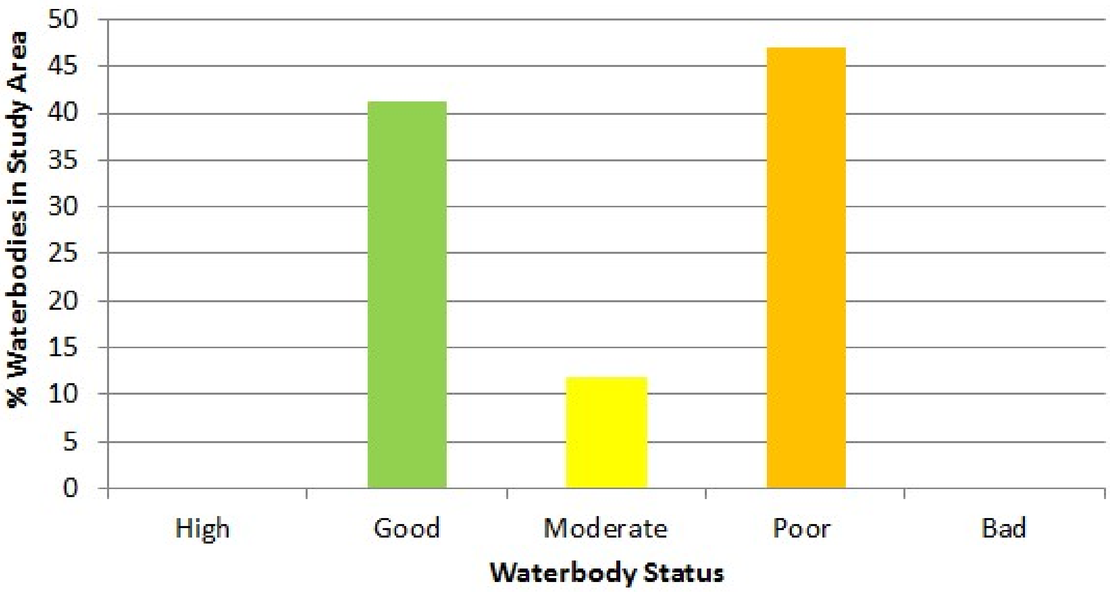


Figure 6.17. Distribution of river status – CB study area.

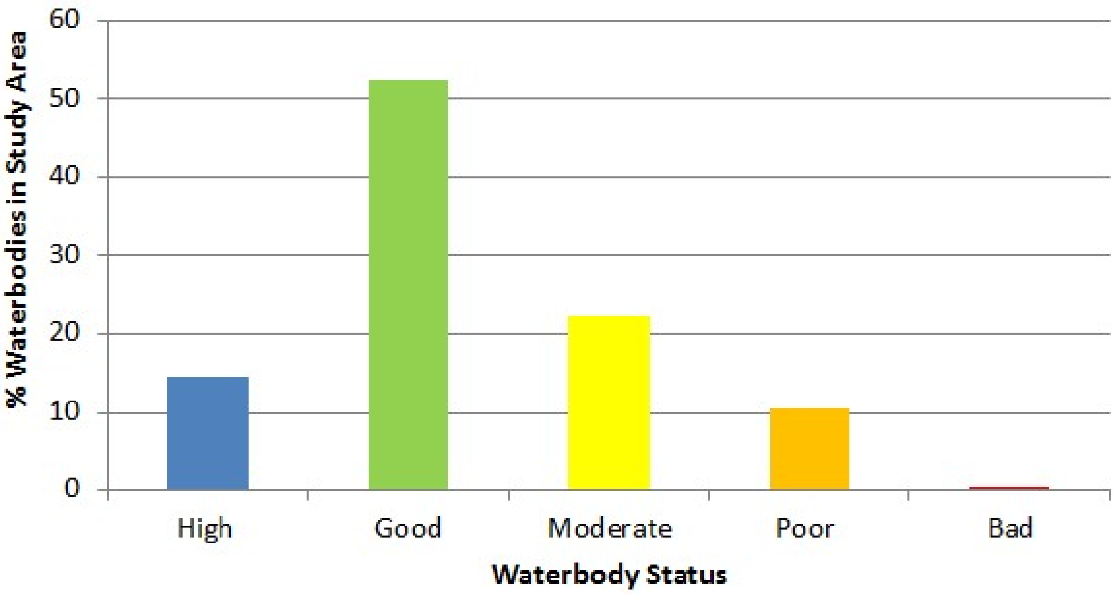


Figure 6.18. Distribution of river status – NCB study area.

Chemical status was also assessed from the concentrations of priority substances. Only one water body, Creegh in the CB study area, was of poor chemical status on this basis -, with an annual average sum of Benzo[g,h,i]perlyene and Indeno[1,2,3,c,d]pyrene of 0.0113 µg/l (EPA, 2011a). Creegh was, however, classified overall as being at 'good' ecological status. Information on priority pollutants in Northern Ireland was not yet available during the preparation of the current report.

The river water body at 'bad' status in the UGEE licence area of the NCB (see Figure 6.13) is the Arigna River (IE_SH_26_110). The 'bad' status was assigned due to the poor quality of macroinvertebrate colonies (assessed with EPA's 'Q-scores'). The Arigna River is located along the 'Connaught Coalfield', a historic coal mining area with waste heaps and active discharges from adits of acid mine drainage (AMD). Even though the river passed the test for supporting physico-chemical conditions, the water quality downstream of the AMD discharges reportedly displays periodic elevated concentrations of nickel and sulphate (EPA/DCENR, 2009). It is inferred, but not conclusively demonstrated, that there could be a causal link between water quality and the reported poor quality of the macroinvertebrate colonies in this catchment.

6.5.2 Lake water bodies

All of the lakes within the CB license area are smaller than 50 hectares (ha), which is below the WFD threshold for status assessment, thus lake water body status in the CB was not assigned by the EPA.

Figure 6.19. shows the distribution of lake water body status in the NCB. The majority of lakes are of 'moderate' status, with only one lake of 'poor' and one lake of 'bad' status.

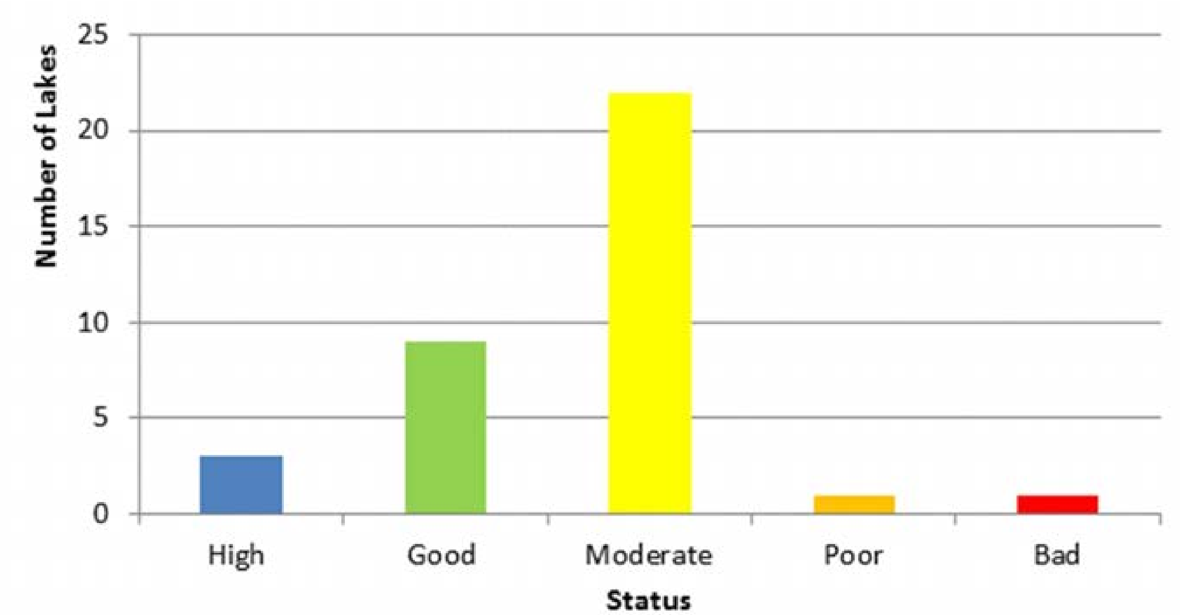


Figure 6.19. Distribution of lake status – NCB study area.

Of the lake water bodies classified as less than 'good', 20 were classified on the basis of monitoring data and the remainder assigned status through desktop review by the EPA and NIEA. Water bodies that failed 'good' status predominantly did so on the basis of elements either relating to biological conditions or elevated phosphorus concentrations, Figure 6.20. None failed on the basis of abstraction pressures.

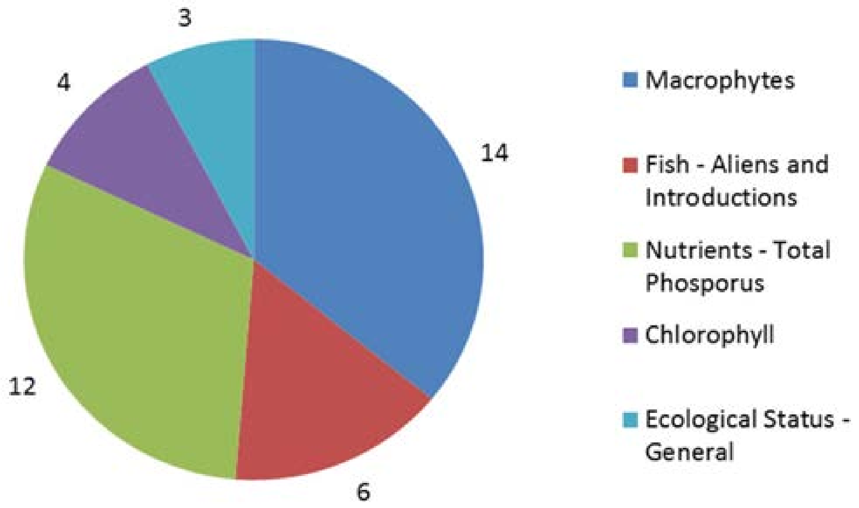


Figure 6.20. Elements driving 'less than good' lake status in the NCB.

6.5.3 Transitional water bodies

Transitional waters are surface waters in estuaries that are of a tidal nature. They are partly saline and substantially influenced by freshwater outflows from rivers. Transitional waters are only directly relevant to the CB study area as the boundaries of the UGEE licence area in the NCB do not extend to the marine environment. Still, many of the rivers in the NCB flow and discharge into transitional or marine waters downstream of the UGEE licence boundaries. In such cases, both transitional and marine water bodies are of indirect relevance to the assessment of potential impact.

As indicated in Table 6.1.3, transitional waters show impact from specific pollutants which have affected their ecological status classification, notably the 'structure and functioning of aquatic ecosystems'.

6.5.4 Coastal water bodies

Of six coastal water bodies associated with the CB study area, the status of five are unassigned due to lack of data. The remaining water body, the Mouth of the Shannon, is classified to be of 'high' status, see Table 6.14.

There are no coastal (marine) water bodies within the NCB study area. Several streams discharge to coastal waters further downstream, and of those that do, Sligo Bay has been assigned 'high' status. Other coastal waters were unassigned in 2009 by the EPA due to lack of monitoring data.

6.5.5 Groundwater bodies

As summarised in Table 6.15, all groundwater bodies in the CB study area were of good quantitative and chemical status. Abstractions are currently considered to be sustainable and there are no perceived issues with groundwater chemistry or resulting impacts on drinking water or surface water bodies. However, it should be emphasised that there are no specific monitoring locations in the UGEE licence area of the CB, and status is inferred from groundwater body data to the south of the Shannon Estuary which are in the same 'reference group' licence (e.g. Glin borehole in Namurian rocks). Accordingly, the assigned confidence level in the UGEE area is considered to be low.

Table 6.13. Summary of transitional water body status

Water body	Status	Elements driving status
Clare Basin		
Clonderalaw Bay	Good	
Doonbeg Estuary	Good	
Lough Donnell	Unassigned	
Lower Shannon Estuary	Moderate	Chemical status (specific pollutants), ecological status
Northwest Carboniferous Basin		
Ballysadare Estuary	Moderate	Ecological Status (fish)
Drowes Estuary	Moderate	Ecological Status
Drumcliff Estuary	High	
Duff Estuary	Moderate	Ecological Status
Erne Estuary	Good	

Table 6.14. Summary of coastal water body status

Coastal water body	Status
Clare Basin	
Cloonconeen Pool	Unassigned
Doonbeg Bay	Unassigned
Mouth of the Shannon (HAs 23;27)	High
Scattery Island Lagoon	Unassigned
Shannon Plume (HAs 27;28)	Unassigned
Southwestern Atlantic Seaboard (HA 23)	Unassigned
Northwest Carboniferous Basin	
Donegal Bay (Erne)	Unassigned
Donegal Bay Northern	Unassigned
Donegal Bay Southern	Unassigned
Portavaud East, Ballysadare Bay	Unassigned
Sligo Bay	High

Table 6.15. Summary of groundwater status – CB study area

	Numbers of water bodies		% of Water bodies	
	Good status	Poor status	Good status	Poor status
Quantitative Status	6	0	100	0
Chemical Status	6	0	100	0
Overall Status	6	0	100	0

As summarised in Table 6.16, all groundwater bodies in the NCB study area are considered to be of good quantitative status. Three groundwater bodies were classified as being of poor chemical status, notably Ballymote, Killarga and Geevagh. In all three cases, the assessment was based on failed phosphorus tests in surface water, whereby the associated karstified limestone aquifers are inferred to contribute greater than 50% of the phosphorus load to the rivers, leading to a breach of the environmental quality standard for phosphorus in rivers. There are several possible sources for the elevated phosphorus concentrations in surface water, but the case-specific circumstances of the three poor status groundwater bodies are not precisely known.

Table 6.16. Summary of groundwater status – NCB study area

	Numbers of water bodies		% of Water bodies	
	Good status	Poor status	Good status	Poor status
Quantitative Status	60	0	100	0
Chemical Status	57	3	95	5
Overall Status	57	3	95	5

6.5.6 Groundwater quality

Table 6.17 lists WFD groundwater quality monitoring stations in respective case study areas, arranged by bedrock formation. These monitoring stations include public and private regulated supplies, based on information received from local authorities in November 2014. All are located in the NCB study area and most stations are associated with limestone formations which are the primary aquifers in the NCB. Some of the drinking water quality stations are also associated with sandstone and shale formations, albeit at locations where these are present near the ground surface, principally along the margins of the NCB.

Table 6.17. Summary of groundwater monitoring locations within study areas

Bedrock formation name	No. of WFD groundwater quality monitoring locations	No. of drinking water quality – groundwater monitoring locations
Dartry Limestone	4	4
Glenade Sandstone		3
Benbulben Shale		3
Dergvone Shale		1
Mullaghmore Sandstone		1
Glencar Limestone	4	1
Gowlaun Shale		1
Lackagh Sandstone		1
Drumgesh Shale		1
Knockmore Limestone	1	
Bricklieve Limestone (upper)		1
Bricklieve Limestone	1	
Central Clare Group[a]		1

[a]in the Clare Basin – all other monitoring locations are in the NCB

Table 6.18 summarises groundwater quality data for the WFD monitoring points in the Dartry Limestone Formation. The data cover the period from 1997 to 2013, and the four monitoring points are:

- Bawnboy (NW_G_031_0200_002);
- Kinlough/Tullaghan (WE_G_0060_1700_002);
- Manorhamilton (WE_G_0042_1700_003); and
- Boho Rising (GBNIGWNW06-C).

Table 6.18. Summary of water quality – Dartry Limestone Formation (1997–2013)

Parameters	Units	Natural back-ground[a]	Count	Min	Max	Median	Average	St. dev.
pH	pH	-	94	6.7	8.5	7.4	7.44	0.36
Conductivity	µS/cm	-	97	121	1233	381	370	145
Total Hardness	mg/l $CaCO_3$	-	115	26.0	368	189	182	75.0
Turbidity	NTU	-	110	<0.1	40.6	0.95	3.28	6.88
Nitrate as NO_3	mg/l	3.3	118	<0.36	6.0	2.4	2.41	1.25
Molybdate Reactive Phosphorus	mg/l P	-	117	<0.003	0.6	0.013	0.025	0.06
Chloride	mg/l Cl	18	118	4.6	29.0	12.4	12.3	2.98
Fluoride	mg/l F-	-	108	<0.1	0.5	0.075	0.081	0.06
Sulphate	mg/l SO_4	10	118	<1	31.5	5	6.14	4.79
Sodium	mg/l Na	19	117	4.4	20.1	7.69	7.70	1.87
Potassium	mg/l K	2.8	118	<0.2	5.8	0.895	1.02	0.86
Magnesium	mg/l Mg	14	117	1.4	20.7	8.16	8.53	5.26
Calcium	mg/l Ca	132	118	21.7	108	64.4	60.7	19.0
Iron	µg/l Fe	130	118	<2.5	1820	19.7	102	247
Manganese	µg/l Mn	32	117	<1	341	3	12.4	36.2
Barium	µg/l Ba	162	103	<5	73.0	11	20.1	15.5

[a]Baker *et al.* 2007

Included are the minimum, maximum, mean, median and standard deviation of reported concentrations. Where the measured values were below the detection limit, these results were substituted with a value of half the limit of detection for the purposes of calculating the relevant statistics.

The concentrations of nitrate in the Dartry Limestone Formation range from <0.36 mg/l to 6.0 mg/l with a mean of 2.41 mg/l (as NO_3). These values are well below the EU Drinking Water Directive maximum admissible concentration (MAC) of 50 mg/l and the groundwater threshold value (Groundwater Regulations S.I. No. 9 of 2010) of 37.5 mg/l. The mean is also below the most stringent groundwater nitrate threshold values of 4 mg/l proposed for GWDTEs set by the UKTAG. The concentration of Molybdate Reactive Phosphorus (MRP) ranges from <0.003 mg/l to 0.2 mg/l. The mean is 0.020 mg/l which is below the groundwater threshold value (Groundwater Regulations S.I. No. 9 of 2010) of 0.035 mg/l, although there were 4 exceedances of the threshold in the period of record.

Six samples were analysed for select volatile organic compounds and hydrocarbons between 1997 and 2013. There were single detections only of Bromodichloromethane 0.10 µg/l and Dibromochloromethane 0.42 µg/l. Both are trihalomethanes (THMs) and concentrations were below the EU Drinking Water Directive maximum admissible concentration (MAC) of 100 µg/l and the groundwater threshold value of 75 µg/l

Table 6.19 summarises groundwater quality data for the WFD monitoring points in the Glencar Limestone Formation, which underlies and may be in hydraulic connection with the Darty Limestone Formation. The data cover the period from 2007 to 2013 for the following four monitoring points:

- Calry (WE_G_0042_2700_001);
- Legland Spring (GBNIGWNW05-C);
- Hanging Rock East (GBNIGWNW10-C); and

- Knockmore Rising (GBNIGWNW50-C).

Table 6.19. Summary of water quality – Glencar Limestone Formation (2007–2013)

Parameters	Units	Natural back-ground[a]	Count	Min	Max	Median	Average	St. dev.
pH	pH	-	48	6.36	8.90	7.40	7.48	0.59
Conductivity	µS/cm	-	48	117	1323	380	399	179
Total Hardness	mg/l $CaCO_3$	-	55	58	279	176	167	67.2
Turbidity	NTU	-	56	<0.11	32	0.95	2.97	5.28
Nitrate as NO_3	mg/l	3.3	57	<0.13	6.64	1.94	2.36	1.32
Molybdate Reactive Phosphorus	mg/l P	-	33	<0.004	0.2	0.008	0.020	0.04
Chloride	mg/l Cl	18	56	7.8	19.4	12.4	12.6	2.77
Fluoride	mg/l F-	-	43	<0.048	0.300	0.075	0.105	0.07
Sulphate	mg/l SO_4	10	57	<0.1	24.0	4.9	4.93	3.52
Sodium	mg/l Na	19	57	4.96	25.0	7.5	7.87	2.65
Potassium	mg/l K	2.8	57	<0.18	2.67	0.6	0.73	0.41
Magnesium	mg/l Mg	14	57	1.71	26	5.11	5.88	4
Calcium	mg/l Ca	132	56	48.5	96.7	73.2	74.7	13.9
Iron	µg/l Fe	130	33	<2	115	8.00	30.7	41.5
Manganese	µg/l Mn	32	57	<0.1	116	1.9	9.73	17.7
Barium	µg/l Ba	162	42	3.5	27	11.7	13.4	5.50

[a]Baker *et al.* 2007

The concentrations of nitrate in the Glencar Limestone Formation range from <0.13 mg/l to 6.64 mg/l with mean of 2.36 mg/l (as NO_3), also below the threshold values referenced above. The concentration of MRP ranges from <0.004 mg/l to 0.2 mg/l with mean of 0.020 mg/l, which is also below the groundwater threshold value (Groundwater Regulations S.I. No. 9 of 2010) of 0.035 mg/l, albeit there were 2 exceedances of the threshold in the period of record.

Approximately 30 samples were analysed for pesticides, VOCs and hydrocarbons between 2008 and 2013 in the Glencar Limestone Formation. The only detections were of the pesticides 2,4-Dichlorophenoxyacetic acid (2,4–D) at 0.07 µg/l, MCPA at 1.52 µg/l, and Azinphos-methyl at 0.005 µg/l. MCPA exceeded the drinking water standard of 0.1 µg/l, but none of the detections were confirmed in subsequent sample rounds. THMs were detected as follows: chloroform at 140 µg/l and Bromodichloromethane at 18.9 µg/l in one sample in June 2009. The total concentrations exceeded the EU Drinking Water Directive maximum admissible concentration (MAC) of 100 µg/l as well as the groundwater threshold value of 75 µg/l. None of the detections were confirmed in subsequent samples. The cause(s) of the single detections have not been ascertained.

6.6 Summary of Environmental Pressures

Existing environmental pressures in the case study areas are outlined in the various published river basin management plans for the first cycle of WFD implementation (2009–2014). Of the approximately 50% of surface water bodies which fail to be at least ‘good status’, the majority are river water bodies which fail for ecological reasons relating to the ‘structure and functioning of aquatic ecosystems’, in which macrophyte and micro-invertebrate communities have been flagged as problematic. Both can be indicative of water quality issues such as nutrient enrichment, resulting in eutrophication which increases biomass and causes a disturbance in the balance of organisms that are present in the water.

The underlying details of the causes of the poor ecological status cases would be subject to further study and clarification and consultation with the EPA and NIEA.

The pressures associated with water bodies that do not meet ‘good status’ objectives are primarily assigned to chemical loading of nutrients (phosphorus especially) and physical modifications (e.g. from dredging/channeling and river bank modifications). The nutrient loading is mainly attributed to diffuse agricultural activities and point-source discharges from municipal wastewater treatment works, as well as multiple small source discharges associated with wastewater effluent from unsewered properties.

It is important to note that the WFD classification of ecological status is not designed to assess potential impacts from UGEE operations. For this to be the case, greater emphasis would need to be placed on key indicator parameters of UGEE activities (see Section 10). This would be needed in order to set a baseline for impact assessment of potential UGEE-related operations in the future.

7 Potential for Impact from Abstractions

UGEE projects require water for several purposes, including drilling operations, well construction, hydraulic fracturing, sanitation and equipment washing. The amount of water needed is case-specific, as a function of the properties of the geological formations, the depths and lengths of drilling to be undertaken, and the targets set by the exploration companies. For drilling, water is needed to mix mud or other additives that serve to stabilise boreholes and remove drill cuttings. For hydraulic fracturing, water is injected with sand and chemicals as part of the process of breaking the target rock formations and releasing the natural gas.

Concrete plans and details of future UGEE projects in both Ireland and Northern Ireland are not yet known. Accordingly, the actual volumes of water that would be needed are not specified. For guidance purposes, ranges of water use requirements for UGEE projects were researched from published international literature.

The highest water use requirements are associated with the hydraulic fracturing programme, over relatively short periods of time, typically measured in days. In the US, cited water demands for hydraulic fracturing range from 100 to 12,000 m^3 per well (Meiners *et al*., 2013), 10,800 to 35,000 m^3 per well (NYSDEC, 2011) and up to 23,000 m^3 per well (USEPA, 2015). Vengosh *et al.* (2014) reported an average water consumption of approximately 15,000–20,000 m^3 for a single hydraulic fracturing well in the US. In Europe, reported demands are slightly lower, and generally range between approximately 5000 and 15,000 m^3 per well (JRC, 2013; Amec, 2014) although higher and lower values can apply depending on case-specific circumstances.

7.1 Development of Water Use Scenarios

The volumes of water that would be required for the development of UGEE operations at a given site or in a given area depend on the:

- Demands for general water use purposes (e.g. sanitation, equipment washing);
- Drilling methods and progress, vertical depths and lengths of horizontal boreholes drilled, and the degree to which water may be needed for drilling incidents such as losses of circulation;
- Number of well pads in a given area;
- Number of horizontal fracturing wells per well pad;
- Details of the hydraulic fracturing programme (e.g. the number of hydraulic fracturing stages (as function of horizontal length) in each well and the actual volumes used in each stage); and
- Timing and duration of build-out scenarios of UGEE projects/operations.

Other factors which directly influence UGEE-related water usage are the proportions of flowback and production waters that are generated from the operations, as well as the degree to which these can be treated and recycled, thereby reducing the volumes of water that would otherwise be abstracted from local sources and/or ‘imported’ or transported from other available sources.

Estimated water use requirement scenarios for the NCB and CB study areas are summarised in Table 7.1 and Table 7.2, based on the ‘probable commercial scenarios’ that were established in *Final Report 4: Impacts and Mitigation Measures* of the UGEE JRP (CDM Smith, 2016).

Table 7.1. Water use requirement scenarios for the total licence area – NCB study area

Description	Unit	Low	Moderate	High
Well pads	No.	75	105	180
Wells per pad	No.	8	12	16
Total wells per study area	No.	600	1260	2880
Required volume of water per well/fracture programme	m^3	5000	10,000	15,000
Flowback of fracture fluid per well/fracture programme	%	25	32.5	40
Recycling rate for flowback water	%	80	40	0

Table 7.2. Water use requirement scenarios for the total licence area – CB study area

Description	Unit	Low	Moderate	High
Well pads	No.	20	30	50
Wells per pad	No.	8	12	16
Total wells per study area	No.	160	360	800
Required volume of water per well/fracture programme	m^3	5000	10,000	15,000
Flowback of fracture fluid per well/fracture programme	%	25	32.5	40
Recycling rate for flowback water	%	80	40	0

Each item listed in the above tables is described below.

7.1.1 Number of well pads

The number of well pads that can be accommodated and/or developed in a licence area would in reality be determined by constraints placed on the developers. Constraints can be of a regulatory nature (e.g. authorisations) and a practical nature (e.g. landowner agreements, cost of development/operations). The theoretical maximum number of well pads that can be accommodated is a function of horizontal well lengths and the spatial configuration of the licence area. With regard to horizontal well lengths, there are no reference materials that provide specific guidance for the two study areas, but on the basis of published plans in England and the US, lengths of 1500 m can be anticipated. On this basis, an estimated (theoretical) maximum of 180 well pads can be accommodated within the NCB licence area and 50 well pads can be accommodated in the CB licence area. This maximum theoretical development is reflected as the 'high' water use scenario in Table 7.1 and Table 7.2.

In reality, certain areas are not physically or geologically favourable or practical for well pad development. Examples are lakes and areas where the unconventional gas target formations are either absent or too shallow for consideration of hydraulic fracturing. A minimum depth limit of 500 m for the latter was indicated by Tamboran (2012) in the NCB. Accordingly, mapped outcrop areas of the Ballyshannon Limestone, Bundoran Shale and Mullaghmore Sandstone Formations were excluded and a 3 km buffer was further applied in an approximate downdip direction, reducing the number of well pads that can be accommodated to 105 in the NCB. This constrains the likely development scenarios towards the Lough Allen Basin subdivision of the NCB. A comparable reduction in the number of well pads to 30 in the CB was assigned by eliminating areas where the interpreted depth to the unconventional gas target formation (i.e. the Clare Shale Basin) is less than 500 m. The downwards revised number of well pads represents the 'moderate' water use scenario in Table 7.1 and Table 7.2.

A third 'low' water use scenario was also defined by reducing the number of well pads arbitrarily to 75 in the NCB and 20 in the CB. This reflects a scenario whereby further spatial constraints would be imposed on the developers. Examples would be restrictions to development near or within boundaries of Special Areas of Conservation (SACs), groundwater Source Protection Zones (SPZs), and other environmentally sensitive locations.

Until prospective UGEE plans become known, there is no accurate way to predict or judge precisely how water use requirements would emerge in the future. The three scenarios in Table 7.1 and Table 7.2 provide ranges which can guide the assessment of water use requirements and water resources availability in respective case study areas. The 'high' scenario is not considered realistic, simply because it includes well pads in locations where UGEE development would not be attempted (e.g. geologically unfavourable areas). The 'moderate' and 'low' scenarios are more realistic, and the actual future scenario could even be somewhere in between.

7.1.2 Number of wells per well pad

Technology is sufficiently advanced that oil and gas companies can drill multiple wells from single well pads. For the three water use scenarios, the number of wells drilled per pad is considered to be 8, 12 and 16, as defined by the 'probable commercial scenarios' in *Final Report 4: Impacts and Mitigation Measures* of the UGEE JRP (CDM Smith, 2016).

7.1.3 Total wells per licence area

The total wells per licence area was calculated by multiplying the number of wells per pad by the total number of well pads in each licence area.

7.1.4 Required volume per hydraulic fracturing programme

The required volume of water for a hydraulic fracturing programme at a single well is guided by published values from UGEE applications in Europe (CDM Smith, 2016), i.e. 5000 m^3 for the low water use scenario, 10,000 m^3 for the moderate water use scenario, and 15,000 m^3 for the high water use scenario.

7.1.5 Flowback volumes of fracture fluid per fracturing event or programme

Based on the 'probable commercial scenarios' (CDM Smith, 2016), an estimated range of flowback volumes between 25 and 40% of the water used is considered realistic: 25% for the low water use scenario, 32.5% for the moderate water use scenario, and 40% for the high water use scenario.

7.1.6 Recycling of flowback water

Flowback water could be treated and partly recycled to reduce the demand on, and supply from, local water resources. Up to 80% recycling can be accomplished as described *Final Report 4* of the UGEE JRP (CDM Smith, 2016). For the water use scenarios, the 80% is used with the low water use scenario, 40% is used for the moderate water use scenario, and 0% (no recycling) is used for the high water use scenario. There is an increasing trend worldwide of recycling some proportion of the flowback water (CDM Smith, 2016), and the degree of recycling is determined by technical considerations (feasibility), cost considerations (treatability of flowback water vs. access to local water sources), and regulatory considerations (e.g. authorisation and ability to discharge wastewater effluents to local water bodies).

There is also a temporal aspect that must be considered, specifically how development would proceed in time, both at an individual well pad and on a cumulative basis across a given licence area. The 'build-out' period of UGEE projects/operations cannot be predicted with any certainty, but for purposes of the UGEE JRP, it has been assumed that build-out would occur in each lease area over a 15-year period beginning gradually, peaking in Years 7 to 11, and subsequently declining to Year 15. There are 3 lease areas in the NCB, and it is assumed that development (by different licences) in each would proceed concurrently. Without knowledge of how UGEE would be planned and developed in the future, this is a 'worst case' or maximum development scenario.

The resulting total annualised water use (m^3/yr) for the build-out period are presented in Figure 7.1 and Figure 7.2 for the NCB and CB licence areas, respectively. The corresponding estimated annualised maximum water use requirements, expressed in m^3/d, for years 7 through 11 of the build-out scenario, are summarised in Table 7.3.

7.2 Maximum Daily Water Demand for UGEE Operations

The annualised water use requirements presented above indicate the progression of total and maximum water use requirements for the 15-year build-out scenario. They do not define the maximum daily water demand on any given day. Rather, this is defined by the number of hydraulic fracturing stages and the volumes of water needed for each stage. Using the maximum water requirement for a hydraulic fracturing programme at a single well of 15,000 m^3 (see Section 7.1), the water demand for a single well would be determined by how the programme is implemented, specifically how many fracturing stages are undertaken and the total duration of programme.

For a single well, a hydraulic fracturing programme is typically completed within a few (3–10) days (CDM Smith, 2016), although the duration of the programme is subject to case-specific circumstances and objectives. Accordingly, if the programme requires 15,000 m^3 of water over a 3-day implementation period, the maximum daily water demand would be 5000 m^3/d for the single well (assuming the same quantity was required each day). If the duration is shorter, or greater volumes of water are required, the daily demand would increase. More significantly, if identical programmes are carried out at multiple wells concurrently, the total daily demand would become significantly greater.

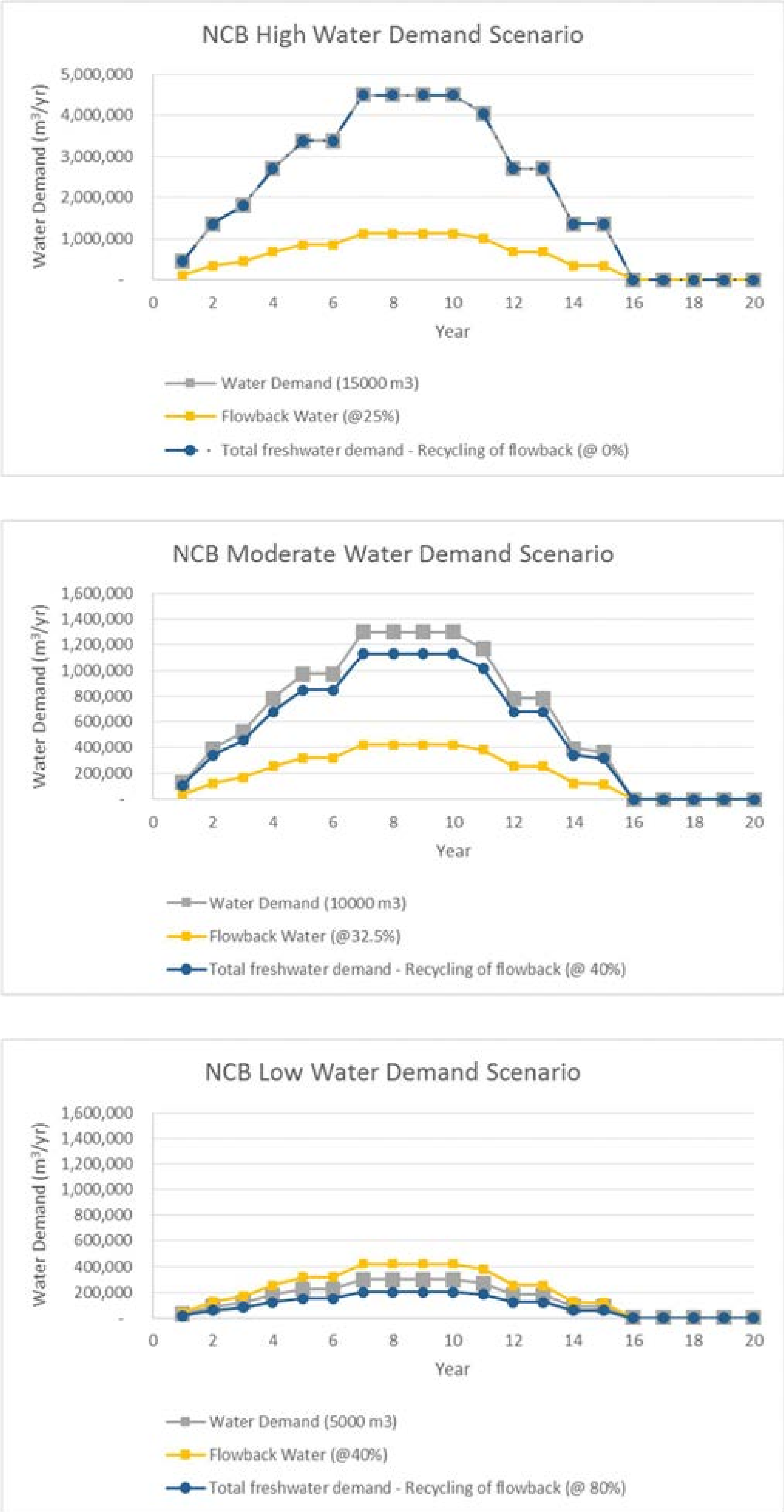
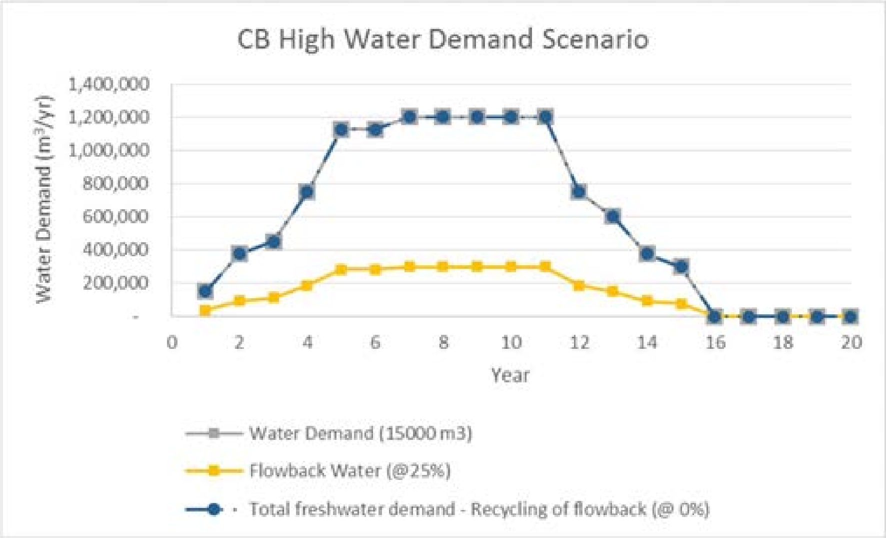
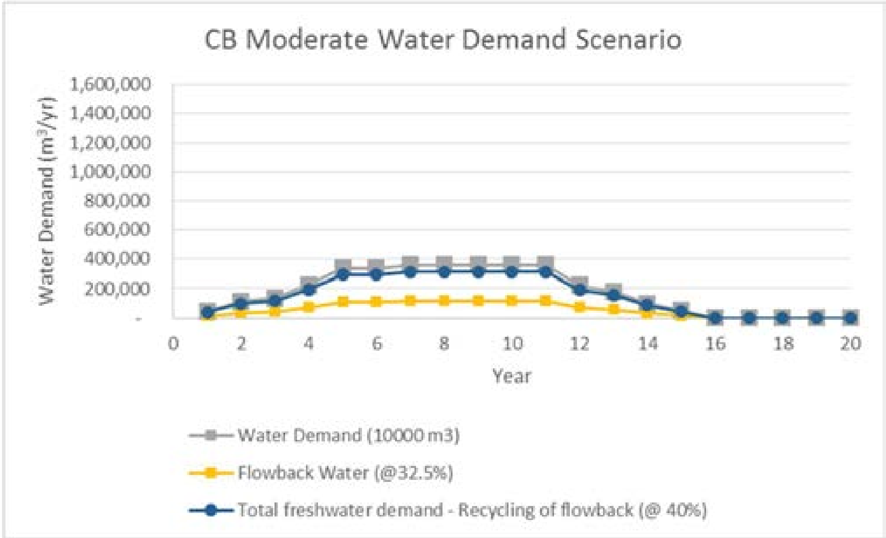


Figure 7.1. UGEE water use requirement – NCB study area.





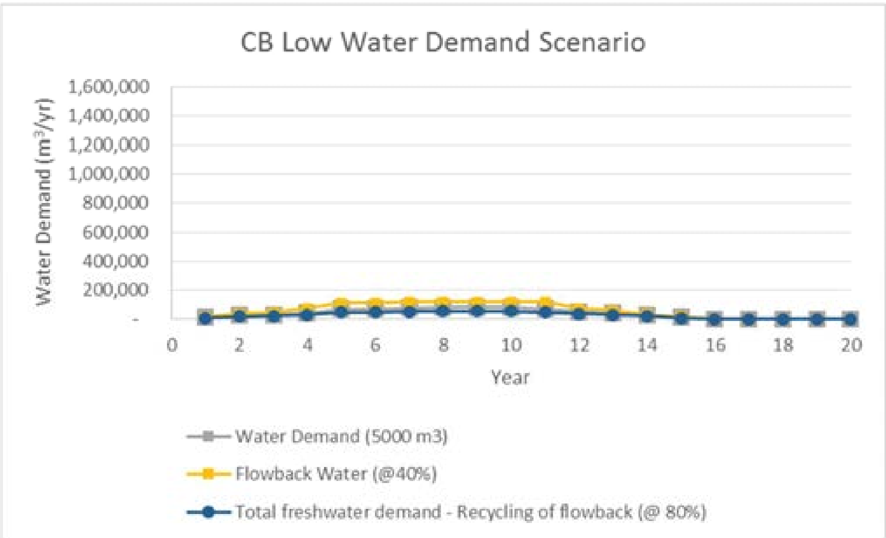


Figure 7.2. UGEE water use requirements – CB study area.

Table 7.3. Estimated annualised water use requirements during the assumed build-out scenario

Water use requirement	Clare Basin	Northwest Carboniferous Basin		
		Demand per lease area	No, of lease areas in NCB	Demand for NCB licence area
High	3288 m^3/d	4110 m^3/d	3	12,330 m^3/d
Moderate	858 m^3/d	1032 m^3/d		3096 m^3/d
Low	149 m^3/d	186 m^3/d		558 m^3/d

For the peak build-out scenario presented in Figure 7.1 and Figure 7.2, approximately 130 wells for the moderate build-out scenario would theoretically be drilled and hydraulically fractured per year in the NCB study area. Assuming 3 days per hydraulic fracturing programme, this equates to 390 days of a demand of 5000 m^3/d in the example given above.

Such development and demand would have to be supplied from multiple sources. Accordingly, all future proposed UGEE-related abstraction plans would have to be carefully reviewed to understand the timeline of total demands, individually and cumulatively, with the involvement of relevant stakeholders and regulatory bodies.

7.3 Sourcing of Water to Meet Demands

It is anticipated that the water required for UGEE projects/operations would be sourced from available water resources within or close to the licence areas in each basin. It is further expected that UGEE developers would try to source water as close as possible to individual wells pads. Precisely how and where the water would be sourced would be determined by practical considerations and cost – specifically the costs of planning, licensing, constructing and maintaining abstraction points versus the costs of purchase and transport of water from existing water supply schemes in the region.

Given the high rainfall in both case study areas, rainwater harvesting is an option to help reduce demands from water abstraction sources. The use of recycled treated wastewater can also reduce water demands, but the ability to recycle treated wastewater effluent from UGEE operations is influenced by the volumes of the available flowback water as well as the chemical nature and treatability of same. Thus, establishing and subsequently monitoring the volumes and quality of flowback and production water become important operational controls (Nicot *et al*., 2014). There is a trend in the industry towards increasing the proportion of recycled flowback and produced water, especially in areas where freshwater resources are limited (Nicot *et al*., 2014). This is also described in *Final Report 4: Impacts and Mitigation Measures* of the UGEE JRP (CDM Smith, 2016).

Any UGEE-related abstractions would be subject to existing control measures (systems of "prior authorisation") in both Ireland and Northern Ireland. In Ireland, abstraction controls are currently defined by:

(a) The Environmental Impact Assessment (EIA) Directive (85/337/EEC), which is included in statutory instrument (S.I.) No. 93 of 1999 (EC (EIA) (Amendment) Regulations, 1999) and referred to in Part 2 of Schedule 5 of the Planning and Development Regulations, 2001;

(b) The Water Supplies Act 1942, as amended by the Planning and Development Act (S.I. 30 of 2000); and

(c) The Planning and Development Regulations (2001) for groundwater abstraction proposals for water supply to Local Authorities.

In Northern Ireland, abstractions of all waters are licensed under the Water Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006.

Article 11.3(e) (Programme of Measures) of the European Union (EU) Water Framework Directive (WFD) (2000/60/EC) requires a system of "prior authorisation" for water abstractions. It also includes provision for measures to be introduced to mitigate potential abstraction impacts on water resources. Different water bodies can be impacted in different ways, e.g. by changes in water levels, flow/discharge, quality, and/or the status/health of associated aquatic ecosystems. With regard to the latter, the European Court of Justice (ECJ) has ruled that Article 6(3) of the EC Habitats Directive (EC 92/43/EEC) applies to abstraction projects, whereby an Appropriate Assessment is required where the potential for impact to Natura 2000 sites is identified (EC, 2006). In Ireland, control measures for groundwater abstractions are specifically addressed by the recently enacted Groundwater Regulations (S.I. No. 9 of 2010).

Within the UGEE licence areas in the NCB, several surface water and groundwater bodies cross the border between Ireland and Northern Ireland. Such water bodies are part of formally designated international river basins under the EU WFD, and in cross-border river basins, Article 3 (Coordination of administrative arrangements within river basin districts) of the WFD requires Member States to coordinate water resources management. Accordingly, the study and prior authorisation of future abstractions of shared water resources and associated ecosystems in the NCB study area would require coordination amongst the relevant regulatory bodies in Ireland and Northern Ireland.

Impacts from abstractions are described in terms of volumes of water per unit time but also by potential changes to water levels, flows, ecosystems and habitats, and water quality. Key descriptors are discussed below based on existing, verified abstractions in the NCB and CB study areas and the potential UGEE-related water demand scenarios that were defined in Section 2.

7.4 Lakes

Lakes are abstracted for public and private water supplies. **The single** largest abstraction from lakes is associated with Lough Erne, where the Fermanagh regional water scheme is supplied from two pump stations at Belleek and Killyhevlin.

Table 7.4 summarises the abstracted lakes within or adjoining the UGEE licence boundaries, indicating respective lake surface areas, approximate storage volumes, delineated catchment areas, estimated daily mean inflows, abstraction rates, and ratios of abstractions and estimated daily mean inflows.

The single largest abstraction from lakes is associated with Lough Erne, where the Fermanagh regional water scheme is supplied from two pump stations at Belleek and Killyhevlin.

Table 7.4. Summary of abstracted lakes – NCB study area

Name	Lake area	Lake volume[a]	Estimated lake catchment area	Daily mean inflow[b]	Abstraction rate	Abstraction as % of daily mean inflow
	(km^2)	(km^3)	(km^2)	(m^3/d)	(m^3/d)	(m^3/d)
Aghalough	0.01	0.04	1.4	2805	50	1.8
Anarry Lough	0.11	0.26	0.8	2963	135	4.6
Annagh Lough	0.35	1.20	1.5	2424	1455	60.0
Clonty Lough	0.11	0.12	10.8	23,590	740	3.1
Drumlane Lough	0.64	3.32	8.8	15,545	250	1.6
Lackagh Lough[c]	0.07	0.15	0.6	1262	236	18.7
Lough Arrow	12.47	134.17	50.5	106,938	432	0.4
Lough Erne Lower	103.8	n/a[d]	4106.6	14,299,645[e]	2,600[f]	0.0
Lough Erne Upper	32.18	n/a[d]	3296.9	12,427,664[e]	44,000[f]	0.4

Name	Lake area	Lake volume[a]	Estimated lake catchment area	Daily mean inflow[b]	Abstraction rate	Abstraction as % of daily mean inflow
	(km^2)	(km^3)	(km^2)	(m^3/d)	(m^3/d)	(m^3/d)
Lough Gill	13.81	160.63	375.2	1439,439	18,902	1.3
Lough Kilsellagh	0.04	0.20	8.7	15,751	4594	29.2
Lough Melvin	22.06	185.69	226.1	705,621	7000	1.0
Lough Nabellbeg	0.01	0.01[4]	0.2	814	83	10.2
Lough Nambrack	0.07	n/a[4]	0.3	656	141	21.5
Lough Naweleian	0.05	0.02	0.5	1138	60	5.3

[a]Estimated from bathymetry data.

[b]Calculated by multiplying catchment areas and estimated specific runoff values.

[c]Flagged as WFD 'at-risk' from over abstraction (CDM, 2009).

[d]Bathymetric maps were not obtained but exist. Upper Lough Erne: mean depth 2.3 m, max. depth 27 m (NIEA, 2015). Lower Lough Erne: mean depth 11.9 m, max. depth 69 m (NIEA, 2015).

[e]From water balance table received from Northern Ireland Water.

[f]Maximum licenced. Actual abstractions are less.

Information obtained from the NIEA indicates that the maximum permissible (i.e. licensed) abstraction from each station are 2600 m^3/d and 44,000 m^3/d, respectively, and that in 2014, the actual abstraction from each station averaged 1640 m^3/d and 24,810 m^3/d, respectively (NIEA, 2015). In Ireland, the single largest lake abstraction is from Lough Gill, where approximately 18,900 m^3/d is abstracted to supply three public water schemes and one private supply. The largest abstraction (8000 m^3/d) supplies the North Leitrim Regional Supply Scheme.

Abstraction pressures in lakes are manifested as changes in natural and/or or regulated water level cycles and residence times. Abnormally low water levels during periods of high net abstraction represent a particular risk of impact on the shallow littoral zones which support the main populations of macrophytes and macroinvertebrates (CDM, 2008). Changes from natural conditions, particularly changes in water level regimes, can cause the drying out of biota, increase exposure to wave action, and result in both freezing and changes in light penetration or water temperature. The significance of these effects depends largely on the extent, duration and timing of abstractions, as well as the ability of biota to recover from such changes. Assessing impacts of abstractions is, accordingly, a complex ecologically-based science, requiring the combined inputs from qualified hydrologists and aquatic ecologists on a case-by-case basis.

In the case of severe abstraction impacts, the volumes abstracted can exceed the ability of a lake's catchment to restore the water level to typical seasonal high levels, resulting in a longer-term decline in lake water levels. Based on the water level records obtained for the NCB study area, see Appendix A, such long-term declines are not apparent in available datasets, noting that not all of the currently abstracted lakes are monitored. With regard to Lower and Upper Lough Erne, lake levels are managed in the context of the Ballyshannon hydroelectric power scheme, and the temporal variability of water levels is gauged and regulated in context of the ecological significance of the lake system (e.g. as a designated RAMSAR site, Area of Special Scientific Interest, Special Area of Conservation, etc.).

The reporting of the 'ecological status' of lake water bodies for WFD implementation purposes (EPA, 2014 and NIEA, 2014a) does not identify current lake abstractions as a significant environmental pressure. Although several lakes in the NCB are classified as being at 'less than good' ecological status, none of these failed classification tests because of abstraction pressures. The majority of 'less than good' ecological status cases are based on other factors that relate to biological conditions and water quality, as a result of physical modifications (e.g. dredging) or elevated nutrient (phosphorus) loading. This is well documented in the published catchment management plan for Lough Melvin (Campbell and Foy, 2008).

Future risks of impact from UGEE-related lake abstractions under the water demand scenarios described in this report are also considered to be small. Volumetrically, the risks would be greater in ‘small lakes’ compared to ‘large lakes’. Further distinction cannot be made or judged without lake-specific knowledge about ecosystems and related environmental sensitivities, as well as water balance studies that define inflows, outflows, and throughflow (turnover rates). It is noted that a study carried out in 2001 by Donegal County Council to investigate water supply options ruled out additional abstractions from Lough Melvin due to the recreational importance of the lake and its assigned ecological significance as a Special Area of Conservation (Campbell and Foy, 2008).

The importance of understanding water balances of lakes is evident from the data received by Northern Ireland Water for the Lower and Upper Lough Erne, where the estimated maximum ‘capacities’ of Lower and Upper Lough Erne are reported to be 40,856,000 m^3/d and 10,738,000 m^3/d, respectively (NIEA, 2015). The ‘capacity’ figures are based on estimation methods which are derived from the study of surface areas of ‘habitable zones’ in each lake, whereby allowable depth changes from abstractions are set to 0.40 and 0.35 m, respectively (NIEA, 2015). The methods account for both natural and induced fluctuations since water levels in both lakes are regulated. The referenced ‘capacities’ of the lakes are defined as the ‘allowable volume changes (m^3/d) due to abstractions for less than 99% of days in a given year’. To be at “good ecological status’ in WFD terms, the reference surface area (habitable zone) of the lakes must be maintained within 5% of natural conditions for 99% of the time (362 days per year) (NIEA, 2015).

The daily maximum water demand of 5000 m^3/d considered for a single well in Section 7.2 represents a negligible volumetric fraction of the reported capacities of Loughs Erne, indicating a negligible risk of impact. However, the scenario of concurrent operations at multiple sites would change the reference point on potential impacts to lakes, and as mentioned above, risks would be greater in small lakes. Accordingly, all future proposed UGEE-related abstractions would have to be carried out individually with the involvement of relevant stakeholders and regulatory bodies, as each lake is different and risks of impact are case-specific.

7.5 Streams/Rivers

The rapid and flashy responses of the stream hydrographs to rainfall that were presented in Sections 2 and 3, as well as the flat slope of the low-flow sections of available flow duration curves, imply that the majority of streams in the two study areas are sensitive to stream abstractions. Impacts would be measured by the resulting changes to ecological conditions, including the stream biota, hydromorphology, and water quality (CDM, 2008). This is also recognised by the UKTAG-derived methods which are applied by both the EPA and NIEA in classifying the ecological status of surface waters for WFD reporting purposes. In both Ireland and Northern Ireland, the methods examine departures from reference conditions with regard to macroinvertebrates, hydromorphology and physico-chemical quality:

- Macroinvertebrates are biological indicators which are measured by counts, distributions and quality of colonies. These are judged by ‘Q-scores’ in Ireland and the ‘Biological Monitoring Working Party (BMWP) biotic score system’ in Northern Ireland.
- Hydromorphological characteristics are described from field observation and survey, notably: channel morphology and flow types, channel vegetation, substrate diversity and condition, barriers to flow continuity (e.g. dams), bank structure and stability, bank and bank top vegetation, riparian land cover and floodplain interaction.
- Physico-chemical conditions are described by results of field and laboratory analysis of water samples.

As reported by the EPA (2014c) and NIEA (2014a), several streams in both case study areas have been classified as being at 'less than good ecological status' in WFD reporting terms, but none failed WFD status objectives on the basis of abstraction pressures alone. The majority of streams which failed 'good ecological status' objectives did so on the basis of biological elements or indicators, in particular the quality of macroinvertebrate colonies. In many cases, the precise cause for the failed status objectives are not certain and subject to further study. Although abstractions may influence the ecological conditions in the related water bodies, it is not considered by the EPA and NIEA to be a single, direct cause of failed status objectives.

Using gauged or estimated flow data and hydrological pressure information (notably abstractions and effluent discharge data from existing licences and knowledge of impoundments), the NIEA also assign a status to the 'hydrological regimes' of rivers and streams in Northern Ireland. The status is reviewed in the context of deviations of water levels or flows that occur from natural reference conditions according to standards that are tabulated in:

- The Water Framework Directive (Priority Substances and Classification) Regulations (Northern Ireland) 2011 – commencing 21 January 2011; and
- The Water Framework Directive (Priority Substances and Classification) (Amendment) Regulations (Northern Ireland) 2015 – commencing 10 February 2015.

In 2014, the 'hydrological regimes' within the NCB study area were mostly classified as either 'high' or 'good'. Streams or sections of streams where hydrological regimes were identified as requiring further study/assessment include:

- Lough Melvin and Arney Local Management Area (NIEA, 2014d): Lower Lough Macnean, Drunharrif Burn, Screenagh, Sillees;
- Lower Lough Erne Local Management Area (NIEA, 2014e): Ballinamallard, Ballycassidy, Lisnarick, Kesh, Glendurragh; and
- Upper Lough Erne Local Management Area (NIEA, 2014f): Newtownbutler, Swanlinbar (upper), Erne, Finn, Starraghen.

For cross-border water bodies, the status assignments have been jointly agreed by the EPA and NIEA. Heavily Modified Water Bodies (HMWBs) are subject to the environmental objectives of 'ecological potential' rather than status. In both jurisdictions, the assignment of ecological potential have been made based on UKTAG guidance methods, considering each HMWB on an individual basis. In an abstractions licensing context, HMWBs are considered in the same manner as any other water body (i.e. case by case basis).

Similar to lakes, the identification of potential abstraction impacts on streams requires survey work and the combined and coordinated assessment by suitably qualified hydrologists and aquatic ecologists. Without detailed study, only cursory or screening-level assessments can be carried out, based on volumetric considerations and/or published reports or records of catchments and their ecological characteristics (e.g. SAC synopsis reports of the National Parks and Wildlife Service (NPWS).

In this context, the Q_{95} flow is often cited as a 'critical' baseline characteristic which is used to identify potentially problematic abstractions. In Northern Ireland, the concept of environmental flows for rivers [originally described by Acreman *et al*. (2006)] have been adopted as standards in regulations in Statutory Rule No. 45 of 2015 (DOENI, 2015). In these regulations, permissible abstractions from rivers are judged by river 'size', where the relevant metric is a natural mean daily flow which exceeds a flow statistic (e.g. the Q_{95} flow), and a river 'type' (i.e. its typology, which are also defined in the regulations by combinations of catchment areas, baseflow indices, and average annual rainfall over the catchment areas). Specifically, the permissible abstraction is defined as a percentage of the natural daily mean flow which exceeds a specified flow metric, for different river types. Accordingly, permissible abstractions can be judged by and take into consideration variable flow conditions (i.e. seasonality) and environmental sensitivity. As such, the environmental flow concept is risk-based (i.e. higher risks during low-flow periods).

This concept is further illustrated by Table 7.5 and Table 7.6, which are reproduced from the 2015 regulations by the DOENI for categories of 'high' and 'good' environmental standards for river flows, respectively. Using Table 51 for descriptive purposes, the permissible abstraction for a river type A1 when the natural mean daily flow exceeds the Q_{95} is 25% of the natural mean daily flow. The corresponding percentages decrease for smaller streams and increase for larger stream flow exceeding a specified larger flow metric (e.g. Q_{60} vs Q_{95})

Table 7.5. Environmental standards for river flows for the "High" category

Permitted abstraction per day as a percentage of the natural mean daily flow(Q)[(1)]		
High		
Column 1	Column 2	Column 3
	Maximum permitted % abstraction at Q exceeding Q_{95}[(2)]	Maximum permitted % abstraction at Q **not** exceeding Q_{95}
A1, A2 (downstream), A2 (headwaters), B1, B2, C2, D2	10	5

[(1)] 'Q' is the mean daily flow for a specified period of time

[(2)] 'Qx' is the Q that is expected to be exceeded by 'x' percent for a specified period of time

Table 7.6. Environmental standards for river flows for the "Good" category

Permitted abstraction per day as a percentage of the natural mean daily flow(Q)				
Good				
Column 1	Column 2	Column 3	Column 4	Column 5
River type	Maximum % abstraction at Q exceeding Q_{60}	Maximum % abstraction at Q exceeding Q_{70}	Maximum % abstraction at Q exceeding Q_{95}	Maximum % abstraction at Q **not** exceeding Q_{95}
A1	35	30	25	20
A2 (downstream), B1, B2	30	25	20	15
A2 (headwaters), C2, D2	25	20	15	10

Accordingly, environmental flows and permissible abstractions are risk-based and can be adjusted for flow conditions. For this reason, the assessment of permissible abstractions requires knowledge of the natural flow characteristics of the river or stream, by way of flow duration curves, which can be derived from one or both of measured (gauged) data and/or modelling techniques.

In combination with other elements of river ecology (e.g. biological indicators, water quality, and hydromorphology), the environmental standard designations for river flows described above are used by the NIEA to classify the ecological status of rivers for WFD reporting purposes.

In the context of UGEE-related abstractions, the temporal aspect of stream flow behaviour is a particularly important variable to be considered:

- The demands for water for hydraulic fracturing programmes, as described in Section 7.2, are of limited duration, measured in days. Thus, the risk of impact from abstractions at any given location are influenced by the timing of the demands against the actual stream flow conditions; and
- In both case study areas, the majority of streams are flashy, with quick hydrograph responses to rainfall and quick recessions to baseflow conditions. Thus, potential future abstraction schemes would have to be assessed against the actual hydraulic response to rainfall in any given catchment.

For these reasons, prior authorisations of UGEE-related abstractions would have to be reviewed in context of catchment hydrological conditions, on a case by case basis. The review should be based on the principles of environmental flows, i.e. factoring in the reference conditions of water level- and flow-dependent ecosystems and habitats.

The Q_{95} flow is a useful low-flow metric which can be used to screen or flag potentially problematic abstractions. For purposes of this report, and as a screening exercise, the daily maximum water demand for a single hydraulic fracturing programme of 5000 m^3/d was compared to the estimated Q_{95} flows in Table 2.2 and Table 3.1. The demand, alternatively expressed as 0.058 m^3/s, exceeds the minimum estimated Q_{95} flows of 0.02 m^3/s and 0.01 m^3/s for subcatchments in the NCB and CB licence areas, respectively. Accordingly, certain streams would likely not be able support the demand based on the estimated Q_{95}. Spatial representations to illustrate the same point are provided in Figure 7.3 and Figure 7.4 for the NCB and CB study areas, respectively. In both examples, several catchments would not be expected to be able to supply the demand under low-flow conditions, thus flagging potential risk of impact to stream biota and associated ecosystems, and warranting further detailed study.

In any future UGEE-related abstraction case, environmental flows would have to be established, based on case- and stream-specific circumstances, taking account of reference conditions of associated ecosystems. In any given case and circumstance, opportunities should also be sought to mitigate potential impacts of abstractions by:

- Reducing demands (e.g. re-cycling of flow-back waters);
- Spreading abstractions to multiple different sources of water;
- Directing abstractions towards lower sections of catchments (higher-order streams);
- Avoiding abstractions from ecologically sensitive catchments and streams; and
- Timing operations such as to avoid overlap between maximum demand periods and low-flow conditions.

Few streams in the NCB and no streams in the CB study areas are presently abstracted for public and private water supplies. As documented in Table 7.7, the single largest relevant abstraction from a stream is 12,000 m^3/d from the River Shannon, which supplies the South Leitrim Regional Water Supply Scheme.

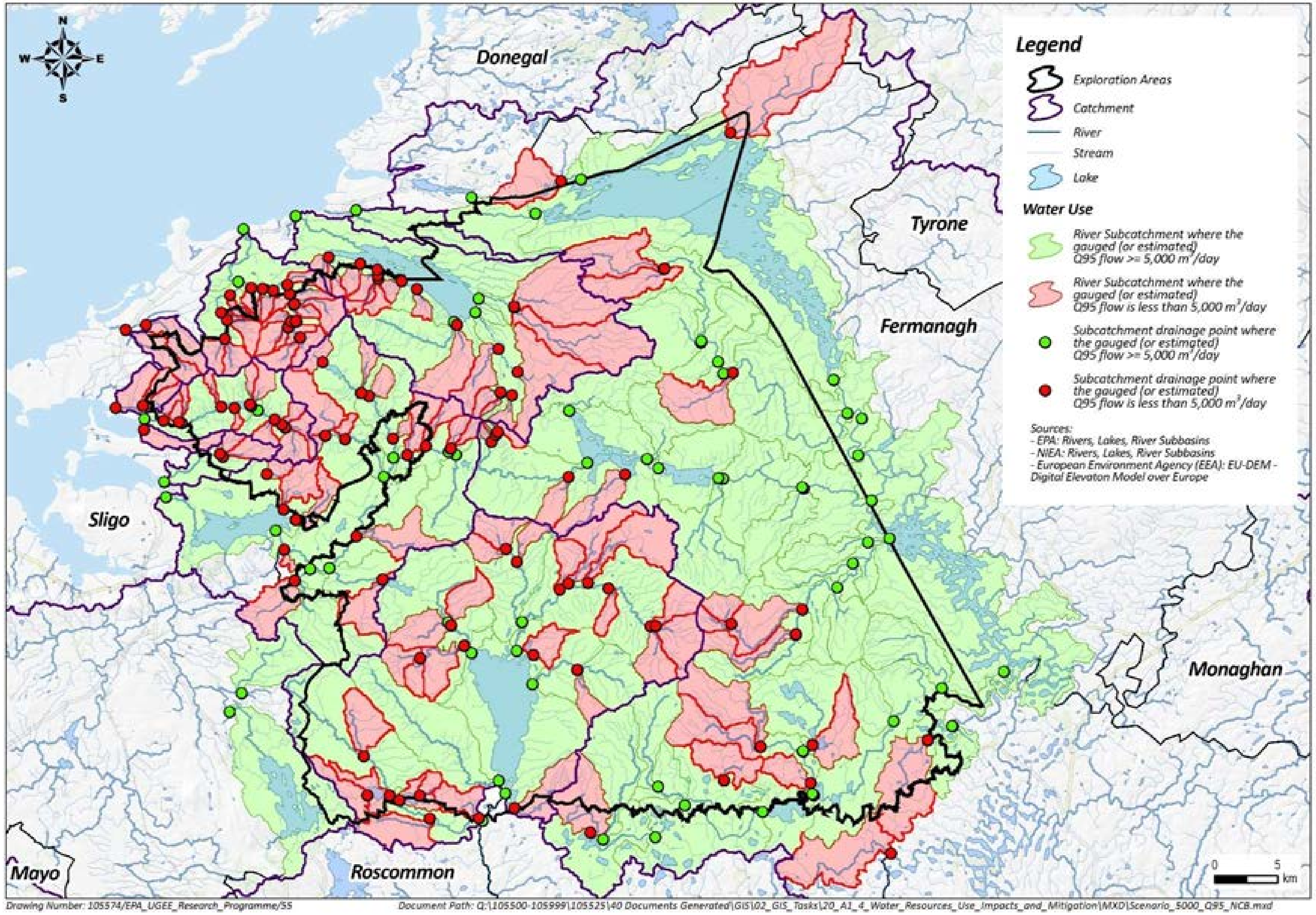


Figure 7.3. Comparison of daily water demand of 5000 m^3/d and estimated Q_{95} flows – NCB study area.

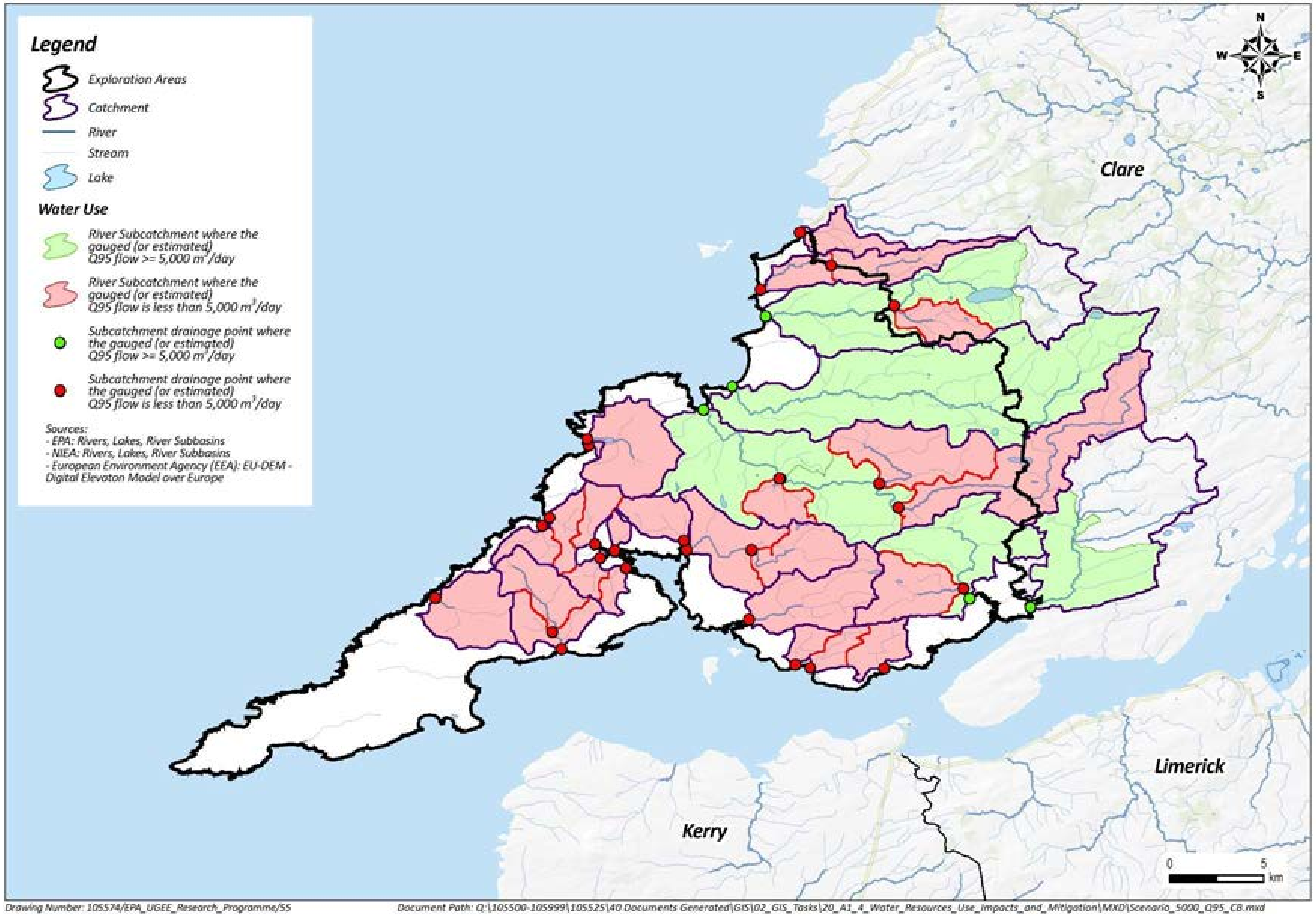


Figure 7.4. Comparison of daily water demand of 5000 m^3/d and estimated Q_{95} flows – CB study area.

Table 7.7. Abstractions from streams – NCB study area

Supply name	Supply type	Stream name	Net abstraction	Q_{95} Flow[a]	Mean flow[a]	Abstraction/Q_{95} flow	Abstraction/mean flow
			(m^3/d)	(m^3/d)	(m^3/d)	%	%
Belturbet P.W.S.	P.W.S.	Erne River	720	135,648	2467,860	0.5	0.03
Erne & Melvin Enhancement Co.	Private (industry)	Cladagh River	4806 (all returned)	14,274	97,244	31.2	4.6
Errington Trout Farm	Private (industry)	Ballycassidy River	1700	2767	211,838	61.4	0.8
North Sligo P.W.S.	P.W.S.	Gortnaleck Stream	925[b]	785	4811	117.9	19.2
North Sligo P.W.S.	P.W.S.	Lyle River	925[b]	553	3775	167.2	24.5
South Leitrim Regional Water Supply Scheme[c]	P.W.S.	River Shannon	12,000	36,754[d]	278,879[d]	32.6	4.3

[a]Estimated at position of abstraction.

[b]The total abstraction rate for North Sligo P.W.S. from the two rivers (Gortnaleck and Lyle) is approx. 1850 m^3/d. The abstraction rates from the individual sources is not measured.

[c]Outside the UGEE licence area but connected to Lough Allen which is in the NCB. Flow estimation based on limited data.

[d]Underestimated values, as estimation does not include all tributaries which are located between abstraction point and Lough Allen. Thus, percentages are overestimated.

The Shannon River abstraction is outside and downstream of the UGEE licence area in the NCB, but is considered relevant to the study area because Lough Allen, which is within the licence area, is regulated to maintain flow in the River Shannon. The daily mean discharge from Lough Allen is 14.4 m^3/s (Jacobs, 2012)

Table 7.7 illustrates the importance of deriving accurate flow estimates for streams. The abstraction from the North Sligo PWS is reportedly 1850 m^3/d distributed over two abstraction points on two separate streams. The distribution of abstraction between the two sources is not known, but assuming a 50–50 distribution, the abstraction rates exceed the estimated Q_{95} for the respective streams. This simple comparison highlights that the streams may be at risk from over-abstraction, notably during low-flow conditions, and further checks on actual flow conditions and related ecology would be recommended. In the case of North Sligo PWS, abstractions are repositioned downstream to the larger Grange River during low-flow conditions (EPA, 2013a).

There are additional abstractions from streams in the NCB study area where the abstraction point is located immediately downstream of springs. Given their position near springs, such abstractions can technically be considered as groundwater abstractions, but they are located at the headwaters of streams and, as such, reduce flows in streams. Spring discharges support baseflow to streams and related ecosystems further downstream in the same catchments. Thus, abstractions from headwaters require a larger geographical focus beyond the headwater location.

7.6 Groundwater

The hydrogeological characteristics of the bedrock aquifers in the two case study areas are complex. They are conceptually understood, but data gaps exist with regard to quantitative data and information. The complexity and, often, unpredictability of bedrock aquifers implies that well yields and influences of abstractions cannot be predicted with certainty without detailed study involving field investigations and monitoring. In the UGEE-context, risks of impact from groundwater abstractions relate primarily to:

- Reduced baseflow to surface water bodies (if groundwater and surface water are hydraulically connected);
- Adverse influence on the supporting conditions of nearby groundwater dependent terrestrial ecosystems (GWDTEs); and
- Hydraulic interference with existing, neighbouring supply wells (public and private).

As part of any prior authorisation process, both desk study and field surveys would be carried out to identify potential features, ecologies, and/or populations that might be affected by the proposed abstractions. Following this, the case-specific risks and mitigation measures would have to be assessed through further study, survey work, testing, and monitoring. All such work should be scoped, carried out and reviewed by suitably qualified hydrogeologists, supported by other specialists in relevant fields.

Groundwater is used extensively for both public and private water supply. Individual abstraction rates range from <10 m^3/d (small group water scheme) to approximately 500 m^3/d (public scheme). Accordingly, groundwater supplies are volumetrically smaller than abstractions from surface water bodies, but are no less important for supply purposes.

Overall, groundwater abstraction pressures in the two study area are low. The large number of private wells serving single homes and farms (in the CB study area especially) are of reduced consequence as the majority of the groundwater that is abstracted for private supply is returned back to the groundwater environment via septic tanks, percolation systems, and livestock.

All groundwater bodies in the two study areas are classified as being of ‘good’ quantitative status with respect to groundwater abstraction pressures (EPA, 2014; NIEA, 2014). Thus, existing abstractions are considered to be sustainable and there are no identified adverse impacts on drinking water sources, surface water bodies, or groundwater dependent terrestrial ecosystems.

Reported yields from pump testing of wells results range from <50 to >400 m^3/d. In context of the UGEE water demand (see Section 7.2), groundwater is a viable source of water to meet demands, at least in part. The ability to develop a sufficient supply to meet demands locally for hydraulic fracturing programmes would be subject to exploration and testing, and may require more than a single supply well at a single location. This would depend on location and case-specific circumstances of both hydrogeology and actual water demands. The chance of drilling productive wells in bedrock aquifers involves study, skill and a degree of good fortune, and is not always guaranteed at the first attempt.

8 UGEE-Related Baseline Monitoring Requirements

Requirements for baseline monitoring are embodied in the European Parliament resolution on the *“Environmental impacts of shale gas and shale oil extraction activities”* (2011/2308(INI)). The resolution specifically:

> “Recognises that shale gas exploration and extraction may possibly result in complex and cross–cutting interactions with the surrounding environment, in particular owing to the hydraulic fracturing method employed, the composition of the fracturing liquid, the depth and construction of the wells and the area of surface land affected”;

and:

> “Acknowledges that the types of rocks present in each individual region determine the design and method of extraction activities; calls for mandatory baseline analysis of groundwater and geological analysis of the deep and shallow geology of a prospective shale play prior to authorisation, including reports on any past or present mining activities in the region”.

The resolution further calls on the European Commission (EC) to:

> “…issue guidance, without delay, on the establishment of both the baseline water monitoring data necessary for an environmental impact assessment of shale gas exploration and extraction and the criteria to be used for assessing the impacts of hydraulic fracturing on groundwater reservoirs in different geological formations, including potential leakage and cumulative impacts”.

In response, the EC issued, in January 2014, a *Communication* (EC, 2014a) which contains guidance on the exploration and production of unconventional gas, as well as a *Recommendation* (EC, 2014b), which outlines non-binding “minimum principles” which new UGEE activities should comply with. Whereas the *Communication* is policy-focused, the *Recommendation* is directed at implementation. As one of its key elements, the *Recommendation* calls on each Member State to produce a Strategic Environmental Assessment (SEA) before granting licenses for exploration and/or production of hydrocarbons, including UGEE. SEAs depend on baseline studies and existing environmental conditions being established.

The EC *Recommendation* also lists several existing EU Directives, including the EIA Directive, that have a direct bearing on planned UGEE activity. Although flexibility is afforded EU Member States in determining how UGEE projects will be approached, the *Recommendation* is an attempt by the EC to harmonise regulation and implementation across the EU. A stated objective is “*to ensure that environmental impacts and risks arising from the techniques used for exploration and exploitation activities, both as regards individual projects and cumulative developments, are adequately identified and managed.*”

The *Recommendation* speaks directly to baseline environmental monitoring. In regards to aquatic environments, baselines should be established for:

- Quality and flow characteristics of surface and groundwater;
- Water quality at drinking water (abstraction) points;

- Presence of methane and other volatile organic compounds in water;
- Existing wells and abandoned structures.

It does not reference associated ecosystems, but in the context of the island of Ireland, there are groundwater dependent terrestrial ecosystems (wetlands) that should be considered in the UGEE JRP, as these are designated as such by their qualifying interests and as Special Areas of Conservation (see Section 5.4).

8.1 Purpose of UGEE-Related Baseline Monitoring

The purpose of baseline monitoring is to produce data which would be used to describe environmental conditions at the present time (i.e. prior to potential UGEE activity) and to be able to identify, assess, and monitor potential impacts in the future (i.e. during and after potential UGEE activity). Accordingly, baseline monitoring would have to be designed such that it can distinguish between impact(s) from UGEE projects and impact(s) from other existing environmental pressures within UGEE-licensed area(s).

Baseline monitoring data would have to be placed and interpreted in a ‘correct’ context, specifically. monitoring would have to factor in the totality of UGEE-related activity, and not just what takes place at individual exploration/production sites. This would include activities which extend across catchments, e.g. from vehicular transport of equipment and materials, construction of reservoirs, pump stations and pipelines, and discharges of wastewater.

8.2 Defining a Baseline Monitoring Programme

Defining a suitable and justifiable baseline monitoring programme for the two case study areas involves consideration of scope, extent and cost.

- The **scope** is guided by the physical (geological) media and receptors (groundwater, surface waters, related ecosystems) to be included, the potential contaminants and associated risks, gaps in the understanding of existing environmental pressures and recommendations on identified characterisation and monitoring needs.
- The **scale** is guided by geography, hydrology and hydrogeology of the case study areas, including the relationship between the geological formations which are targeted for UGEE operations and the water resources and ecosystems which are used and/or may be hydraulically linked to the same formations (via *pathways*).
- The **cost** is influenced by the above, as well as by the potential need for new monitoring installations (e.g. where data gaps exist), the type and timing of measurements to be made, and the parameters which are selected for laboratory analysis.

The baseline monitoring to be defined and implemented under the UGEE JRP is a sub-regional monitoring programme which covers the entire case study areas. It is different from the baseline monitoring that would be required of UGEE operators as part of the licensing process. The UGEE operator monitoring would be case- and site-specific, and would be designed to ensure protection of specific receptors. Furthermore, this would be handled under planning regulations, guided by the requirements of the EIA Directive and other statutory instruments which follow regulatory review. It is noted that the Institute of Geologists of Ireland (IGI) recently published “Guidelines for the preparation of soils, geology and hydrogeology chapters on Environmental Impact Statements” (IGI, 2013) which is directly relevant to any future EIAs associated with UGEE planning and activity.

The current report addresses baseline monitoring at the sub-regional (basin) scale which, in the context of an SEA, also addresses “*cumulative impact*”, i.e. the totality of potential impacts from

UGEE-related activity. Plans for actual drilling sites have not yet been determined, and for this reason it has to be assumed that UGEE projects could take place anywhere within the two indicated licence areas.

An understanding of baseline conditions requires an appreciation of quantitative and qualitative aspects of environmental characterisation, as well as risks to human health and ecosystems. Because an objective is also to monitor for deviations from the baseline over time, which could result from UGEE activity, monitoring is a long-term commitment for the regulators and decision-makers involved in licensing and enforcement. The data collected from this monitoring would inform about trends as well as impact. Finding a balance between scope, extent and cost is challenging in the best of circumstances. For this reason, baseline monitoring would likely be an iterative process, evolving in time, whereby initial monitoring and assessment informs recommendations about subsequent monitoring.

Baseline monitoring of groundwater conditions within the case study areas is considered especially challenging, as it is affected by a range of geological, hydrogeological and anthropogenic factors, and there is typically a paucity of available data on the groundwater environment. Groundwater levels and chemistry are also subject to temporal variations, both in the short-term and long-term (episodic vs. seasonal).

9 Baseline Monitoring 'Best Practice'

A review of baseline monitoring practice internationally yields much information about the importance and need for baseline monitoring, but few details on the specifics of monitoring. There is notably a lack of guidance on frameworks or methodologies that address the '*where, why, how* and *how often'* of UGEE-related baseline monitoring. Still, common approaches and 'high-level guidance' can be discerned from published research and lessons learnt, mostly guided by literature in countries where UGEE projects have been implemented so far. Useful information can also be sourced from countries where UGEE projects are planned or where some degree of baseline monitoring has begun.

Consensus views that emerge from published research and lessons learnt are:

1. Baseline monitoring is both desirable and necessary: a) to identify and be able respond to impact; and b) to address questions of accountability.
2. Baseline monitoring is historically inadequate in many places where UGEE activity has taken place. With specific reference to the Marcellus Shale in the USA, Vidic *et al.* (2013) argue that *"It is difficult to determine whether shale gas extraction in the Appalachian region since 2006 has affected water quality regionally, because baseline conditions are often unknown or have already been affected by other activities…"*
3. Baseline monitoring data should be made publically available, as a responsibility and as a step towards building trust and transparency in technology, safety of operations, and assessment of impact.
4. Baseline monitoring is a shared responsibility between those who are licensed to carry out UGEE projects and those who regulate UGEE projects. This covers risk assessment as well as general UGEE-related research.
5. With specific reference to water resources and related aquatic ecosystems, quantitative aspects of baseline monitoring are as important to consider as qualitative aspects, whereby flow and discharge characteristics of hydro(geo)logical systems have a direct influence on aquatic habitats and ecosystem health.

The need for baseline monitoring in international literature is often cited as a pre-condition for licensing of UGEE activity. This trend now also (or especially) applies to the USA, where some states such as New York and North Carolina have banned or placed moratoria on UGEE operations until appropriate risk assessments are carried out, which involve baseline monitoring.

A comprehensive panel review of environmental impacts from shale gas extraction in Canada and internationally by the Council of Canadian Academies (CCA) concluded that *"in most instances, shale gas extraction has proceeded without sufficient environmental baseline data being collected"* (CCA, 2014). The CCA also emphasised that shale gas projects must be undertaken on the basis of *"good science",* whereby *"sound and comparable data"* are required for decision-making purposes.

Importantly, the panel review concluded that data on environmental impact are as yet "not conclusive" and that some of the "possible environmental and health effects of shale gas development may take decades to become apparent. These include the creation of subsurface pathways between the shale horizons being fractured and fresh groundwater, gas seepage along abandoned wells, and cumulative effects on the land and communities. Similarly, monitoring strategies, data, and information on the effectiveness of mitigation measures take time to develop, acquire, and assess."

Claims of impact on the environment and human health from the unconventional gas industry are well documented in the media, and such claims tend to be accompanied by counter-claims from the oil and gas industry. A report by the US Government Accountability Office (USGAO, 2012) concluded that the environmental and public health risks of shale gas development cannot easily be quantified, nor can the magnitude of potential adverse effects or their likelihood of occurrence be determined. The report also concluded that *"there are relatively few studies that are based on comparing pre-development conditions to post-development conditions – making it difficult to detect or attribute adverse conditions to shale oil and gas development."* A similar conclusion is reported from Canada (CCA, 2014; Brisson *et al.* 2010), whereby uncertainty with, and paucity of, pre-development baseline data makes impact identification both challenging and subject to dispute.

Questions that tend to dominate the discourse on impact are: a) are 'sufficient' baseline monitoring data available; and b) how 'good', 'adequate' or 'conclusive' are the data? These questions speak to the '*what, where, how, how often and how long'* of monitoring, as well as data quality.

9.1 Principal Contaminants of Concern

Contaminants of concern are many. They relate to both onsite and offsite activity. Comprehensive overviews of potential contamination sources are provided by the EC (2014c), AEA (2012), and USEPA (2011, 2015). Impacts from onsite activity can result from: drilling and well construction; hydraulic fracturing testing/operations; gas seepage; blowouts at wells; leaks and spillages (e.g., fuel tanks), and wastewater management. In addition to wastewater, other waste products include drilling muds, related soil/rock cuttings and sediments/sludges. Impacts from offsite activity can result from transportation (e.g. vehicular traffic, accidental spills), new constructions, and leaks associated with, for example, pipelines and valves.

Drilling and well construction activity most often involves methods which make use of non-toxic chemical additives such as bentonite, barite, and other inert viscosity enhancers (e.g. foam or cellulose–based materials). Some of these products can also be biodegradable. Hydraulic fracturing, however, involves the use of chemicals introduced into the hydraulic fracturing fluid to improve the efficiency of the process (USEPA, 2012). A summary of commonly used groups of chemicals is reproduced in Table 9.1 (Stuart, 2011).

Table 9.1. Example of volumetric composition of hydraulic fracturing fluid

Constituent	Composition (% by volume)	Example	Purpose
Water and sand	99.50	Sand suspension	"Proppant" sand grains hold microfractures open
Acid	0.123	Hydrochloric or muriatic acid	Dissolves minerals and initiates cracks in the rock
Friction reducer	0.088	Polyacrylamide or mineral oil	Minimises friction between the fluid and the pipe
Surfactant	0.085	Isopropanol	Increases the viscosity of the fracture fluid
Salt	0.06	Potassium chloride	Creates a brine carrier fluid
Scale inhibitor	0.043	Ethylene glycol	Prevents scale deposits in pipes
pH-adjusting agent	0.011	Sodium or potassium carbonate	Maintains effectiveness of chemical additives
Iron control	0.004	Citric acid	Prevents precipitation of metal oxides
Corrosion inhibitor	0.002	n,n-dimethyl formamide	Prevents pipe corrosion

Constituent	Composition (% by volume)	Example	Purpose
Biocide	0.001	Glutaraldehyde	Minimises growth of bacteria that produce corrosive and toxic by-products
Breaker	0.01	Ammonium persulphate	Allow a delayed breakdown of gel polymer chains
Crosslinker	0.007	Borate salts	Maintains fluid viscosity as temperature increases
Gelling agent	0.056	Guar gum or hydroxyethyl cellulose	Thickens water to suspend the sand
Oxygen scavenger	-	Ammonium bisulphate	Removes oxygen from the water to prevent corrosion

Chemicals that may be used incorporate biocides, corrosion inhibitors, weighting agents and pH buffers. Although several of these additives are inorganic salts which are non-toxic, others involve acids and organic compounds which are reactive, can be toxic, and must be quantified by specialised laboratory analyses. The unconventional gas industry has long been criticised for its lack of transparency about the chemicals it uses as hydraulic fracturing additives, often claiming that they are ‘trade secrets’. Regulations in most countries now require full or ‘substantial’ disclosure for authorisation prior to use.

Chemicals are also present in flowback and production waters, which are subsequently subject to management involving treatment and discharge. Flowback water is water which returns to the surface from a well as a result of the high-volume and/or high-pressure hydraulic fracturing process. Production water is fluid that returns from a well during its production phase (USEPA, 2012). Useful overviews of the constituents of flowback and produced water are provided by Alley *et al*. (2011) and Haluszczak *et al.* (2013). They contain natural gas, constituents of the initial fracturing fluid, breakdown products of the same, and substances which may become mobilised from the geological formations by the fracturing process. Key signature constituents include strontium, barium, bromine, salts, hydrocarbons and naturally occurring radioactive materials (NORM) (NYSDEC, 2011; USEPA, 2012). The need to consider and include the constituents of such fluids in decisions about baseline monitoring is consistent with the EC *Recommendation* on unconventional gas (see Section 8), which stresses that baseline and operational monitoring should include “operational parameters”.

It should be noted that the additives that would be used for any future UGEE activity in the case study areas are not yet known, and specific information on fluid chemistry does not exist. Both the chemical constituents and their relative proportions would be influenced by the chemical characteristics of the formation waters and the case-specific nature of the hydraulic fracking operation itself.

9.2 Baseline Monitoring of Groundwater Quality

Baseline monitoring of groundwater quality at the sub-regional scale is carried out to document existing environmental conditions and pressures ahead of UGEE activity, so that potential changes in conditions can be documented over time. Accordingly, monitoring parameters to be included in a baseline characterisation and monitoring programme should reflect both general environmental pressures as well as potential impact from future UGEE activity, both at a specific drilling location (well pad) and in offsite areas. The list of chemical parameters that are relevant is comprehensive, and covers:

- Dissolved natural gas components;
- Stable isotopes (of natural gas components, notably methane);

- General physico-chemical parameters (e.g. pH, redox, temperature, specific conductance);
- Major ions;
- Salts;
- Metals;
- Nutrients;
- Organic hydrocarbons;
- Hydraulic fracturing chemicals and possible reaction/degradation products (depending on which chemicals are used in the hydraulic fracturing process);
- Trace elements; and
- Naturally occurring radioactive materials (NORM), including radon.

As a result, the logistical and financial burden of baseline monitoring can be significant. For practical and cost reasons, there is a need to consider ‘common’ or ‘indicator compounds’ that signal the presence of UGEE-related contaminants. This is accomplished by ‘chemical fingerprinting’, and although the chemical science may be complex, international literature (see below) provides useful background information to be considered.

9.2.1 Consideration of methane gas

Baseline monitoring for methane gas in groundwater is included as one of the “minimum principles” in the EC *Recommendation* referenced previously. Methane is the primary contaminant of concern with respect to UGEE as it is the primary constituent of natural gas. Methane gas can be of ‘thermogenic’ or ‘biogenic’ origin, and the distinction is of significance. Thermogenic methane is most often associated with oil and natural gas fields, as well as coal deposits, and is formed during thermal decomposition of organic matter at depth under high pressures. Biogenic methane is unrelated to the processes that form fossil fuels, and is formed at low temperatures by anaerobic bacterial decomposition of sedimentary organic matter (Wright, 1999). It is, accordingly, most often associated with natural shallow anaerobic groundwater environments, such as peat bogs, wetlands and river/lake sediments, but also anthropogenic pollution sources such as landfills, septic tanks and farm waste.

The presence of methane gas in groundwater can be misinterpreted if it is not sampled and assessed in the appropriate context, i.e. with consideration of its origin. Table 9.2 provides a summary of different of main gas constituents and their possible formation processes (USEPA, 2011).

Table 9.2. Types of natural gas, constituents and process of formation

Type of natural gas	Main constituents	Process of formation
Thermogenic gas	Methane, ethane, propane, butane and pentane	Geological formation of fossil fuel
Biogenic gas	Methane and ethane	Chemical breakdown of organic materials by methane-producing microorganisms

Methane is the main constituent of thermogenic natural gas, including unconventional gas, followed by ethane, propane, butane, and carbon dioxide. Other constituents may also be present, e.g. noble gases and radon. In contrast, biogenic gas consists almost entirely of methane. Gas geochemistry reveals whether a gas is of biogenic or thermogenic origin. An absence of propane and butane (and to some extent ethane) relative to methane would indicate a biogenic origin, whereby methane and ethane are the dominant products from biodegradation (Jones *et al*., 2000). Detection of methane along with the other gas fractions would, accordingly, indicate the presence of thermogenic gas and, possibly, impact from UGEE activity. Other distinguishing characteristics of biogenic vs thermogenic methane gas are summarised in Table 9.3 (Ward, 2012).

Table 9.3. Biogenic and thermogenic methane gas characteristics

Biogenic	Thermogenic
High C_1/C_{2+} ratio (>100)[1]	Low C_1/C_{2+} ratio (<100)
Low $\delta^{13}C$ values (>–64‰) and δ^2H (>–175‰)	Higher (less negative) $\delta^{13}C$ (<–50‰) and δ^2H values (<–240‰)
Measurable ^{14}C	No ^{14}C

Note: C_n = number of carbon atoms in each molecule: C_1 = methane; C_2 = ethane; C_3 = propane; C_4 = butane, etc.

From Table 9.3, biogenic methane contains lighter fractions of carbon and is isotopically lighter (i.e. more depleted in ^{13}C) than thermogenic methane.

Monitoring of methane and other constituents of natural gas in groundwater is currently ongoing in England, Scotland and Wales under the direction of the British Geological Survey (BGS). The monitoring, which began in 2012, aims to establish methane levels in groundwater as well as their origins through isotope analyses. Samples are collected from both potable water supplies and dedicated monitoring boreholes. In the 2014 and 2015 phases of sampling, quarterly sampling at selected sites was undertaken to provide information on the variability of methane concentrations throughout the year (BGS, 2014).

In Canada, Pinti *et al.* (2013) reported on regional baseline groundwater sampling from 130 wells in a study area to the south of the St. Lawrence River. The focus was on measuring the distribution (presence/absence) of dissolved gases in groundwater and to determine their origin. The majority (>80%) of the methane detected was concluded to be of biogenic origin.

Past sub-regional surveys of methane gas in groundwater in the United States (US) have mostly been carried out after unconventional gas operations began. Survey results are usually framed in a research context, where researchers have sought to explore whether or not an impact on water resources from the shale gas industry has taken place. A study conducted by Duke University (Osborn *et al*., 2011) sought to evaluate the impact of unconventional gas extraction on groundwater in Pennsylvania and New York by analysing samples from both active and non-active areas of unconventional gas extraction (involving hydraulic fracturing). Methane in samples from active areas was determined to be from deep, thermogenic sources compared to methane in samples from non-active areas, which were determined to be of biogenic origin. The study concluded there was evidence of methane contamination of shallow aquifers overlying the Marcellus and Utica shale formations (the targets for ‘fracking’). This conclusion was contested by Molofsky *et al*. (2011) who presented alternative geological explanations, whereby thermogenic methane was reported to also originate from within the shallow formations rather than via gas migration from the deeper shale formations. The contrasting theories demonstrate just how important it is to build up a scientifically rigorous database of baseline conditions prior to UGEE operations, and that sampling programmes are appropriately scoped.

A similar survey of shallow wells above an oilfield in Colorado found that 78% of samples collected from 223 wells had detectable concentrations of dissolved methane (Li and Carlson, 2014). The occurrence of methane did not correlate with proximity to oil and gas wells, and the methane was concluded to be almost entirely of biogenic, shallow origin. Even for the few cases where the gas was concluded to be thermogenic origin, the specific pathways (natural or man-induced) could not be deduced.

Darrah *et al.* (2014) distinguished between natural sources of methane from "anthropogenic contamination" in domestic water wells using analyses of noble isotope and hydrocarbon gases, where the natural gas detected in several clusters of domestic wells was attributed to poor well construction practices associated with hydraulic fracturing wells rather than gas migration through geological formations induced by hydraulic fracturing. The reported analytical work involved the assessment of natural gas presence/abundance in the shallow aquifers and isotopic compositions of groundwater near shale-gas wells (e.g., C_2H_6/CH_4, δ13C-CH_4, ^4He, ^{20}Ne, and ^{36}Ar). Where gas contamination was identified, the relative proportions of thermogenic hydrocarbon gas (e.g., CH_4, ^4He) were significantly higher, and the proportions of atmospheric gases (air-saturated water; e.g., N_2, ^{36}Ar) were reportedly much lower, relative to background groundwater.

As demonstrated by Darrah *et al.* (2014), emerging noble gas techniques reinforce carbon isotopes and hydrocarbon ratios data. Attribution of origins of methane gas through isotope analyses is unquestionably a complex science, involving specialised sampling techniques and laboratory capability, as well as specialised personnel to be able to interpret data. It remains, nonetheless, best practice in a baseline monitoring context in terms of determining the presence, source and origin of methane/natural gas in groundwater.

Whereas the origins of the methane gas can be deduced from noble gas and isotopic study, the mechanism by which deep gas migrates to shallow depths is subject to different arguments and possible causes. The case study of Darrah *et al.* (2014) concluded that gas migration was the result of poor well construction practices associated with hydraulic fracturing wells, which is a recognised and acknowledged concern generally. The finding lends support to Brantley *et al.* (2014) who, as part of a Canadian research study, inspected the "violations database" maintained by the Pennsylvania Department of Environmental Protection. They concluded that *"Through March 2013, 3.4% of gas wells were issued NOVs [notices of violations] for well construction issues and 0.24% of gas wells received NOVs related to methane migration into groundwater*." Although the percentages are small, the number of wells the percentages derive from is large. Using similar data, Vidic *et al.* (2013) concluded that *"219 out of 6466 wells in the Marcellus Shale received NOVs for well construction problems, including casing or cementing issues."* Brantley *et al.* (2014) further reported that *"Between 2008 and 2012, 161 of the ~1000 complaints received by the state described contamination that implicated oil or gas activity: natural gas was reported for 56% and brine salt components for 14% of the properties."*

9.2.2 Consideration of other groundwater quality parameters

The parameters which the USEPA have elected to examine (in the context of drinking water impact study) are summarised in Table 9.4 (USEPA, 2012). The *"Permitting Guidance for Oil and Gas Hydraulic Fracturing Activities Using Diesel Fuels"* (USEPA, 2014) further recommends that baseline "geochemical information" be obtained in groundwater for the following parameters:

> "Total dissolved solids; specific conductance; pH; chlorides; bromides; acidity; alkalinity; sulfate; iron; calcium; sodium; magnesium; potassium; bicarbonate; detergents; Diesel Range Organics; BTEX compounds; isotopic methane and radionuclides."

Table 9.4. Analyte groups and examples of chemicals monitored by the USEPA

Analyte groups	Examples
Anions	Bromide, chloride, sulfate
Carbon group	Dissolved organic carbon,[a] dissolved inorganic carbon[b]
Dissolved gases	Methane, ethane, propane
Extractable petroleum hydrocarbons	Gasoline range organics,[c] diesel range organics[d]
Glycols	Diethylene glycol, triethylene glycol, tetraethylene glycol
Isotopes	Isotopes of oxygen and hydrogen in water, carbon and hydrogen in methane, strontium
Low molecular weight acids	Formate, acetate, butyrate
Measures of radioactivity	Radium, gross α, gross β
Metals	Arsenic, manganese, iron
Semivolatile organic compounds	Benzoic acid, 1,2,4-trichlorobenzene, 4-nitrophenol
Surfactants	Octylphenol ethoxylate, nonylphenol
Volatile organic compounds	Benzene, toluene, styrene

[a]Dissolved organic carbon is a result of the decomposition of organic material in aquatic systems.

[b]Dissolved inorganic carbon is the sum of the carbonate species (e.g. carbonate, bicarbonate) dissolved in water.

[c]Gasoline range organics include hydrocarbon molecules containing 5–12 carbon atoms.

[d]Diesel range organics include hydrocarbon molecules containing 15–18 carbon atoms.

In North Carolina, which is one of few states in the US that has had the opportunity to conduct baseline monitoring at a regional scale prior to unconventional gas development, the United States Geological Survey (USGS) is leading a groundwater baseline study within a 200 km^2 pilot area, compiling an inventory of public and private supply wells and sampling a subset of 50 wells for analyses of:

- General physico-chemical parameters;
- Major ions;
- Dissolved gas components – methane and ethane;
- Radioisotopes – radium, strontium;
- Stable isotopes – oxygen, deuterium, carbon (in methane);
- Metals;
- Volatile organic compounds (VOCs);
- Semi-volatile organic compounds (SVOCs); and
- Dissolved inorganic and organic carbon.

In Quebec, Canada, regional baseline groundwater monitoring (Lavoie *et al.*, 2014) included the following suite of parameters:

- General physico-chemical parameters,
- Major and minor ions
- Dissolved gas components – methane, ethane and propane;
- Trace inorganic elements such as alkalinity, metals, nutrients and sulphur;
- VOCs
- Stable and radiocarbon isotopes (δ^2H and $\delta^{18}O$, ^3H and ^{14}C) (on a subset of samples, in methane).

In England and Wales, the BGS baseline groundwater monitoring programme which was referenced previously includes the following suite of parameters, in addition to dissolved natural gas components in groundwater:

- General water chemistry (physico-chemical and major ions);
- CO_2 and dissolved organic carbon (DOC);
- Carbon and Hydrogen stable isotopes of methane, ^{14}C, stable isotopes of CO_2, and dissolved inorganic carbon (DIC);
- Trace organics (i.e. VOCs); and
- Groundwater residence time indicators (chlorofluorocarbons, SF6 gases).

There is commonality between the parameters included in respective baseline monitoring programmes. In combination, they point towards what may be considered as 'best practice'. The comprehensive lists are, arguably, a reflection of the historic lack of 'adequate' or 'sufficient' baseline monitoring data, which has proven to be problematic for both the gas industry and public alike.

In the US, baseline monitoring requirements are becoming stricter, both for operators (e.g. "Rule 609" in Colorado) and as implemented by state authorities and river basin commissions. For example, the Delaware River Basin Commission (DRBC) recently developed both location-specific and regional baseline monitoring programmes in catchments that have not yet undergone unconventional gas development. The monitoring covers both groundwater and surface water quality, in addition to air quality, biological monitoring and toxicity testing of fish. The DRBC is also pursuing "ambient" monitoring surveys on an annual basis at more than 100 sites in Pennsylvania and New York to assess biological and habitat changes throughout the region. The Susquehanna River Basin Commission (SRBC) has highlighted the range of baseline monitoring needs which arise from both scientific and regulatory points of view, which in addition to groundwater monitoring emphasises needs for expanded monitoring of streams and rivers during low-flow periods, chemical screening of surface waters, aquatic resource surveys, and installation of continuous water quality monitoring stations at remote locations (Hintz, 2013).

In Canada, the regulatory environment is similarly adapting to stricter baseline monitoring practices. In Quebec, where unconventional gas targets underlie intensely cultivated agricultural areas along the St. Lawrence Valley, regional authorities commissioned more than 60 studies to evaluate environmental risk of hydraulic fracturing and develop a regulatory framework for how development should proceed, *if* it should proceed (Gouvernement de Quebec, 2014). Two important initiatives which are relevant to the island of Ireland situation are:

- A *"Program for Groundwater Knowledge Acquisition",* supported by the Quebec Ministry of the Environment; and

- A Strategic Environmental Assessment (SEA) on unconventional gas development which was published in summary form in January 2014, and which took account of the baseline work carried out since 2011.

The “Program for Groundwater Knowledge Acquisition” has included hydrogeological characterisation and baseline monitoring in physiographic and hydrogeological settings that are not unlike those on the island of Ireland. Stable carbon ($\delta^{13}C$) and hydrogen ($\delta^{2}H$) isotope ratios of methane have been used in conjunction with concentration ratios of methane to higher-chain hydrocarbons to evaluate sources of methane in approximately 130 wells, similar to the approach pursued by the BGS in the UK. Results from Lavoie *et al.* (2014) indicate that natural gas in groundwater originates mainly from biogenic sources (methane dominant; less abundant ethane and propane), and the same study also reports that higher methane concentrations tend to be associated with $Na\text{-}HCO_3$ type groundwater, while lower methane concentrations are detected in $Ca\text{-}HCO_3$ type groundwater.

In addition to groundwater sampling, soil sampling has also been carried out to characterise subsurface gas dynamics and transport processes of methane, CO_2 and radon. Soil gas has been sampled for pore-space CO_2, ^{13}C, radon, methane and hydrocarbons (C_2-C_4) at 250 sites in total, located along transects. It has been interpreted that “anomalous” concentrations of CO_2, methane, ethane, butane and radon coincide spatially with higher concentrations of dissolved hydrocarbons in groundwater.

Aside from North America and the UK, South Africa is proceeding with initial environmental studies and baseline characterisation of water resources associated with the regionally extensive Karoo sedimentary basin. This follows the decision by the South African government to break the unconventional gas exploration moratorium which was in effect until September 2012. Baseline studies are now being carried out as part of a five-year research initiative “*to review and improve our understanding of the deep geology, hydrogeology, seismicity and natural gas-leakages of the Karoo, and to establish a forensic base-line of ground-water quality and water-levels across the Karoo.”* (NMMU, 2014).

The geochemical signature(s) of the deep Karoo groundwater system(s) is largely undefined, but preliminary isotopic studies indicate that the methane is both of thermogenic and biogenic origin (Talma and Esterhuyse, 2013). Baseline monitoring parameters proposed for groundwater in the Karoo studies are physico-chemical parameters, trace metals, dissolved gases (methane. ethane, radon), VOCs and SVOCs, radiochemistry and stable isotopes.

9.2.3 Groundwater monitoring using domestic wells

Groundwater impact studies in the US and baseline monitoring studies in Canada and the UK have made use of domestic wells. This reflects, perhaps, the fact that claims of impact often originate with private well owners or citizens groups.

One significant advantage of incorporating domestic wells in a prospective baseline monitoring programme is to be able to document the groundwater quality of private water supplies in a given region prior to, during and after UGEE operations. Ideally, basic information about the wells can be collated through surveys to determine which aquifer(s) is being pumped (i.e. sampled) and whether or not potential external influences may affect the interpretation of water quality data. Such surveys of domestic wells would establish their locations, well construction details (to the extent possible) and whether or not raw (untreated) water can be sampled from the subject well.

- The *location* informs about the geological formation and aquifer unit that the well is (most likely) pumping water from. Domestic wells tend to be relatively shallow (<100 m deep), thus the aquifer unit can be reasonably inferred from this.
- Details such as *well depth* provides confirmation of the likely aquifer unit which is being pumped, and detail on *casing installation(s)* informs about risks of impact on the collected sample from surface or shallow sources of pollution, as described below.
- Wellhead discharge *piping* inform about the ability to collect 'raw' (unaffected) groundwater samples, and whether sample taps at appropriate locations would need to be installed to accomplish this objective.

Of primary importance is well construction detail. A typical design and installation of a domestic well on the island of Ireland involves advancing surface steel casing through subsoil to bedrock. Below the bedrock surface, the well is either an open borehole to total depth or is fitted with PVC well construction materials (i.e. blind casing and slotted screens). The surface steel casing is often not properly cemented in place, which leaves a gap in the annular space between the casing and the drilled borehole wall. This gap can allow leakage of surface water or shallow (perched) groundwater in subsoils to enter the well. Such inflows may carry pollutants (e.g., nutrients, bacteria) to the groundwater which would otherwise not be present. In such cases, groundwater quality data have to be reviewed with care, as data may otherwise be misinterpreted in terms of environmental pressures and impact. This issue is not restricted to private wells for single homes – it is a frequent observation also with private wells associated with industry, commerce or leisure (e.g. hotels, golf clubs). In recognition of the prevalence of poor well construction practices, both the EPA and the IGI have published guidance documents on the drilling and proper construction of water supply wells (IGI, 2007; EPA, 2013b).

Another complication which may arise from the type of installation described above is that private wells are rarely, if ever, constructed with consideration of cross-flows in the borehole, resulting from intersection of water-bearing intervals (e.g. fractures or solution conduits) with different 'heads' or pressures, such that when pumps are not operating, groundwater from shallow intervals may mix with waters from deeper intervals and potentially from different geological formations altogether. This too can impact on water quality interpretations.

The ability to physically sample raw (untreated) water requires that samples are collected before it is treated or stored in any reservoirs. Post-treatment or post-storage samples can be influenced by changes to temperature, pressure, and redox conditions of the water, and may thus not be reflective of true groundwater conditions. This is particularly important for dissolved gas concentrations, where groundwater exposed to the atmosphere 'loses' dissolved gases from off-gassing. Changes in pH and redox potentials can also lead to changes in the speciation and solubility of minerals and metals. Accordingly, samples from boreholes/wells should be collected from sampling taps connected directly to the pump rising main.

In the UGEE context, domestic well sampling would be of added value *if* 'suitable' candidate wells were identified from surveys and vetted against the above factors. In this regard, private well owners could play a monitoring role by having their water regularly tested. However, there is no onus or requirement on owners of private wells (for single homes) to test water quality, and if testing were to be done, the financial burden associated with a wide suite of parameters can be significant. As well, the sampling methods, procedures and specialised equipment that are needed for many of the key indicator compounds described previously makes sampling by private instances unrealistic. Such wells would have to be sampled by qualified individuals who come equipped with procedures, materials and relevant experience.

9.3 Baseline Monitoring of Surface Water Quality

Baseline monitoring for surface water quality has received comparatively little attention in international literature, yet the potential for impact across catchments is significant, both from onsite and offsite UGEE activity. Surface water impacts may individually be of local scale (associated with individual drill pads) or may cumulatively take on added significance at the catchment scale.

Impacts on surface water can be of a physical nature as much as a chemical nature. Several international researchers have reported that land disturbance from drilling and well pad activity, as well as offsite transportation and construction activity, has impacted on the discharge of sediments into streams, raising total suspended solids and turbidity levels in the process (e.g. Olmstead *et al.*, 2013). Entrekin *et al.* (2011) documented streamflow turbidity in areas that are undergoing natural gas development and reported a correlation between well density and stream turbidity in seven catchments monitored.

The impacts are associated with both controlled (licensed) and uncontrolled (deliberate/accidental) discharges to surface waters. Discharges from fuel spills, improperly stored chemicals, and/or inadequately/improperly treated wastewater to streams or other water features can all, in the worst of circumstances, impact both on environmental conditions as well as human health. An example of the latter is described from Pittsburgh in Pennsylvania, where in 2010 the Pittsburgh Water and Sewer Authority noted that concentrations of total trihalomethanes (THMs) and the relative fraction of brominated THMs were increasing in the treated water supply of the city. States *et al*. (2013) attributed the impact to elevated bromide concentrations in the source river and concluded that "*most of*" the bromide could be "*traced*" to industrial wastewater discharges associated with oil and gas activity in the Marcellus shale. Bromide (Br^-) is frequently present in 'flowback water' and can, at higher concentrations, lead to the formation of bromine where free chlorine is used as a disinfectant (e.g. at water treatment plants). The bromine can react with organic matter to form THMs. There are other reported cases where bromide concentrations in rivers have increased in natural gas development areas (Barbot *et al.* 2013; Haluszczak *et al.* 2013).

Even simple activities such as land clearing and vegetation removal, if not conducted and controlled properly, can cause runoff and sedimentation to rivers. With reference to sub-regional baseline monitoring, measurement and characterisation of 'simple' physico-chemical parameters would, therefore, be important.

Sub-regional monitoring approaches for surface waters are, arguably, less complicated than groundwater. They still have to be comprehensive given the wide range of potential surface and site contaminants that are used with UGEE operations and which can discharge to surface water bodies. Although there is an analytical rigour to be pursued, monitoring for dissolved gases is more complex, due to degassing in the surface (atmospheric) environment, and that gases in surface water would likely originate from the groundwater that discharges into the surface waters, making pathway identification and groundwater flow contributions important to quantify. Monitoring for dissolved gases in surface waters is more of a local-scale issue related to individual hydraulic fracturing sites.

9.4 Baseline Monitoring of Sediments

Waste fluids associated with UGEE (e.g. drilling fluids and flowback waters), even though they are typically de-sanded and de-silted, can be difficult to contain. Recent reviews of the risks to water resources from UGEE activity in North America highlight the practice of disposing of waste fluids to freshwater streams or ponds/lakes. Waste fluids may retain trace chemicals and contain metals (e.g. barium and strontium) and/or NORM which can adsorb to stream sediments in proximity to surface water discharge locations. There are cases from the abandoned mining industry in Ireland where compounds such as pyrite oxidise to form sulphuric acid, which in turn impacts on water quality by decreasing pH, precipitating metals and impacting benthic elements in aquatic ecosystems (CDM, 2008). A similar situation could arise from UGEE activity.

Warner *et al*. (2013a) recorded "higher maximum activities of both ^{226}Ra (8732 Bq/kg) and ^{228}Ra (2072 Bq/kg) in the sediments… these Ra activities were 200 times greater than any background sediment samples collected…". Similarly, Vengosh *et al*. (2014) noted that "Disposal of the NORM-rich Marcellus waste fluids to freshwater streams or ponds would cause radium adsorption onto the stream sediments in disposal and/or spill sites….disposal of treated wastewater originating from both conventional and unconventional oil and gas production in western Pennsylvania has caused radium accumulation on stream sediments downstream of a disposal site from a brine treatment facility."

Accordingly, the accumulation of NORM in sediments in freshwater environments should be considered during both planning of UGEE-related activity and baseline and operational monitoring of same.

9.5 Baseline Monitoring of Water Quantity

Potential water use requirements associated with UGEE operations were summarised in Section 7. Large abstractions, even short-duration abstractions, can cause environmental stresses and impact, depending on the source of the water and the conditions of the water resource at the time of abstractions. For example, abstractions from smaller streams during natural low-flow conditions can result in changes in water temperature, sediment transport, channel shape and the connectivity between channel intervals, all of which can adversely affect river biota. Abstractions can also impact on water quality by reducing the natural assimilative capacity of streams. Similarly, large abstractions from smaller lakes can result in lowering of water levels in ecologically sensitive areas, and large abstractions from springs can reduce streamflow and water balances of lakes, where these are dependent on the spring discharges for ecological health.

Potential abstractions from smaller sources would require special attention as they involve greater risks of impact, where impact may involve lowering of water levels, lowering of streamflows, reduced spring discharges, and reduced fluxes to sensitive wetland habitats. As UGEE activity is rarely confined to single locations, abstractions have a cumulative impact potential which requires careful assessment, regulation and monitoring. In time, monitoring data will be compiled for characterisation of hydrological behaviour, including trends, and assessed in context of general demands and water availability.

Risk of impact is greatest when the abstraction takes place during natural low-flow conditions, when demands from other users – e.g. human consumption, agriculture/commerce, and ecosystems – are also greater. In terms of groundwater and lakes, the risk of impact is higher during *critical periods of a season* (e.g. mating or spawning seasons, growing seasons), when water levels are important for access to sensitive habitats. To assess changes on ecosystems, a wide range of metrics such as populations and diversity of aquatic species should be characterised and monitored.

With regard to risk of impact, special attention should be given to requirements of existing statutory instruments and efforts by the EPA and NIEA to maintain "good quantitative status" of water bodies (see Section 6.5). Groundwater/surface water interactions are especially important to consider, as are the presence and environmental needs of groundwater dependent terrestrial ecosystems (GWDTEs) and other wetlands. The NCB includes karstified limestone aquifers where ground and surface water bodies are in hydraulic continuity; thus changes in the quantity and quality of surface waters can and will affect groundwater, and vice versa.

The assessment of abstractions and water availability has to consider the different water balance components and quantitative and ecological 'status' indicators of catchments, including:

- Meteorological parameters (e.g. rainfall, evapotranspiration) – data sourced from Met Éireann (Ireland) and the Met Service (Northern Ireland);
- River stages and flows – EPA and local authorities (Ireland), OPW (Ireland), Rivers Agency (Northern Ireland);
- Lake levels – EPA and local authorities (Ireland), NIEA (Northern Ireland);
- Spring discharges – EPA (Ireland), NIEA (Northern Ireland); and
- Groundwater levels – EPA and GSI (Ireland), NIEA and GSNI (Northern Ireland).

Relevant hydrometric monitoring is taking place within both case study areas and recommendations for additional monitoring under the UGEE project, taking account of identified data gaps, are presented in Section 10.

10 Design of Sub-regional Baseline Monitoring Programmes

In preparing the specifications for recommended sub-regional baseline monitoring programmes in the two case study areas, the approach that was followed:

1. Coordinates and builds on past and existing monitoring initiatives to take advantage of monitoring data which already exist, thereby reducing the potential for duplication of effort and associated costs;
2. Uses conceptual hydrogeological models to screen candidate sampling and measurement locations;
3. Considers the information which has been collated on potential receptors to guide the selection of monitoring points; and
4. Responds to best practice information on baseline monitoring in international literature, particularly with respect to parameters that should be included for laboratory analyses.

Sub-regional monitoring has to be comprehensive in extent, by definition and as guided by baseline monitoring best practice. However, baseline monitoring should also allow for flexibility, whereby monitoring is adapted to actual findings and as new information is obtained during the life of the monitoring programme, both with respect to what is monitored for and where sampling is carried out. Thus, a key concept behind the recommended approach is ‘adaptive monitoring’. Two relevant examples of this approach are:

1. A scenario in which dissolved natural gas constituents are not detected in a groundwater sample or the concentrations are below a specified trigger level. In this case, further isotope analysis of the sample to document the chemical fingerprint and likely source/origin of the gas constituents would not yield meaningful results, and would thus not be carried out. The trigger levels that would be proposed are those used by the BSG for baseline monitoring of methane in England and Wales.
2. Similarly, if gross alpha and gross beta radiation screening of groundwater samples do not exceed specified threshold values, then further analysis to document activity levels of naturally occurring radioactive materials (NORM) may not be necessary since the total radioactivity levels are below relevant thresholds [dosage/health-based guidance values as described by RPII (2013)].

Finally, the baseline monitoring targets receptors at the sub-regional scale, covering the entire case study areas. It is different from the baseline monitoring that would be required of UGEE operators as part of a future planning and licensing process.

International literature provides examples of potential impact on water resources, and the primary lesson to be learnt is that a precautionary and comprehensive approach to baseline monitoring should be adopted. This is because: a) the potential nature and extent of future UGEE activity in Ireland and Northern Ireland are not known; b) the associated hydrogeology and potential pathways of water and contaminant movement are complex; and c) the science behind impact identification is still evolving.

Experiences from baseline monitoring approaches in other countries are useful as guidance, but these cannot be used directly as analogues to the island of Ireland situation, as baseline monitoring has to consider knowledge about water users in the case study areas and the hydrogeological conditions which dictate water resources availability and pathways, which in turn influence water and contaminant migration.

The sub-regional monitoring approach recommended for the two case study areas is receptor-focused and targets analyses of constituents and compounds which: a) describe general environmental pressures; b) can be used to fingerprint both natural gas presence/origins and other chemical impacts; and c) are capable of addressing “cumulative impact” from UGEE activities at the catchment scale.

10.1 Groundwater

There is a wide range of geological and hydrogeological settings present within the study areas which have to be factored into the design of baseline monitoring networks. Establishing a representative baseline monitoring network for groundwater is considered particularly challenging for several reasons:

- Several different bedrock formations are present with different lithological characteristics and potential influences on natural groundwater quality;
- Several different aquifer types and potential receptors are also present;
- Groundwater and surface water interactions are significant, especially in the karstified limestone environments of the NCB;
- Groundwater levels and chemistry in different bedrock aquifers are subject to temporal variations, both in the short-term and long-term (episodic vs. seasonal).
- The baseline monitoring network must incorporate suitable locations for the sampling and analysis of dissolved natural gas constituents in groundwater. This requires that raw water samples can be collected which has not been exposed to the atmosphere. To date, such monitoring has not been carried out on the island of Ireland. Thus the challenges involved also reflect the need to both research and adopt appropriate sampling methods.

The following points highlight the basis for the design and selection of groundwater monitoring points which are presented for the NCB and CB study areas in Sections 11 and 12, respectively.

- The designed monitoring programme is guided by the conceptual understanding of groundwater flow and associated pathways at the catchment scale.
- Existing WFD monitoring points would be included in the monitoring network to take advantage of the existing database of groundwater quality and to allow for continuation of sampling at those sites where longer-term records exist;
- All public and private regulated groundwater supply wells are prioritised for sampling. Selected wells (see Sections 11 and 12) have been inspected in the field and are deemed suitable for sampling purposes, pending minor works such as the installation of raw water sampling taps.
- All public and private regulated water supplies sourced from springs and used for human consumption and/or livestock are also prioritised for sampling.
- “Other” private groundwater supplies, represented mostly by private wells that supply single homes, farms and commercial activities are also included. As documented by the ground-truthing survey of existing groundwater abstraction points in Appendix G, public supply wells are not present in the UGEE licence area of the CB, and the monitoring would thus mostly rely on sampling from private wells. In this instance, supplies associated with commercial activity and larger cattle farms are favoured over domestic wells supplying single homes, as larger abstractions draw on larger volumes of aquifer, thus increasing the likelihood of obtaining samples representative of true aquifer conditions.

Most of the existing public and private regulated supply wells that have been inspected are reasonably well constructed, and most have properly grouted casing materials and wellhead protection measures. In contrast, private wells supplying single homes and farms are rarely constructed to the same standard, and risks of groundwater quality impact from surface pollutants are greater, e.g. by ingress of surface water via the annular space between the drilled borehole wall and the casing. Such private wells are nonetheless of value and interest, for two reasons:

- They are representative of wells and groundwater that is accessed and used in both study areas; and
- They provide for improved spatial coverage in areas where public and private regulated supplies are absent.

Even with the consideration of such private wells, there remain areas without spatial coverage of groundwater sampling points. At such locations, the drilling, installation and testing of new monitoring wells would be recommended.

To the extent practicable, all of the key bedrock formations in respective study areas are represented in the recommended sampling programme (see Sections 11 and 12). Most bedrock formations, even poorly permeable formations, are used for water supply purposes to some extent. The Leitrim Group rocks in the NCB are not considered to be primary receptors, but monitoring of related formations is nonetheless important as natural gas was detected in several of the related formations during drilling of Drumkeeran No.1, and documenting the presence of gas would, therefore, be important in the context of subsequent data interpretation. Similarly, the former coal mines associated with the Connaught Coalfield near Lough Allen extracted coal from thin seams within Leitrim Group rocks, and the chemical signature of the Coalfield groundwater is, accordingly, important to document for the interpretation of baseline conditions.

With regard to springs, these represent groundwater discharges. It is recognised that some of the spring water in karstic flow systems has only a short residence time in the subsurface environment. However, the karstic spring water has nonetheless interacted with groundwater in the surrounding rocks. Drew (2012) conclusively demonstrated that dyes injected into an active swallow hole in the Burren region of Co. Clare migrated to both: a) springs, rapidly, via conduit flow; and b) private wells, via slower and more "diffuse" pathways (i.e. fracture networks). In effect, water that flows through conduits has the ability to diffuse outward into the fracture 'matrix' surrounding the conduits. Conduits also have the ability to act as drains (i.e. receptors) of surrounding groundwater when water levels in the conduit system are lower than in the surrounding fractured aquifer. Accordingly, and as concluded by the EPA (2014a), "*a river or stream that sinks should be regarded as groundwater unless defensible evidence exists that diffuse dispersion (through fracture systems) is not important for a given site or setting*."

10.1.1 Former abstraction wells

A small number of idle former public and private supply wells are present in the CB study area. These are presently covered over and have not been in use for many years (in some cases up to 20 years). Those that can be accessed are nonetheless potential groundwater sampling points if it can be established that they are still usable. This would entail clearing and opening the wellheads, measuring total depths and checking for potential blockages, airlifting to clean the wells, and lowering a camera to video-inspect the physical integrity of the wells. If deemed suitable, they could be included in the sampling programme. Alternative wells would otherwise have to be located or new monitoring wells would have to be drilled and installed in their place.

10.1.2 New monitoring wells

The ground-truthing survey of existing abstraction wells and springs (see Appendix G) indicated that there are gaps in the spatial coverage of existing wells in both case study areas. To address the identified gaps and provide for improved spatial coverage of suitable sampling points, it would be necessary and recommended to drill and install a subset of new monitoring wells across both case study areas. Because sub-regional baseline monitoring is receptor-focussed, such new monitoring wells would be installed in a similar manner to existing supply wells in order to represent and document receptor conditions, i.e. the quality of groundwater that is used or accessed for water supply purposes and/or which discharges to surface water bodies via shallow groundwater pathways. Accordingly, new monitoring wells would be drilled in key bedrock formations within or near their outcrop areas to depths of approximately 100–150 m, *as a guide*, to be consistent with existing abstraction wells in respective study areas.

There are no right or wrong well depths which can be specified at any given location, as water strikes and influxes of groundwater to wells depend on the presence of water-yielding fractures or conduits at the locations selected for drilling. Final well depths at any given location would be determined by findings during drilling and consideration of budgetary constraints. Findings during drilling include observations made about lithology, water strikes, and volumes of water airlifted from the borehole, similar to the approach adopted for the EPA "poorly productive aquifer" drilling programme (Moe *et al.*, 2010). During drilling, a pilot borehole would be advanced initially, which would be geophysically logged and from which decisions about installation details or abandonment are made. If, for example, a 'dry' pilot borehole is drilled, a decision to abandon may be made. To reduce the risk of drilling 'dry' boreholes, it is recommended that boreholes be sited on or near mapped faults (as potential pathways), guided by existing geological maps published by the GSI and GSNI.

The new monitoring wells would not be 'conventional' monitoring wells like those which are typically installed at landfills, contaminated land or Integrated Pollution Prevention and Control (IPPC) sites. Rather, the wells would be installed so that they could be pumped as supply wells in order to draw on larger volumes of groundwater for representative sampling and analysis of natural gas constituents and NORM in the key bedrock formations. Accordingly, the wells would have to be of sufficiently large diameters to accommodate pumps for sampling purposes. It is envisaged that new monitoring wells would be advanced with 8-inch diameter steel casing to bedrock, then completed as nominally smaller diameter open or screened boreholes to total depth. Rather than installing wells with short open or screened sections, i.e. to collect samples from discrete intervals, the monitoring wells would be completed with long open sections, similar to supply wells.

New monitoring wells would be sited on or close to mapped faults which display significant vertical and/or lateral displacements. Faults represent potential preferential pathways of groundwater movement in fractured bedrock aquifers, and thus wells located in fault zones would be more likely to accomplish monitoring objectives. Fault traces and relative displacements have been mapped by the GSI and GSNI and could, therefore, guide the initial siting of recommended wells. All candidate sites would have to be field-verified and locations would have to be adjusted in the field as necessary based on, for example, site access and landowner agreements. Thus, new wells would to the extent possible be sited on public land. Practical matters related to the siting of new wells would affect the final costs of baseline monitoring programmes, and should, therefore, be concluded prior to tendering for drilling services.

New wells would be constructed to high standards, following best practice guidelines and experiences (e.g. IGI, 2007; Moe *et al.*, 2010). Subsequent to the conclusion of baseline monitoring, the wells could be used for other purposes, e.g. as supply wells or incorporated into existing WFD monitoring networks. The data that are collected during drilling, testing and monitoring of the new wells would add value to the general hydrogeological characterisation of fractured bedrock aquifers on the island of Ireland.

As stated above, the groundwater samples obtained from new wells would be representative of shallow receptor conditions. The new wells would not be sufficiently deep to address the critically important technical questions with respect to the hydrogeological conditions of deeper bedrock formations. Although a sub-regional approach to deep hydrogeological characterisation (and subsequent monitoring) would provide valuable data for the overall assessment of environmental risk associated with UGEE activity, the operational aspects and environmental risks of hydraulic fracturing are both case- and location-specific. Thus, a sub-regional approach would not necessarily produce the answers that are needed at the case- and location-specific scale for individual UGEE operations. For this reason, it is argued that detailed hydrogeological characterisation and subsequent monitoring of deeper bedrock formations is best addressed once the locations, circumstances and plans for prospective UGEE activity become known. Accordingly, the onus of related works is placed on the UGEE companies, as determined by statutory instruments and the terms and conditions which are set and supervised by relevant regulatory bodies.

10.1.3 Abandoned gas exploration wells

Abandoned past hydrocarbon exploration wells in the study areas represent potential man-made pathways for gas migration from deeper formations. Although these wells were partly plugged and/or sealed at the time of exploration, very little is known about the present-day physical integrity of the wells, with specific regard to:

- The wellhead 'finishing' at the surface;
- The steel casings that were used for well construction purposes;
- The cement plugs that were emplaced at indicated depth intervals inside the wells; and
- The cement grout in the annular spaces between the steel casings and borehole walls.

It would, therefore, be recommended that as part of any future baseline monitoring programmes, initial surveys of these wells would be conducted to:

- Monitor for the presence of natural (methane) gas in soils close to wellheads;
- Verify if the wellheads can be safely and securely opened for further well integrity inspection; and
- Determine if the wells could serve as potential monitoring points in a baseline monitoring programme and subsequently during prospective UGEE operations. If the wellheads are accessible and can be opened, simple depth sounding inside the wells would verify the depth of the first blockage, which should correspond to the first cement plug that is indicated on well abandonment drawings by the exploration companies. Different findings would indicate potentially different completion details or well integrity issues (e.g. casing collapse), from which decisions about the next inspection steps would be made.

The end goal would be a decision about potential use of the wells for monitoring purposes. Care would need to be taken so as not to cause damage to the wells, and further work beyond the initial survey would not be recommended if the indicative costs are prohibitive (judged against the merits and benefits of the monitoring). Inspection work inside the wells might involve one or more of the following:

- Checking the total depth to first blockage inside the well;
- Airlifting and cleaning the well (to the first blockage) if this is possible;

- Running a camera-survey of the inside of the well;
- Running borehole geophysical logs that would inform about well integrity to complement the camera survey, notably calliper, acoustic and optical televiewer, and cement bond logs (subject to equipment suitability with regard to borehole diameters and risk of losses).

There are 16 past exploration wells of relevance within or in vicinity of the two study areas (14 in the NCB and 2 in the CB). Based on existing abandonment drawings and preliminary observations made during the abstractions survey carried out as part of the UGEE JRP, approximately half of the wells may be accessible and the other half are either known or suspected to be elaborately covered over (e.g. by massive concrete blocks).

With regard to the abandoned exploration wells acting as potential pathways for gas migration from deeper formations, it is recommended that these sites be considered for screening level monitoring of ground gas, including methane emissions, near the respective wellheads. The topic of potential gas emissions is relevant as gas emissions could be related to well construction integrity. There are simple screening level monitoring techniques that could be applied and which would be relatively inexpensive to implement. However, before any final recommendations could be made, the potential and suitability for soil gas screening at and near wellheads would have to be determined from initial inspection of wellhead conditions.

10.2 Surface water

The existing WFD monitoring networks for surface water bodies would serve as the basis for sub-regional baseline sampling programmes. Like groundwater, the objective would be to take advantage of the longer-term water quality records that exist. There are overlaps between parameters analysed for WFD purposes and parameters recommended for UGEE project purposes, thus cost savings would be achieved by integrating the respective sampling programmes. The list of parameters for the UGEE project would, however, be more extensive than the WFD monitoring. The additional data would provide new insights into the baseline environmental conditions of related catchments.

The existing WFD monitoring network for rivers and lakes is extensive, in particular the operational monitoring network which targets specific ‘poor ecological status’ cases and which tracks identified environmental pressures.

Recommended analytical parameters for baseline monitoring purposes in surface waters differ from groundwater monitoring, as follows:

- Dissolved gases would not be included, but would be relevant at a later time at a local- and subcatchments scale near planned sites, should UGEE licencing be considered in the future;
- A greater emphasis would be placed on physico-chemical parameters and salts, i.e. indicators of intensive land use modifications (e.g. soil movement and channeling) and accidental/deliberate releases of sludges and wastewater discharges from drill pad operations, as well as the management of flowback waters.

If UGEE proceeds in the future, it can be argued that detailed baseline monitoring of surface waters would be most relevant near drill pads and related installations, and that surface water monitoring would only serve to flag episodic releases or discharges from individual operations. Whilst this argument has merit, surface water should be considered in a broader perspective for baseline monitoring purposes, notably establishing baseline conditions of all UGEE-relevant parameters across catchments, thereby addressing the question of potential cumulative impact within respective licence areas. The cases of THM impact at water supply treatment plants in Pittsburgh (see Section 9.3) is a good example of the need for broad surface water monitoring and assessment.

It would be further recommended that continuous monitoring of certain field parameters be considered in a baseline monitoring programme and that potential cumulative impacts be assessed. Relatively inexpensive automatic data logger installations would be proposed that measure specific conductivity (as a proxy for salinity), temperature, pH, and turbidity. Continuous measurements of field parameters are proposed because sub-regional monitoring must be able to document and describe the variability of parameters that is characteristic of karstified limestone aquifers, both seasonally and during individual, episodic rainstorm events. Such installations would be arranged for in a subset of selected rivers and lakes.

As described previously, both the EPA and NIEA implement extensive monitoring networks for biological elements under the WFD, and the results of Q-scores in Ireland and the BWMP biotic score system in Northern Ireland could be accessed in the future to assist in the description of existing environmental conditions and the assessment of potential impacts.

10.2.1 Water framework directive register of protected area

A sub-regional baseline monitoring programme linked to potential future UGEE activity would effectively be an extension of the existing WFD monitoring networks in both study areas. Priority for baseline sampling would be given to WFD sites where water quality data are already available so as to build up the existing data sets further. In this context, it would be assumed that site access is available and that there would be no health or safety concerns with the monitoring activity, which would need to be verified prior to baseline monitoring implementation.

A UGEE sampling network would include monitoring stations at downstream locations of most catchments and a select number of upstream sampling locations in the same catchments which would serve as reference sites. Surface water bodies which include WFD protected areas would be prioritised for baseline monitoring purposes because of their inherent value as a resource or sensitivity as a receptor. Accordingly:

- Drinking Water Protected Areas (i.e., raw water from public drinking water supplies) would be represented in the sampling programme;
- Salmonid Waters (lakes and rivers) would be represented in the sampling programme;
- Margaritifera Sensitive Areas would be represented in the sampling programme. In the NCB, these are only present in the Swanlinbar river catchment, which is a cross-border catchment that drains into Upper Lough Erne. In the CB, only the Doonbeg river catchment is relevant. The freshwater pearl mussel (*Margaritifera margaritifera*) is a sensitive freshwater species and is reported to be in decline primarily due to sedimentation and eutrophication (NPWS, 2014).
- Surface water bodies within designated WFD protected areas for habitats or species would also be represented in the sampling programme.

It would be recommended and proposed to monitor coastal shellfish waters directly, as these are influenced by numerous inputs beyond the UGEE licence areas, and the associated water quality would be further influenced by the flushing action of tides. The main streams that discharge into the shellfish waters from the study areas would be included in a recommended monitoring network. Based on similar reasoning, streams that flow into coastal bathing water protected areas would also be included in the monitoring programme.

As nitrate is not a particular contaminant of concern for UGEE projects, nitrate sensitive areas are less relevant in a baseline monitoring programme.

Finally, monitoring locations associated with specific point sources such as wastewater treatment plant discharge locations are not representative of catchment- or sub-regional conditions. Accordingly, they would not be included in baseline sampling, although discharge and environment data produced by responsible public bodies would be collated and included in the overall assessment of potential impact. If there would be point sources near a future UGEE site, the point sources should be characterised and monitored during pre-development activity by UGEE operators, which in turn would be guided by terms and conditions of monitoring required by UGEE and environmental regulatory bodies.

10.3 GWDTEs

As introduced by Kilroy *et al.* (2008) and subsequently detailed by Kimberley and Coxon (2013), different habitats have different types and degrees of groundwater dependencies, and the *supporting conditions* for habitats usually fall into the following three categories: water chemistry, water levels and/or water flux (i.e. throughflow).

10.3.1 Water chemistry

Certain GWDTEs are known to be sensitive to nutrient inputs (nitrogen and phosphorous) and metals, and can thus be affected or stressed by related environmental pressures (UKTAG, 2014). GWDTEs that need lower level of nutrient inputs are considered to be of higher conservation value as they tend to show higher diversity of species. UKTAG (2014) have derived threshold values for nitrate for each habitat type based on existing groundwater quality data that is known to be hydraulically linked with a particular habitat type, and which is in favourable conservation status. Using these threshold values, the Rooskey Turlough in Co. Fermanagh was, for example, deemed by the NIEA to be at risk from not meeting WFD ecological status objectives. Equivalent thresholds for other parameters were not developed on the basis of data quality questions or lack of data availability, and the UKTAG recommended that thresholds for other parameters should be developed on a site-specific and case by case basis, and using local knowledge.

There is generally a lack of knowledge about the chemical supporting conditions for GWDTEs, and further study is needed. A complicating factor in site-specific study is the recognition that water chemistry at any selected habitat/wetland site may be affected and modified by natural processes which could alter the concentrations of, for example, nutrient concentrations in the surrounding and supporting groundwater body (UKTAG, 2014).

10.3.2 Groundwater levels and flow

Groundwater levels and flow are critical to most GWDTEs, and hydraulic impact by means of drainage or abstractions can result in damage to related ecosystems. Thus, to assess risks of impact and potential damage, the natural supporting conditions of individual GWDTEs and habitats should be understood. This would be achieved by a combination of piezometer installations, water level measurements, spring discharge measurements and sampling.

10.3.3 Implications for sub-regional baseline monitoring

The conceptual ‘ecohydrogeological models’ presented by Kimberly and Coxon (2013) are useful for highlighting the main dependency characteristics of the different habitat types that are present in the two study areas. However, they cannot, and are not intended to, convey or describe specific hydrogeological or hydrochemical conditions which may apply to an individual habitat at a given location. The environmental science of groundwater dependent habitats is inherently site-specific, and baseline monitoring at a given site (habitat) would only provide indications of the specific conditions that apply to that site. To broaden the understanding and draw bigger-picture conclusions, several sites would have to be selected for monitoring, thereby building up a volume of data from which patterns may become apparent. However, there is a risk that uncertainty may accompany location-specific results, which in turn may obscure interpretations.

Kimberly and Coxon (2013) also noted that not all habitat types with qualifying interests as GWDTEs are actually groundwater-dependent at any given location, citing the examples of transition mires, active raised bogs and alluvial forests. Furthermore, the specifics of groundwater-dependencies are not recorded in national datasets (Ireland and Northern Ireland), and in combination, these issues complicate the assessment of which mapped habitats should or can reasonably be represented in a sub-regional baseline monitoring network.

Guided by Kimberly and Coxon (2013), the following habitat types are considered to be substantially groundwater-dependent:

- Turloughs (habitat code 3180);
- Petrifying springs with tufa formation (*Cratoneurion*) (7220); and
- Calcareous fens (7230 and 7210).

Accordingly, these would be retained as the most appropriate candidates for sub-regional baseline monitoring purposes. However, even with this guidance, the approach towards monitoring of groundwater-dependent habitats requires location-specific study, where monitoring is ultimately guided by findings and conceptual hydrogeological models of individual habitat settings. Prior study involves site investigation to ensure that monitoring takes place at relevant locations (in three dimensions). The need for prior study is supported by existing wetland research, including work carried out by Trinity College Dublin (TCD), Queens University of Belfast (QUB) and the Dundalk Institute of Technology (DkIT) as part of the Tellus Border research initiative led by the GSI and GSNI. Specifically, Rolston and McCarthy (2014) proposed a five-phased framework for the assessment of wetland habitats which involves prior site investigation and short-term monitoring as a basis for design of appropriate and representative long-term monitoring programmes.

Determining and selecting which habitats to include in sub-regional baseline monitoring depends on project objectives and priorities. In the context of GWDTEs and potential impact from UGEE, the most relevant topic to be addressed would be the chemical-isotopic signature of methane associated with organic-rich environments such as peats and fens, which are abundant in the NCB especially. The detection and monitoring of methane from related habitats is a challenging task, for several reasons:

- The generation of methane is localised and emissions are subject to both spatial variations within individual habitats and temporal variations as a function of atmospheric pressures and the position of the *water* table (Laine *et al.*, 2007).
- The majority of relevant habitats are geographically widespread and occur as individual entities which are often disconnected from one another.
- Methane can exist in both dissolved and free-phase forms in the subsurface, and the solubility of dissolved methane gas in groundwater would be further influenced by the ambient pressure with which water has equilibrated.

Because habitat characteristics and groundwater dependencies are case-specific, baseline monitoring of relevant, priority GWDTEs/habitats would be considered more appropriate if or when details about future planned UGEE activities become known. Such monitoring should be included as part of the terms and conditions of planning and assessment of UGEE plans, placing the onus of monitoring on the developer with appropriate definition and supervision of works by regulatory bodies.

There is merit in baseline monitoring of habitats which are known to be significantly groundwater dependent at all times, notably turloughs and petrifying springs with tufa formations. There is also merit in monitoring fens, if only to document the chemical fingerprint of methane in groundwater in organic-rich habitats. However, the site specific nature of such habitats and their geographic spread makes design of a meaningful and representative monitoring network difficult. Monitoring of fens for methane also requires good fortune as conditions and emissions would be different between, and even within, fens. Thus, monitoring of fens can be a project objective, but this requires significant investment in prior study to ensure that the investment would yield meaningful results.

10.4 Hydrometric Monitoring

Information on existing hydrometric monitoring is primarily sourced from the EPA and OPW in Ireland, and by the Rivers Agency in Northern Ireland. Additional data were also sourced from the ESB and Waterways Ireland, and research was conducted into past hydrometric studies of both study areas, including flood studies, catchment management plans, and design studies related to large abstractions.

There are four basic categories of hydrometric monitoring:

- Groundwater levels
- Spring discharges
- Stream flows and water levels
- Lake and reservoir levels

Each is discussed in turn. Meteorological data for the study areas are readily obtained for stations within and near the two study areas from Met Éireann (Ireland) and the Met Office (Northern Ireland).

10.4.1 Groundwater levels

Groundwater levels are monitored in five wells within or near the NCB study area under WFD monitoring initiatives by the EPA and NIEA. Groundwater level monitoring is not carried out in the CB. The monitoring wells in the NCB record water level changes in the Dartry and Ballyshannon Limestone Formations. Groundwater levels are not monitored in other bedrock formations, which includes formations that are used for water supply purposes. For this reason, augmented groundwater level monitoring would be recommended in both study areas to document natural fluctuations and longer-term responses of key formations to hydrometeorological conditions. Monitoring would be carried out using pressure transducers that can also record temperature, pH, and electrical conductivity.

10.4.2 Spring discharge records

There are hundreds of springs present in the two study areas, of which only a fraction are likely represented in available mapping. Despite their hydrogeological and ecological significance, spring discharge records are sparse to non-existent. Only one spring at Manorhamilton in the NCB is equipped for automatic discharge measurement. The general lack of spring discharge data represent a significant data gap, particularly in the NCB where springs are used for water supply and where large springs discharge from karstified limestone aquifers. Springs are not confined to limestone areas. They are present everywhere and also discharge from units (and possibly fault zones) in the Leitrim Group. Visits in April 2015 to 24 springs which are used for public or private regulated water supply, and which discharge from rocks of the Leitrim Group, indicated small discharges of generally less than 10 l/s. In contrast, measurement of a selected subset of large karst springs during the same period indicated discharges that were up to two orders of magnitude greater – e.g. approximately 700 l/s and 480 l/s were measured at Shannon Pot (to the NE of Lough Allen) and 'Hanging Rock rising' (near Lower Lough MacNean), respectively. Comparably large springs do not discharge from the Leitrim Group, but small springs are also associated with the limestones.

In the context of the assessment of available water resources for future UGEE-related activities, inferences about spring hydraulics can be gained from the conceptual hydrogeological models which in turn are informed by region-specific observations and knowledge of spring hydraulics in other places on the island of Ireland. Karst springs show much larger ranges of discharges compared to non-karst springs and tend to respond much faster to rainfall events. This is also reflected by episodic and/or seasonal changes in water chemistry. Nonetheless, there is an inherent danger in generalising about karst conditions as karst hydrogeology is notoriously unpredictable. At the local scale, and in the context of potential future abstractions for UGEE activity, springs (as a potential source of water or as a baseflow component to aquatic ecosystems) would have to be assessed individually on a case-specific basis.

Selected springs would be recommended for discharge and water quality monitoring, as described in Sections 11 and 12, and springs that are related to habitats with qualifying interests as GWDTEs are considered further in relevant sections on GWDTEs.

Due to the very large number of springs present, it would not be possible to measure all, and priorities would be recommended as follows:

- Springs used for public and private regulated water supply in all the major bedrock formations, particularly in the Bundoran and Benbulben Shale Formations and the Mullaghmore Sandstone Formation (this would entail measurement of spring overflows, i.e. the portion of a spring discharge which is not used for drinking water supply);
- Karst springs in the Dartry and Ballyshannon (and chronostratigraphic equivalent) formations;
- Springs (and other discharges) that contribute water to the Arigna River, which is considered to be of 'bad' ecological status, possibly due to pollutant loading from abandoned mine drainage.

In terms of the timeframe of the baseline monitoring programme, it would not be feasible or necessary to install multiple and engineered weir structures on springs. Instead, it is envisaged that temporary structures involving staff gauges and slotted standpipe solutions fitted with transducers could serve monitoring purposes within a defined monitoring period. Manual spot measurements would be periodically carried out to develop rating curves, where the ultimate objective would be to document seasonal and/or storm-related high and low flow conditions, as well as discharge recession characteristics. A set of transducers, recording water level, pH, temperature and electrical conductivity would be installed on a subset of karst springs for these purposes and to allow for estimation of time-lags of water pulses to move through respective conduit systems. High-flow stages could also be recorded by simple tubes fitted with corks which float to indicate maxima levels between times of equipment maintenance or manual flow measurements.

A station akin to that described above would be considered particularly important on the Shannon Pot rising (spring). This recommendation is grounded in the characterisation of a potentially deeper groundwater flow system in the karstified Dartry limestone (see Section 2.11). The hydrogeological setting, discharge mechanism, and water quality of the spring suggests that a deeper groundwater flow system may be present in a westward direction from the Cuilcagh Mountain, parallel to the Belcoo Fault and Cuilcagh Dyke. Whilst Shannon Pot would be sampled extensively for water quality, gauging of the spring would be recommended in the context of studying the details of the water balance of the spring, which would also involve manual measurement of point recharge locations represented by swallow holes on Cuilcagh Mountain. Shannon Pot is hydraulically represented at the

Dowra gauging station on the River Shannon upstream of Lough Allen, but at this location, the hydraulic response of Shannon Pot is partly masked by several other stream flow contributions.

10.4.3 Streams/rivers

As documented in Section 6.4, there are 28 active gauging stations with automatic flow recorders that measure water levels and flows within the NCB study area, and only 1 such station in the CB. Many catchments do not have flow records but estimates of key flow metrics (e.g. mean and 95-percentile flows) can be derived from:

(a) The EPA HydroTool for estimating flows in ungauged catchments in Ireland;

(b) The low-flow estimation tool called “Low Flows Enterprise” in Northern Ireland; and

(c) Transposing data from neighbouring catchments with similar physical and geological characteristics.

Gauging stations that reflect larger catchment areas incorporate flow contributions from numerous springs. This is particularly significant in the Cuilcagh Mountains where some of the largest springs in the region discharge from cave and conduit systems of the Dartry Limestone (e.g. Marble Arch). As an example, the downstream gauging station on the Arney River in Co. Fermanagh, which flows into the Upper Lough Erne drainage systems, reflects a multitude of hydrological influences including throughflow and storage within the Loughs MacNean.

In the CB study area, only one automatic long-term recording station, operated by the OPW, exists, notably on the Doonbeg River. Because the other catchments in the study area are of similar physical and geological nature as the Doonbeg catchment, the Doonbeg gauge can be used as a surrogate for the other catchments within the UGEE licence area. The EPA HydroTool can also be used to estimate flow statistics for the other catchments.

Overall, stream flows and hydrological responses are considered to be reasonably well documented at the sub-regional scale within the NCB, and new permanent stations are not considered necessary for the purposes of the UGEE JRP. Existing data can be used to estimate stream flow metrics and describe anticipated hydrological responses in respective regions, either directly from gauged data or indirectly by transposing metrics to neighbouring catchments or, as indicated above, applying HydroTool (in Ireland only).

For reference purposes, the primary data gaps inferred from the review of existing stations and data are as follows:

- Swanlinbar catchment – a gauge near Swanlinbar would be helpful to document the hydrology associated with the eastern end of Cuilcagh Mountain, where several streams merge and flow in the direction of the Upper Lough Erne drainage system;
- Arigna – a gauge at the downstream end of the Arigna River would be helpful in future water quality assessments as the Arigna catchment is classified as being at ‘bad’ ecological status, possibly from impacts of the former Arigna mines. The river also has potential UGEE significance, both as a source of water for supply purposes and as a receptor of contamination, since the areas of Arigna and Drumkeeran are considered as “prospects” for UGEE. The stream water quality is already impaired by periodically elevated concentrations of certain metals which are attributed to adit discharges from the former Arigna mines.
- Feorish catchment (between Lough Allen and Lough Arrow – a gauge on the Feorish River would strengthen the documentation of stream flows in the area between Lough Allen and Lough Arrow. Like Arigna, this is an area of potential UGEE significance given its proximity

to Arigna/Drumkeeran. It is also a karst environment, and is located very close to the regional Curlew Fault, which is the southern structural boundary of the NCB.

In these catchments, it would be recommended that manual spot measurements and temporary gauges be established in a similar manner to that described in Section 10.4.2.

10.4.4 Lakes

In the NCB study area, lake water levels are actively monitored with automatic recorders in Loughs Erne, Lough Melvin, Lough Gill, Lough Arrow, Upper and Lower Lough Macnean, and Lough Allen. Most of these are used for water supply purposes or are hydraulically regulated.

In the CB study area, Doo Lough and Lough Acrow are the only lakes of significance to the UGEE JRP. Although both are located marginally outside the UGEE licence area, Doo Lough is the main source of public water supply in western Co. Clare and Lough Acrow is used to augment the supply to a group water scheme during high water demand periods. Doo Lough has an established long-term record of lake level data from which hydrological responses and trends can be assessed.

In the immediate context of sub-regional UGEE baseline monitoring, data gaps in lake level monitoring are noted in the NCB with regard to Loughs Glenade and Glencar. Both are part of designated Special Areas of Conservation (SACs) and receive inputs from numerous streams and small springs, including petrifying springs.

Several small lakes which are abstracted in the NCB are also not monitored. These tend to be higher altitude lakes which supply small group water schemes, in some cases only a few houses. Examples include Loughs Lackagh and Tents to the north of Lough Allen. Monitoring of such lakes is not considered important in the sub-regional context, but could become important in the local-scale context if future UGEE activity targets such lakes for water supply. Until the actual locations of UGEE sites and plans for water supply become known, monitoring of small upland lakes is not considered meaningful.

10.4.5 Turloughs

Six turloughs are named within the NCB study area. One is in Northern Ireland (Rooskey-Fardrum) and the others are in Ireland (Lough Alteneen near Lough Gill and Loughs Augh, White, Black and Edentinny near Lough Arrow). As groundwater-dependent habitats, individual turloughs have unique characteristics and hydraulic control mechanisms which vary from one turlough to another. Accordingly, the hydrological responses of each to dry and wet-weather conditions would also vary. Only one, Rooskey-Fardrum, has been studied (Kelly *et al.* 2003) and monitored to date (by the NIEA under WFD monitoring initiatives).

Some of the turloughs form relatively large lakes in wet weather conditions and during winter seasons. Given the nutrient enrichment which is documented from WFD monitoring at Rooskey-Fardrum, the turloughs in Ireland would merit further consideration for water quality monitoring as part of the UGEE JRP.

Given their ecological significance, the turloughs are unlikely to be used for abstraction purposes in a UGEE context. Should this be proposed in the future, each turlough would have to be assessed technically in detail on an individual basis, based on actual plans for UGEE development.

One item that require technical clarification is the apparent omission of Lough Bo (near Lough Arrow) from the list of turloughs which was sourced from the NPWS. Lough Bo is considered and mapped as a turlough by the GSI and has been, together with Lough Nasool, proposed for NHA designation.

10.5 Sediments

It is known that chemical constituents associated with UGEE flowback and production waters can partition from the surface water and accumulate in associated sediments near points of discharge, notably metals, radionuclides and selected high molecular weight organics. As reported by Warner *et al*. (2013a) and Vengosh *et al.* (2014), radium isotopes are the principal UGEE-related contaminants of concern in sediments. Although contamination of sediments is primarily considered a local-scale issue in the literature, it could become a concern at the catchment-scale in a scenario where multiple drill pads are active.

A database of metals and selected NORM in stream sediments was generated for the NCB as part of the Tellus Border project (Gallagher *et al.*, 2015a) and results were summarised in Section 2. Radium isotopes were not included in the analyses. For this reason, further analyses of radium isotope activity levels are recommended.

In the CB, equivalent datasets to those generated by the Tellus Border project do not yet exist but is planned. It is, therefore, proposed that an overall baseline value for radioactivity be determined by screening for gross alpha and gross beta activity, broadly following screening procedures adopted and described by the Tellus Border project (e.g. Johnson, 2005; Smyth, 2007). Where relevant screening levels are exceeded, stream sediments samples would be further analysed for radium isotopes (e.g. Ra-226 and Ra-228).

11 Recommended Baseline Monitoring – NCB

This section provides a recommended baseline monitoring programme for the NCB. The information is presented broadly in the same order as the discussion on design approach in Section 10.

11.1 Groundwater Quality

Existing wells and springs that are recommended for groundwater quality monitoring are shown in Figure 11.1 and Figure 11.2, respectively, and are summarised in Table 11.1 and Table 11.2.

11.1.1 New monitoring wells

The drilling and installation of approximately 10 new monitoring wells would be recommended in the NCB. These are needed to improve the spatial coverage for characterisation and monitoring of dissolved methane (and other natural gas constituents) in groundwater. Approximate locations and justification for candidate new borehole sites are shown in Figure 11.3 and provided in Table 11.3. The selection of sites is based on the following principles:

- Wells should be sited in areas where existing and suitable wells were not identified during the ground-truthing survey of existing groundwater abstraction points. Wells should also provide vertical coverage of groundwater conditions in the bedrock formations that are of hydrogeological significance to UGEE in the NCB, not just the primary Dartry aquifer.
- Wells should be included and sited in general areas that have been flagged as “prospects” for UGEE activity, as presented by exploration companies in public forums or as described in exploration files held by the Petroleum Affairs Division of the DCENR (in Ireland) and the GSNI (in Northern Ireland). As summarised in Section 2, the main prospects have been flagged in the following areas: Kilcoo Cross, Arigna/Drumkeeran, and Dowra.
- Wells should be sited to target mapped fault zones with ‘considerable’ (>100 m) vertical displacements, preferably juxtaposing the main shale formations of the Tyrone Group against sandstone or limestone formations.
- It is proposed that two wells be drilled into the Lackagh Sandstone Formation of the Leitrim Group to be able to document the chemical and isotopic signature of natural gas constituents (notably methane) that are associated with coal beds of the Connacht Coalfield west of Lough Allen.

As is the case with any drilling operation, there is an inherent risk that some of the drilled boreholes could prove to be ‘dry’ (i.e. of low yield and potentially unsuited for sampling). Risks can be reduced if targets for drilling are sited on or near faults, especially those involving brittle rock types, due to due to the potential for enhanced fracture permeability. Still, there is no guarantee that any borehole drilled at any given location would be ‘productive’. Productive, high-yielding wells are not a requirement for sampling purposes to meet project objectives, but ‘dry’ and low-yielding wells can complicate sampling procedures and the representivity of results.

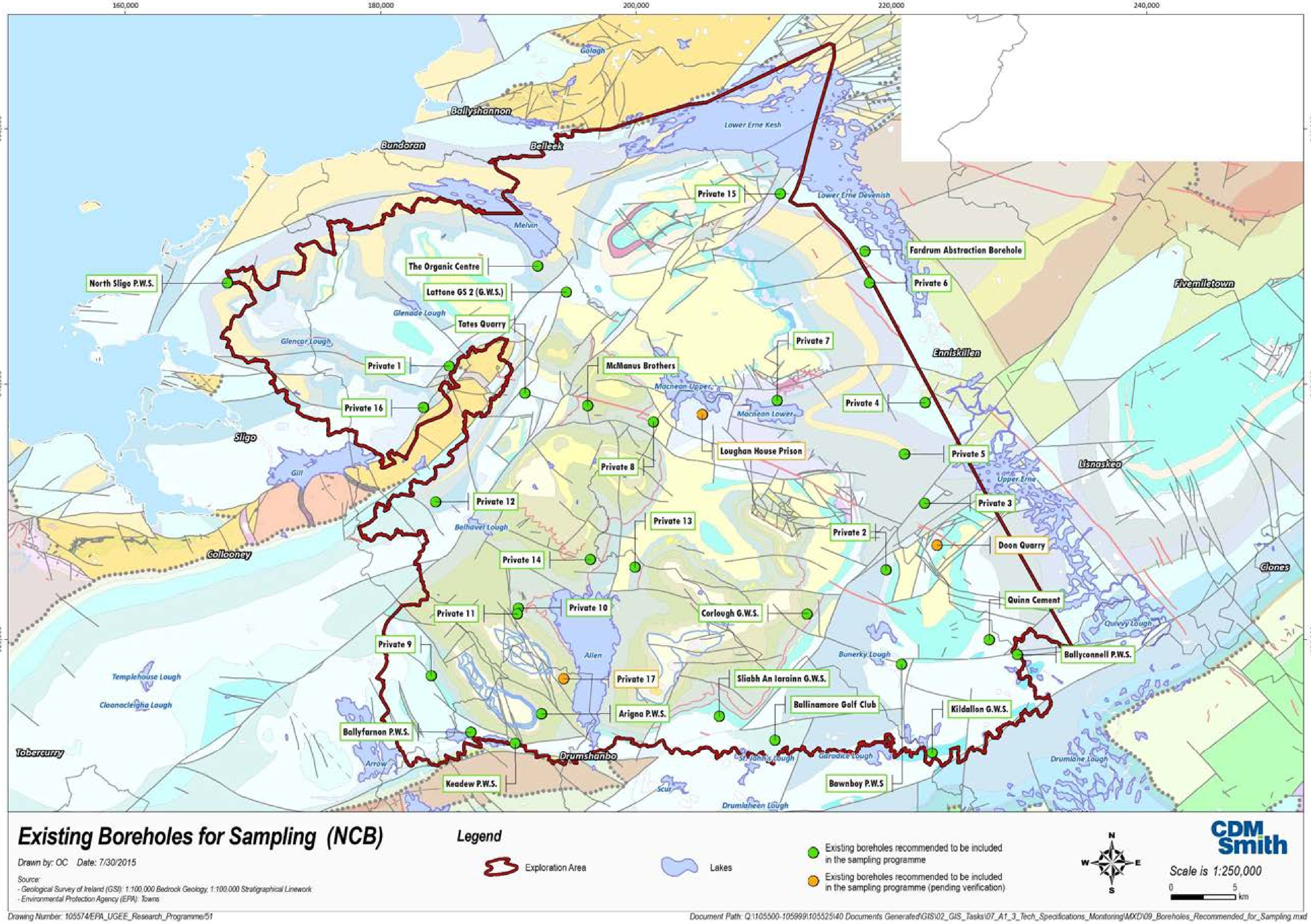


Figure 11.1. Existing wells recommended for sampling – NCB study area.

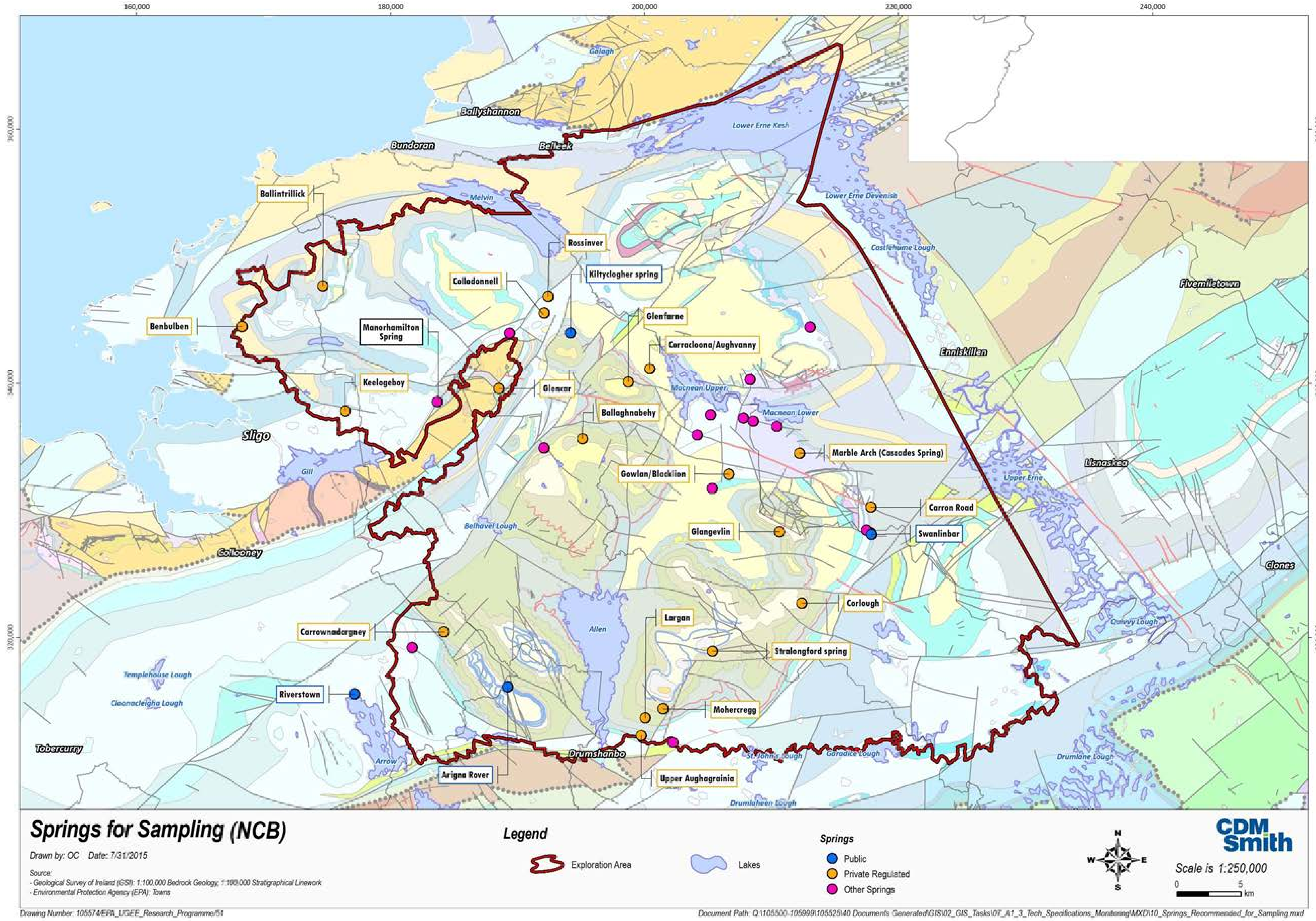


Figure 11.2. Springs recommended for sampling – NCB study area.

Table 11.1. Details of existing wells recommended for sampling – NCB study area

Supply name	Supply type	County	Easting	Northing	Aquifer type	Bedrock (code)	Bedrock formation[a]	Justification for sampling	Comments	Minor works
Arigna P.W.S.	P.W.S.	Roscommon	192609	314178	Pu	GO	Gowlaun Shale	PWS maintained by Roscommon Co. Co.	The borehole is becoming obsolete in May/June 2015 and communication with Roscommon Co. Co. will be necessary to arrange access/sampling. Depending on plans to remove existing pump, the borehole may have to be sampled using a separate pump supplied by project.	Discuss future access and pumping arrangements with Local Authority/Install well cap.
Ballinamore Golf Club	Private	Leitrim	210884	312110	Rkc	BM	Ballymore Limestone	Straightforward access with limited minor works required.	One borehole used for golf clubhouse. The water used for the golf course is abstracted from the river.	Construct alternative well cap to prevent surface water ingress.
Ballyconnell P.W.S.	P.W.S.	Cavan	229878	318801	Rkc	DA	Dartry Limestone	PWS maintained by Cavan Co. Co.	Two boreholes exist in this recently developed plant. The boreholes are located in close proximity to a lake.	Assess influence of surface water from adjacent lake.
Ballyfarnon P.W.S.	P.W.S.	Roscommon	187068	312722	Rkc	BKU	Bricklieve Limestone (upper)	PWS owned by Roscommon Co. Co. A new borehole has recently been constructed.	The treatment plant which is maintained by Glan Agua is currently being upgraded. The new borehole would be the primary abstraction point with the old borehole becoming a backup.	–
Bawnboy P.W.S.	P.W.S.	Cavan	220809	318039	Rkc	DA	Dartry Limestone	PWS owned by Cavan Co. Co. Site is also part of EPA's WFD groundwater monitoring network.	Two boreholes are present onsite – active borehole switched every 3–4 weeks. The plant is maintained by EPS Group.	–
Corlough G.W.S.	G.W.S.	Cavan	213419	221990	Pu	DE	Dergvone Shale	Two auxiliary boreholes constructed to a high standard regulated by Cavan Co. Co.	The boreholes are not currently is use due to 'bad taste'. Caretaker turns on pumps every couple of weeks to keep in working order.	Assess integrity of pumps.
Doon Quarry	Private	Fermanagh	223597	327374	2A	DA	Dartry Limestone	Two boreholes used for quarry activities pumping from main aquifer.	One borehole located in above ground chamber (uncovered) and the other located in a below ground chamber (covered)	Install raw water sampling tap and wellhead cover/verify borehole details.
Fardrum	Private	Fermanagh	217934	350418	2A	BS	Ballyshannon Limestone	Pumps water from Ballyshannon Lst	Unable to visit during abstractions survey.	To be verified.
Keadew P.W.S.	P.W.S.	Roscommon	190551	311856	Rkc	BK	Bricklieve Limestone	PWS maintained by Roscommon Co. Co. Site is also part of EPA's WFD groundwater monitoring network.	The borehole is becoming obsolete in May/June 2015 and communication with Roscommon Co. Co. would be necessary to arrange access/sampling. Depending on plans to remove existing pump, the borehole may have to be sampled using a separate pump supplied by project.	Discuss future access and pumping arrangements with Local Authority.
Kildallon G.W.S.	G.W.S.	Cavan	223220	311109	Rkc	DAcr	Dartry Limestone	Two boreholes supplying a GWS with limited minor works required.	Both boreholes are located in below ground chambers approximately 300 m away from the treatment house.	Install raw water sampling tap at wellhead.
Lattone GS 2 (G.W.S.)	G.W.S.	Leitrim	194558	347211	Rkc	DA	Dartry Limestone	One borehole with limited minor works required located on an important aquifer.	One house on scheme. The wellhead is located in a small above ground chamber/shed located in front of a domestic dwelling.	Install raw water sampling tap at wellhead (TBC).
Loughan House Prison	Private	Cavan	205197	337602	Rkc	DAmk	Dartry Limestone	Located in the centre of the study area, three boreholes supply a large prison population.	Permission to survey and sample was granted after the conclusion of the abstractions survey.	Not yet visited. To be verified.
McManus Brothers	Private	Leitrim	196217	338315	Pu	DE	Dergvone Shale	Artesian borehole with apparent high levels of sulphur. Limited minor works are required.	The wellhead is located in a shed on the premises. The raw water sampling tap is currently a black discharge pipe.	Install raw water sampling tap.
North Sligo P.W.S.	P.W.S.	Sligo	168008	347932	Ll	BN	Bundoran Shale	PWS operated by Sligo Co. Co. Recently constructed borehole to best practice standards. Large abstraction.	The wellhead is located in an above ground chamber in front of the treatment plant.	Install raw water sampling tap.
Private 1	Private	Leitrim	185374	341427	Ll	GC	Glencar Limestone	One borehole used for quarry activities located in an area where a limited number of boreholes exist.	The borehole is located within the quarry yard. Abstraction rate varies depending on production levels. The raw water tap is currently a black discharge pipe.	Construct adequate surface water drainage/Install raw water sampling tap and well cap.
Private 10	Private	Leitrim	190805	322447	Pl	CN	Carraun Shale	Domestic borehole supplying one house with limited minor works required.	The wellhead is located in a below ground chamber in the garden. A new pump was installed approximately four years ago.	Survey wellhead/Install raw water sampling tap (TBC).
Private 11	Private	Leitrim	190726	322010	Pu	DE	Dergvone Shale	Domestic well recently constructed by Leitrim Co. Co.	The wellhead is located in an above ground chamber in garden and water is pumped to adjacent treatment shed. Appropriate tools required to open manhole in order to access wellhead.	Install raw water sampling tap/survey wellhead.
Private 12	Private	Leitrim	184296	330779	Ll	BB	Benbulben Shale	Domestic borehole with no minor works required. Located in an area with few other wells.	The borehole is located in a small above ground wooden chamber at the front of the domestic dwelling.	–

Supply name	Supply type	County	Easting	Northing	Aquifer type	Bedrock (code)	Bedrock formationa	Justification for sampling	Comments	Minor works
Private 13	Private	Leitrim	199927	325636	Ll	BE	Bellavally Shale	Domestic borehole supplying one house with limited minor works required.	The wellhead is located in a chamber below ground at the front of the domestic dwelling.	Install raw water sampling tap.
Private 14	Private	Leitrim	196437	326252	Pl	CN	Carraun Shale	New borehole constructed to a high standard with limited minor works required.	The pump is due to be connected to power in mid-2015. The borehole is located in a below ground chamber in the middle of a private laneway.	Verify that pump is connected to power prior to sampling/Install adequate well cover (TBC).
Private 15	Private	Fermanagh	211314	354928	2C	GC	Glencar Limestone	Two private boreholes used to supply water to a large farm. It is the only borehole identified in the NE section of the study area.	The boreholes are located in below ground chambers in the farmyard and there is a possibility of animals/machinery in close proximity to well covers.	–
Private 16	Private	Leitrim	183344	338169	Rkc	DAmk	Dartry Limestone	One recently constructed domestic borehole with no minor works required.	The borehole is located beneath a manhole at the rear of the house. The well is not currently in use – should be connected by late-2015.	Confirm borehole/pump is operating.
Private 17	Private	Roscommon	194338	316920	Pu	DE	Dergvone Shale	Located west of Lough Allen in an area with few identified wells.	The borehole has been used as a monitoring well by the adjacent quarry in the past. In order to survey the borehole and request permission from the well owner, communication with the Quinn Group is recommended.	Not yet defined.
Private 2	Private	Cavan	219599	325435	Ll	mk	Mudbank Lst	Farm borehole used for livestock suppl. Located in area where a data gap would otherwise exist.	One borehole located in a below ground chamber in farmyard – possibility of animals/farm machinery in close proximity to well cover	Possibly construct superior wellhead protection (TBC).
Private 3	Private	Fermanagh	222625	330655	2C	BB	Benbulben Shale	One borehole supplying water to farm and domestic dwelling. No minor works are required.	The wellhead is located at ground level in the yard at the rear of the domestic dwelling.	–
Private 4	Private	Fermanagh	222660	338549	2A	BS	Ballyshannon Limestone	One borehole supplying a large farm with limited minor works required.	The borehole is located on a hill above the farmyard. The wellhead is located in an above ground chamber (uncovered).	Install well cap.
Private 5	Private	Fermanagh	221038	334511	2C	BB	Benbulben Shale	Private borehole with limited minor works required is used for supplying water to farm livestock.	The wellhead is located in an above ground cement chamber in garden. Uncertainty exists to whether the raw water tap is located before or after filtration.	Verify presence/location of raw water sampling tap.
Private 6	Private	Fermanagh	218301	347949	2A	BS	Ballyshannon Limestone	One borehole supplying a large farm with limited minor works required.	The wellhead is located in the corner of the farmyard. No wellhead protection currently exists.	Install well cap/wellhead protection.
Private 7	Private	Fermanagh	211053	338703	2C	GC	Glencar Limestone	New borehole constructed to a high standard with limited minor works required.	The wellhead is located in a below ground chamber at rear of the domestic dwelling.	Verify presence of raw water sampling tap.
Private 8	Private	Leitrim	201360	337047	Lm	GD	Glenade Sandstone	A domestic borehole located in the centre of the study area and limited minor works are required.	The borehole is located in a shed in the garden, adjacent to the domestic dwelling.	Install raw water sampling tap.
Private 9	Private	Sligo	183956	317164	Rkc	BKU	Bricklieve Limestone (upper)	One domestic borehole with limited minor works required. Located in an area where a data gap would otherwise exist.	The wellhead is located in an above ground chamber (uncovered) adjacent to the house. The raw water sampling tap is currently the kitchen tap.	Install well cap/raw water sampling tap (TBC).
Quinn Cement	Private	Cavan	227683	319966	Rkc	DA	Dartry Limestone	Two boreholes with limited minor works required abstracting large volumes of water.	The wellheads are located in designated sheds on the premises.	Install raw water sampling tap/verify borehole details.
Riverstown P.W.S.	P.W.S.	Sligo	177159	315584	Rkc	BKL	Bricklieve Limestone (lower)	Two auxiliary boreholes located outside the study area but groundwater pathways may exist due to karst.	–	Not yet defined.
Sliabh An Iarainn G.W.S.	G.W.S.	Leitrim	206537	313987	Rkc	BK	Bricklieve Limestone	One borehole constructed to a high standard supplying a GWS.	The wellhead is located in an above ground chamber adjacent to the treatment plant. Surface water had pooled within the chamber at the time of the abstractions survey possibly due to recent snowfall.	Construct adequate surface water drainage.
Tates Quarry	Private	Leitrim	191307	339272	Rkc	DA	Dartry Limestone	One borehole pumping from an important aquifer.	Artesian well. No pump installed – plans to install pump in 2015/2016. Ongoing communication with well owner necessary. Possibility that sampling may be conducted using a submersible pump.	Assess borehole integrity/Discuss future pumping arrangements with well owner.
The Organic Centre	Private	Leitrim	192296	349278	Ll	BB	Benbulben Shale	One borehole constructed to a high standard with limited minor works required.	The wellhead is located in an above ground chamber on the premises.	Verify presence of raw water sampling tap/install raw water sampling tap.

[a]As indicated by published geological maps of GSI and GSNI. Deeper wells could intersect and pump water from more than a single formation.

2 A, highly productive aquifer; 2B, low productive aquifer; 2C, low productivity aquifer.

Table 11.2. Details of springs recommended for sampling – NCB study area

Spring name	Classification	County	Easting	Northing	Bedrock formation	Aquifer type
Aghaboy	Other Spring	Fermanagh	217842	328253	Benbulben Shale	Ll
Arigna Rover	Public	Roscommon	189237	316144	Lackagh Sandstone	Pl
Ballaghnabehy	Private Regulated	Leitrim	195111	335667	Briscloonagh Sandstone	Pl
Ballintrillick	Private Regulated	Sligo	174687	347699	Benbulben Shale	Ll
Barran rising	Other Spring	Cavan	204124	335933	Dartry Limestone	Rkc
Benbulben	Private Regulated	Sligo	168320	344499	Mullaghmore Sandstone	Lm
Boho Rising	Other Spring	Fermanagh	213030	344440	Dartry Limestone	2A
Brackymore	Other Spring	Leitrim	189387	343960	Dartry Limestone	Rkc
Carron road	Private Regulated	Fermanagh	217854	330286	Benbulben Shale	2B
Carrownadargney	Private Regulated	Sligo	184203	320458	Dergvone Shale	Pu
Coolodonnell	Private Regulated	Leitrim	192114	345559	Dartry Limestone	Rkc
Corlough	Private Regulated	Cavan	212371	322732	Gowlaun Shale	Pu
Corracloona/Aughvanny	Private Regulated	Leitrim	200425	341172	Glenade Sandstone	Lm
Glangevlin	Private Regulated	Cavan	210638	328338	Briscloonagh Sandstone	Pl
Glencar	Private Regulated	Leitrim	188542	339598	Ballyshannon Limestone	Rkc
Glenfarne	Private Regulated	Leitrim	198738	340100	Briscloonagh Sandstone	Pl
Gowlan/Blacklion	Private Regulated	Cavan	206650	332850	Dartry Limestone	Rk
Hanging Rock rising	Other Spring	Fermanagh	210434	336626	Glencar Limestone	2C
Keelogeboy	Private Regulated	Sligo	176433	337842	Dartry Limestone	Rkc
Kiltyclogher spring	Public	Leitrim	194177	343985	Carraun Shale	Pl
Largan	Private Regulated	Leitrim	200075	313696	Dergvone Shale	Pu
Manorhamilton Spring	Other Spring	Leitrim	183683	338570	Dartry Limestone	Rkc
Marble Arch Cascades	Private Regulated	Fermanagh	212200	334500	Dartry (Knockmore Member)	2A
Marlbank Rising	Other Spring	Fermanagh	208590	337060	Dartry (Knockmore Member)	2A
Mohercregg	Private Regulated	Leitrim	201478	314420	Gowlaun Shale	Pu
Mrs. Creamers Spring	Other Spring	Leitrim	192090	334912	Briscloonagh Sandstone	Pl
Mullyard Rising	Other Spring	Fermanagh	208340	340300	Dartry (Knockmore Member)	2A
Riverstown	Public	Sligo	177159	315584	Bricklieve Limestone (lower)	Rkc
Rossinver	Private Regulated	Leitrim	192431	346889	Dartry Limestone	Rkc
Saint Patricks Well	Other Spring	Leitrim	202245	311749	Bricklieve Limestone	Rkc
Shannon pot	Other Spring	Cavan	205325	331753	Meenymore Formation	Ll
Spring D	Other Spring	Sligo	181,710	319,200	Bricklieve Limestone (upper)	Rkc
Stralongford spring	Private Regulated	Leitrim	205351	318909	Gowlaun Shale	Pu
Sumera	Other Spring	Fermanagh	217496	328467	Dartry Limestone	2A
Swanlinbar	Public	Cavan	217893	328131	Benbulben Shale	Ll
Ture rising	Other Spring	Cavan	207802	337294	Dartry (Knockmore Member)	Rkc
Upper Aughagrainia	Private Regulated	Leitrim	199766	312314	Bellavally Shale	Ll
White Fathers Cave	Other Spring	Cavan	205193	337537	Dartry Limestone	Rkc

2 A, highly productive aquifer; 2B, low productive aquifer; 2C, low productivity aquifer.

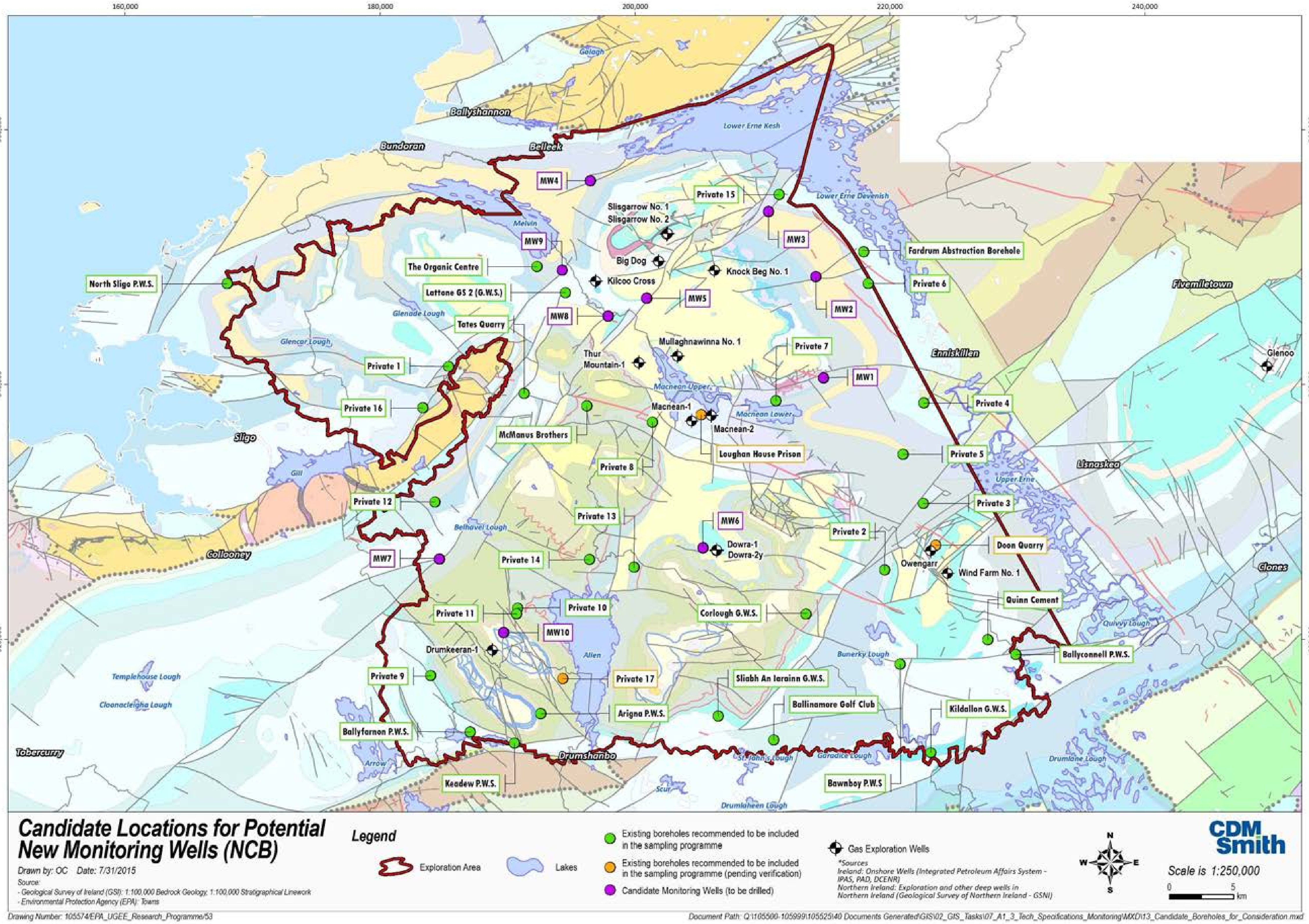


Figure 11.3. Candidate locations for recommended new monitoring wells.

Table 11.3. Candidate new monitoring wells – NCB study area

Candidate monitoring well	Easting	Northing	Justification
MW1	214,800	340,500	Targets Dartry aquifer at the base of the West Fermanagh Scarplands SAC. Location is of hydrogeological interest. A structurally complex area – the well would be drilled in fault zone at contact between Benbulben Shale and Dartry Limestone. The location marks the intersection between NW-SE reverse fault and E-W Belcoo Fault, adjacent to a mapped dyke trajectory. MW1 is a location of hydrogeological interest, but given the proximity to private well #7, is considered the least critical of the indicated new wells in terms of (receptor-focused) baseline monitoring.
MW2	214,200	348,500	East of West Fermanagh Scarplands, targeting the Mullaghmore Sandstone. Well would be drilled at or near the E-W faulted contact between Mullaghmore Sandstone and Benbulben Shale.
MW3	210,500	353,600	Well targets the north-eastward continuation of the Kilavil-Belhavel Fault on northeast-side of exploration area at transition between Ballymote Syncline and Lough Allen Basin subdivisions (see Section 2.8). The fault displays an apparent vertical displacement of several hundred metres. Private well is located nearby and pumps from the Ballyshannon Limestone. The new wells would target the faulted contact between the Mullaghmore Sandstone and Dartry Limestone.
MW4	196,500	356,000	New well would cover the NW corner of the Kilcoo Cross ‘prospect area and the northern extremity of the study area where suitable private wells have not been located. The groundwater potential is considered low due to the shale formations which dominate this area. However, there is a paucity of data, and the new well would be drilled at the intersection of faults that juxtapose the Bundoran Shale, Mullaghmore Sandstone and Benbulben Shale against one another, and is therefore of hydrogeological interest.
MW5	189,705	320,534	Located in Kilcoo Cross prospect area. Located between Kilcoo Cross, Big Dog and Mullanawinna exploration wells. Targets the intersection of significant faults that juxtapose the Glenade Sandstone and Dartry Limestone.
MW6	205,355	327,183	Located in Dowra prospect area, near and downdip of the Dowra gas exploration wells. Located in a window of Meenymore Sandstone. Well would likely be completed in Meenymore but could extend through to Dartry depending on thickness of the Meenymore.
MW7	184,650	326,300	Located at western margin of the Drumkeeran prospect in the Lough Allen Basin, on the Kilavil-Belhavel Fault which at the indicated position juxtaposes the Lisgorman Shale (presumably Benbulben Shale equivalent), Dartry Limestone and Carraun Shale, thus displaying a considerable vertical displacement.
MW8	197,888	345,381	Located between Kilcoo Cross and Thur Mountain exploration wells. Located at intersection of faults between Dartry Limestone and Glenade Sandstone. Opposing dips across fault indicated by mapped structural linework (70 deg. NW and 16 deg. SW).
MW9	194,296	348,998	Located at western end of Kilcoo Cross prospect area. Located at the continuation of the North OX Mountain Fault, which juxtaposes the Dartry Limestone and Benbulben Shale.
MW10	200,919	346,802	Located in Drumkeeran prospect area. The objective is to sample groundwater of the Lackagh Sandstone to document the Connacht Coalfield ‘signature’ of groundwater quality, including natural gas fingerprint of the coalfield. The actual location of drilling could be on either of the two hills west of Lough Allen, thus the location shown is ‘indicative’ until site selection from field inspection is made.

Candidate wells MW2 and MW4 are considered the higher risk cases in this regard. MW10 in the Arigna/Drumkeeran area would be located on high ground, and thus invariably needs to intersect water-bearing fractures that are likely to reflect localised (perched) conditions only. Accordingly, it is anticipated that well depth would be shallow, and several attempts may be necessary in vicinity to obtain a suitable well for sampling purposes. Despite the risks of drilling ‘dry boreholes, obtaining groundwater samples from the Coalfield rocks to document the natural gas signature in groundwater is considered relevant to the UGEE JRP.

11.1.2 Sampling and measurement

Analytical parameters and frequencies of sampling are presented in Section 13. Wells that are not already equipped for pumping would have to be sampled using portable equipment which includes a submersible pump and generator. The majority of existing bedrock supply wells are open boreholes or fitted with slotted PVC pipe along their lengths. Accordingly, groundwater samples represent inflows from potentially several discrete borehole intervals, and are thus ‘depth-averaged’ samples that describe the groundwater quality that is used or accessed for water supply purposes.

It is recommended to equip a subset of wells and the karst springs identified in Figure 11.4 with multi-parameter probes to automatically record water levels (as appropriate in wells), pH, temperature and EC for the baseline monitoring period. This is recommended in order to document ranges of storm and seasonal variability of named field parameters, recognising that extreme events may not be captured within the timeframe of a baseline monitoring programme. Springs in the Cuilcagh, Geevagh, and West Fermanagh karst terrains are represented in the recommended monitoring in the NCB.

On the use of multi-parameter probes, there are two items that would require careful attention:

(a) A tendency for biofouling of instruments to occur, especially during summer months, which may affect automatic readings in time. Hence, the use of probes requires periodic checks and maintenance, possibly even replacement; and

(b) In wells that are not actively pumping, such as new monitoring wells, the depth that the probes are installed to can be expected to influence what is recorded. Transducers should be installed to depth where most of the flux of water in respective boreholes occur, which is determined from observation and logging during drilling. This is particularly important in karstified limestones, where conduits can act as significant preferential pathways of water movement.

Judgement about yield and suitability for sampling purposes is case-specific based on results of drilling and hydraulic testing. Risks can be minimised by siting well drilling in areas of greater potential for enhanced fracture permeability, i.e. faults and brecciated dyke margins.

Each site would have to be visited and field verified for suitability of drilling, establishing contact with landowners, and site access. Alternate well sites would have to be determined and proposed if the original sites cannot be secured or are deemed unsuitable.

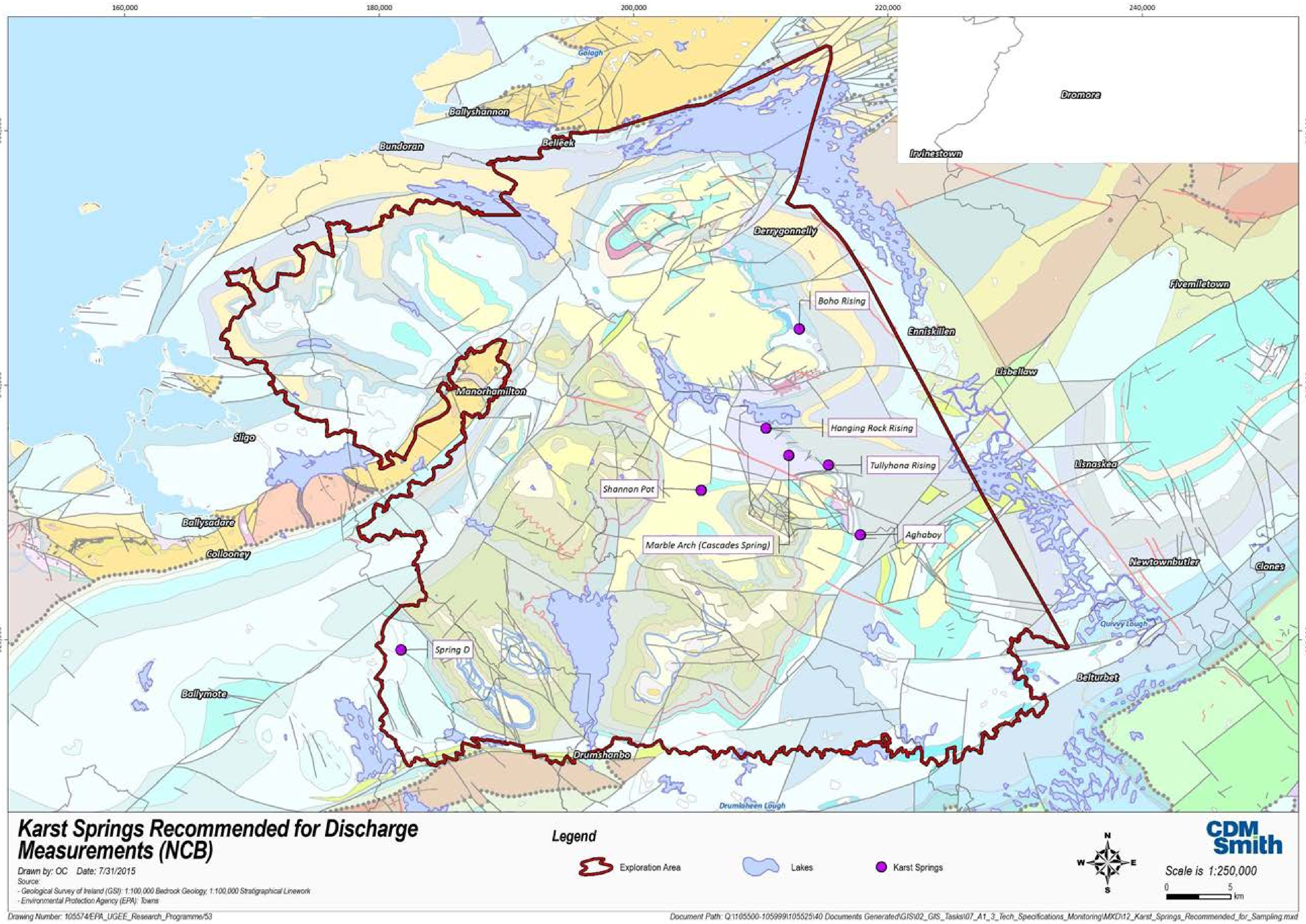


Figure 11.4. Karst springs recommended for discharge measurements – NCB study area.

11.1.3 Abandoned gas exploration wells

Fourteen abandoned gas exploration wells were drilled in the past within the UGEE licence area in the NCB. These wells represent potential pathways for gas migration. It is recommended that their current status be verified by inspection as described in Section 10.1.3 of the current report. The purpose is to determine if any of the wells can be accessed as potential monitoring locations. The wells represent potential pathways for gas migration and their current status should be verified. Only half of the wells are expected to be potentially accessible based on available “temporary abandonment” sketches contained in well completion reports, and ground-truthing is recommended to ascertain facts.

It is also recommended that passive soil gas monitoring be considered in the baseline monitoring programme, pending field verification at each site.

11.2 Surface Water

Figure 11.5 and Figure 11.6 show the proposed river and lake monitoring stations, respectively, as well as their locations within respective surface water catchments. Analytical parameters and frequencies of sampling are presented in Section 9.

Table 11.4 presents WFD protected areas associated with each of the 32 proposed river monitoring locations and describes each site. The main sensitive surface water receptors are the pearl mussel in the Swanlinbar River, salmonid waters as designated, shellfish waters and bathing waters on the coast of Sligo, and a variety of SACs/SPAs habitat types including lakes and coastal bays. Table 11.5 presents the WFD protected areas associated with each of the 15 proposed lake monitoring locations and describes each site. The lakes are either drinking water supplies or part of a WRD protected area SAC/SPA.

11.3 GWDTEs

Three turloughs are recommended for water quality sampling:

- Roosky-Fardrum Turlough (Ballyshannon Limestone); and
- Loughs Augh and White (Bricklieve Limestone).

The former is sampled from an existing monitoring well which connects to karst conduits that support the turlough hydrology. The latter two are considered representative of the cluster of turloughs that have been noted by both the GSI and the NPWS in the Geevagh/Lough Arrow area. As they represent groundwater-fed lakes, they would be sampled as surface waters, following procedures that apply for lakes. The exception is Rooskey-Fardrum, which would be sampled from an existing monitoring wells that is known to intersect the same conduit system which supplies groundwater to the turlough. Accordingly, sampling for methane gas would be attempted in this borehole, although it is recognised that degassing of gas may occur if the conduit system is under unconfined conditions.

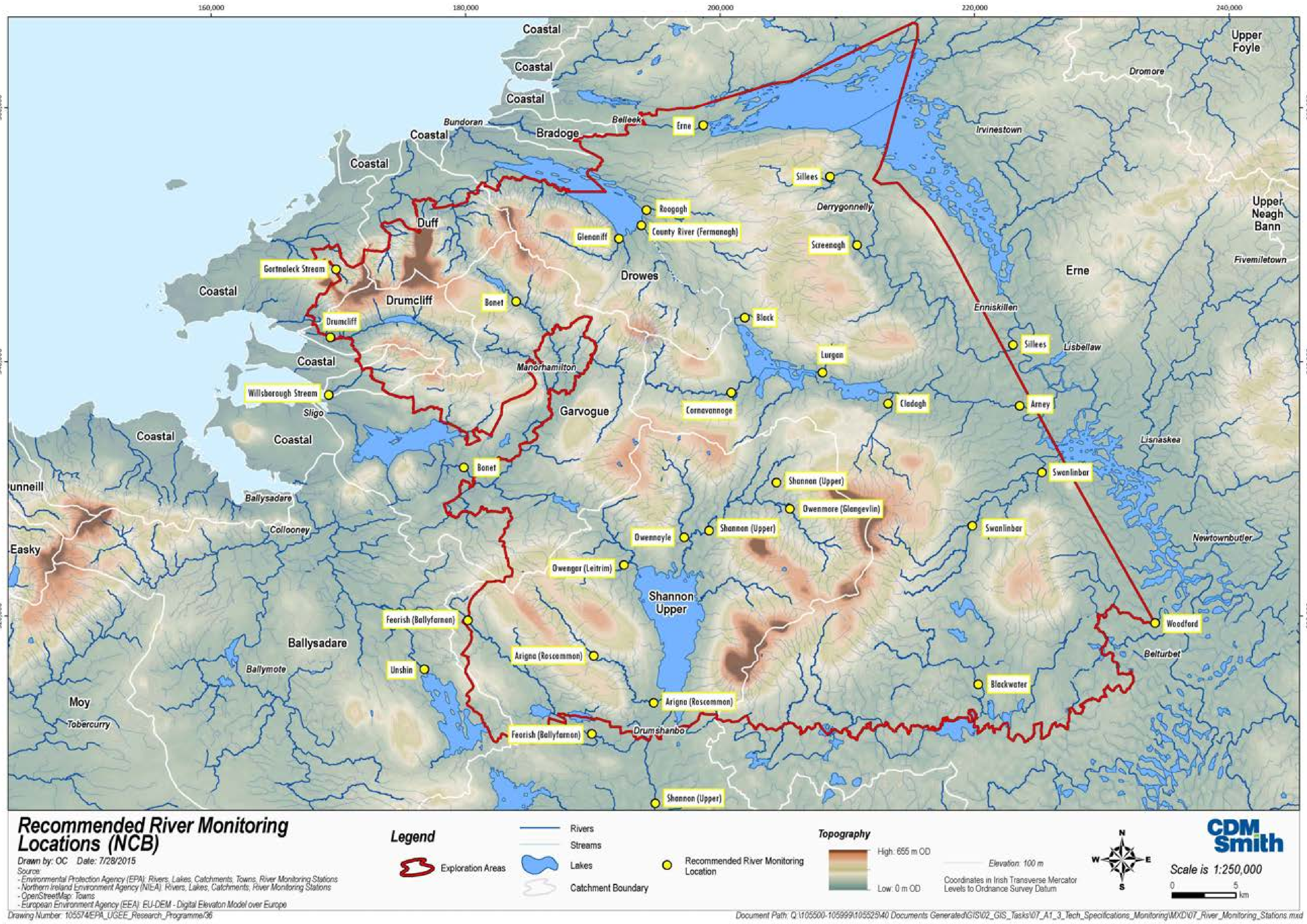


Figure 11.5. Recommended stream monitoring locations – NCB study area.

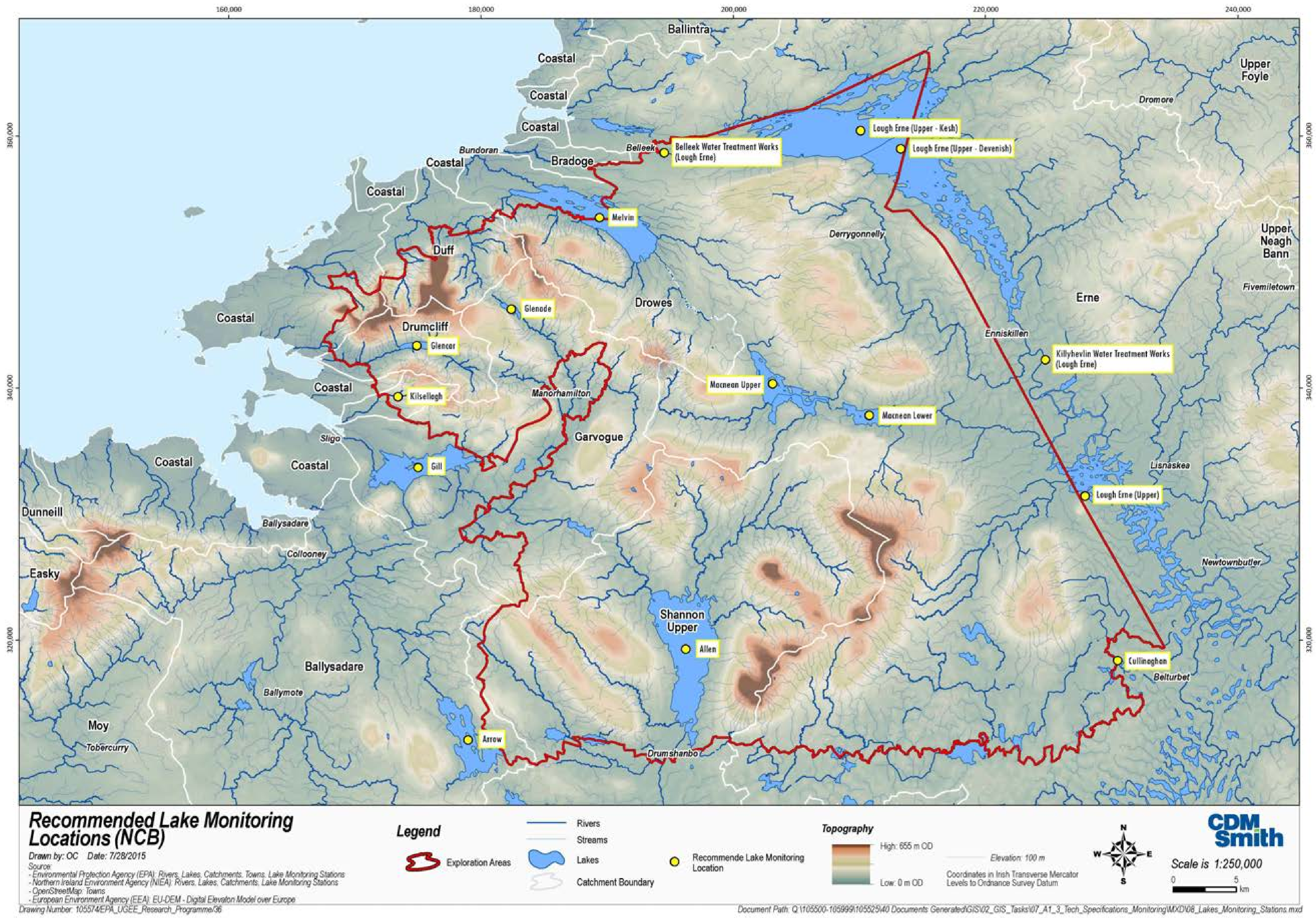


Figure 11.6. Recommended lake monitoring locations – NCB study area.

Table 11.4. Details of recommended stream monitoring locations – NCB study area

Water body name	WFD station ID	Station name	Catchment name	WFD Protected Areas						Protected species	Description	Easting	Northing
				Drinking water	Salmonid	Shellfish waters	Bathing waters	WFD SAC	WFD SPA	Pearl mussel			
Unshin	RS35U010100	Bellarush Bridge	Ballysadare	N	N	N	N	N	N	N	DS Lough Arrow and study area	176765	315778
Glenaniff	RS35G020200	Bridge U/S Lough Melvin	Drowes	N	N	N	N	N	N	N	US of Lough Melvin	192042	349680
County River (Fermanagh)	UKGBNIF10657	County River (Fermanagh) At County Bridge	Drowes	N	Y	N	N	Cycle 1/Cycle 2	N	N	US Lough Melvin	193814	350714
Drumcliff	RS35D040300	Br 2 Km U/S Drumcliff Bridge	Drumcliff	N	N	Y	Y	Cycle 2	Cycle 2	N	DS Drumcliff Catchment, Sligo Bay shellfish waters, Sligo Bay bathing waters	169376	341908
Blackwater (Newtowngore)	RS36B040400	Br D/S Blackwater Br	Erne	N	N	N	N	N	N	N	DS Blackwater River	220292	314598
Cornavannoge	RS36C040600	Br U/S L Macnean	Erne	N	N	N	N	N	N	N	DS of Cornavannoge River, US Lough Macnean	200889	337557
Swanlinbar	RS36S010300	0.6Km D/S Swanlinbar Br	Erne	N	N	N	N	N	N	Y	US location, pearl mussel river	219830	327107
Roogagh	UKGBNIF10654	Roogagh River At Garrison	Erne	N	Y	N	N	Cycle 1/Cycle 2	N	N	Glen River, US Melvin Lough	194206	351938
Erne	UKGBNIF10661	Erne River At Rosscor Viaduct	Erne	Y	Y	N	N	N	N	N	River Erne, US Lough Erne	198687	358614
Woodford	UKGBNIF10734	Woodford River At Aghalane	Erne	N	Y	N	N	Cycle 1/Cycle 2	Cycle 1/Cycle 2	N	DS Woodford River -> Upper Lough Erne	234179	319446
Swanlinbar	UKGBNIF10735	Swanlinbar River At Thompsons Bridge	Erne	N	Y	N	N	Cycle 1/Cycle 2	Cycle 1/Cycle 2	N	DS Swanlinbar River -> Upper Lough Erne	225287	331299
Arney	UKGBNIF10736	Arney River At Drumane Bridge	Erne	N	Y	N	N	Cycle 1/Cycle 2	Cycle 1/Cycle 2	N	DS Arney River -> Upper Lough Erne	223565	336522
Black	UKGBNIF10743	Black River At B52 Road Bridge	Erne	N	Y	N	N	N	N	N	DS Black River, US Macnean Lough	201935	343475
Cladagh	UKGBNIF10744	Cladagh River At Gorteen	Erne	N	Y	N	N	N	N	N	DS Cladagh River	213207	336703
Sillees	GBNIF10906	Sillees River At Dresternan Bridge	Erne	N	Y	N	N	N	N	N	US Sillees River	208644	354564
Sillees	UKGBNIF10746	Sillees River At Drumkeen New Bridge	Erne	Y	N	N	N	N	N	N	DS Sillees River & study area, US Erne River	223020	341306
Screenagh	UKGBNIF10752	Screenagh River At Aghakeeran	Erne	N	N	N	N	Cycle 1/Cycle 2	N	N	DS West Fermanagh Scarplands SAC	210767	349164
Lurgan	UKGBNIF10757	Lurgan River At Belcoo	Erne	N	Y	N	N	N	N	N	DS Lurgan River, US Macnean Lough	208056	339140
Bonet	RS35B060050	Bridge 1.5 Km D/S Glenade L	Garvogue	N	N	N	N	N	N	N	US Bonet River	183985	344737
Bonet	RS35B060600	1.8 Km D/S Dromahaire Bridge	Garvogue	N	N	N	N	N	N	N	DS study area – US Lough Gill	179877	331674
Arigna (Roscommon)	RS26A020100	At Altagowlan School	Shannon Upr	N	N	N	N	N	N	N	US Arigna mines	190056	316865
Arigna (Roscommon)	RS26A020300	Mount Allen Bridge	Shannon Upr	N	N	N	N	N	N	N	DS Arigna mines, US Lough Allen	194772	313128
Feorish (Ballyfarnon)	RS26F020050	Bridge N. Of Coolemoneen	Shannon Upr	N	N	N	N	N	N	N	US location for Feorish River	180204	319654
Feorish (Ballyfarnon)	RS26F020400	Bridge 1.5 Km S.W. Of Keadew	Shannon Upr	N	N	N	N	N	N	N	DS of study area	189919	310705
Owengar (Leitrim)	RS26O020200	Bridge At Annaghgerry	Shannon Upr	N	N	N	N	N	N	N	DS Owengar, US Lough Allen	192449	323990
Owenmore (Glangevlin)	RS26O030300	Br W Of Legnagrow Lough	Shannon Upr	N	N	N	N	N	N	N	DS Owenmore River, US Shannon	205471	328432
Owennayle	RS26O050100	Br D/S Owennayle Br	Shannon Upr	N	N	N	N	N	N	N	DS Owennayle, US Shannon	197167	326197
Shannon (Upper)	RS26S020100	Shannon Br Derrylahan	Shannon Upr	N	N	N	N	N	N	N	US Shannon, close to the source of river	204442	330496
Shannon (Upper)	RS26S020300	Dowra Br	Shannon Upr	N	N	N	N	N	N	N	Shannon River US Lough Allen	199137	326735

Water body name	WFD station ID	Station name	Catchment name	WFD Protected Areas						Protected species	Description	Easting	Northing
				Drinking water	Salmonid	Shellfish waters	Bathing waters	WFD SAC	WFD SPA	Pearl mussel			
Shannon (Upper)	RS26S020500	Battle Br	Shannon Upr	Y	N	N	N	N	N	N	DS of Upr Shannon, DS Lough Allen, US large public DW supply	194902	305220
Willsborough Stream	RS35W010300	Br On Sligo-Bundoran Road	Stream	N	N	Y	N	N	Cycle 2	N	US Sligo Bay, Sligo Bay shellfish waters	169258	337375
Gortnaleck Stream – North Sligo PWS	na	Gortnaleck Stream – North Sligo PWS	Coastal	Y	N	N	Y	N	N	N	Large DW supply, Donegal Bay Southern bathing waters	169822	347267

Table 11.5. Details of recommended lake monitoring locations – NCB study area

Water body name	WFD station ID	Station name	Catchment name	WFD Protected Areas						Protected species	Description	Easting	Northing
				Drinking water	Salmonid	Shellfish waters	Bathing waters	WFD SAC	WFD SPA	Pearl mussel			
Arrow	WERBD_35_116	Arrow	Ballysadare	Y	N	N	N	N	Cycle 1	N	Private DW supply	178991	312053
Melvin	UKGBNIF10957	Lough Melvin (Ic) Mid Deep Point	Drowes	Y	Y	N	N	Cycle 1/Cycle 2	Cycle 1/Cycle 2	N	SAC/SPA, Public DW supply Bundoran/Askill WSS	189382	353508
Glencar	WERBD_35_119	Glencar	Drumcliff	N	N	N	N	Cycle 1	N	N	Upland SAC lake	174919	343333
Cullinaghan	NWIRBD_36_123	Cullinaghan	Erne	N	N	N	N	Cycle 1	N	N	SAC – Lough Oughter And Associated Loughs	230477	318329
Lough Erne (Upper)	UKGBNIF10677	Upper Lough Erne At Corraslee	Erne	Y	Y	N	N	Cycle 1/Cycle 2	Cycle 1/Cycle 2	N	Large lake, source public DW supply	227895	331426
Macnean Lower	UKGBNIF10956	Lower Lough Macnean (Ic) Mid Deep Point	Erne	N	Y	N	N	N	N	N	Large lake	210798	337811
Lough Erne (Upper – Kesh)	UKGBNIF10998	Lower Lough Erne (Kesh) Mid Deep Point	Erne	Y	Y	N	N	N	N	N	Large lake, source public DW supply	210093	360406
Lough Erne (Upper – Devenish)	UKGBNIF10999	Lower Lough Erne (Devenish) Mid Deep Point	Erne	Y	Y	N	N	N	N	N	Large lake, source public DW supply	213272	358967
Macnean Upper	UKGBNIL0003	Macnean Upper	Erne	N	Y	N	N	N	N	N	Large lake	203121	340313
Gill	WERBD_35_117	Gill	Garvogue	Y	N	N	N	N	N	N	Large public DW supplies	175023	333693
Glenade	WERBD_35_117	Glenade	Garvogue	N	N	N	N	Cycle 1	N	N	Upland SAC lake	182429	346230
Allen	SHIRBD_26_155a	Allen	Shannon Upr	N	N	N	N	N	N	N	Large lake	196231	319255
Kilsellagh	WERBD_35_118	Kilsellagh	Stream	Y	N	N	N	N	N	N	Large public DW supply	173421	339301
Belleek Water Treatment Works (Lough Erne)	na	Belleek Water Treatment Works (Lough Erne)	Erne	Y	N	N	N	N	N	N	Large public DW supply – abstraction location TBC with Northern Ireland Water	TBC	
Killyhevlin Water Treatment Works (Lough Erne)	na	Killyhevlin Water Treatment Works (Lough Erne)	Erne	Y	N	N	N	N	N	N	Large public DW supply – abstraction location TBC with Northern Ireland Water	TBC	

Petrifying springs are proposed to be sampled as follows:

- A group of 3 springs in the West Fermanagh Scarplands SAC;
- A group of 3 springs in the Benbulben, Gleniff and Glenade Complex SAC to the north of Glencar Lough.

Comprehensive monitoring of all petrifying springs is not possible or necessary, so two representative clusters of 3 springs in each SAC is recommended. The selection of which specific springs to include are based on field inspection and health & safety considerations.

11.4 Hydrometric Monitoring

11.4.1 Spring discharge records

Spring discharge records are sparse. Whereas the majority of springs are small (10 l/s or less), and are conceptually better understood in terms of their roles and overall contributions to the water balance of the NCB, the larger karst springs warrant further attention. Conduits can act as collector systems of ‘diffuse’ groundwater in the fractured limestones, and the conduits also collect water from point recharge locations such as collapse dolines and active swallow holes. Whereas zones of contributions have been inferred for many of the larger cave/conduit systems in the region from dye tracer testing, the quantitative aspect of the karst is less well defined.

It is, therefore, recommended that large karst springs be included for baseline monitoring purposes, in order to document the hydraulic responses and ranges of discharges that are associated with the karst, as follows:

- Cuilcagh Mountains – Dartry Limestone – Aghaboy (East Cuilcagh); Cascades, Hanging Rock (or Ture) and Tullyhona (North Cuilcagh); Shannon Pot (West Cuilcagh);
- West Fermanagh Scarplands – Dartry Limestone – Boho; and
- Geevagh – Bricklieve Limestone – Spring “D” (Thorn *et al.*, 1990) near Geevagh village.

These are selected as they represent significantly large springs in each karst area. There are no known equivalent (large) springs associated with the Ballyshannon Limestone.

It is not considered feasible or necessary to install engineered weir structures in the timeframe of the baseline monitoring programme. Improved discharge datasets and hydraulic characterisation can be achieved with temporary gauge solutions involving staff gauges and slotted standpipes with transducers at secured, appropriate locations (i.e. locations where there is a reasonable degree of natural channel control). Cross-sectional measurements at selected locations would have be surveyed, and manual flow measurements would have to be carried out at prescribed times to generate rating curves, as guided and adjusted according to prevailing hydrometeorological conditions. The intent would be to capture the range of variability of flows and recession characteristics following storm events.

11.4.2 Groundwater levels

New monitoring wells should be equipped with transducers to record changes in groundwater levels as well as temperature and EC. If possible, a selected number of existing abstraction wells should also be equipped with transducers noting that the presence of downhole submersible pumps and discharge lines may not allow for transducer installations (i.e. due to insufficient space in the well).

The data generated from the transducers would supplement the WFD monitoring carried out by the EPA and NIEA in five existing wells in the NCB study area currently. The data would also supplement and add value to the hydrogeological characterisation of fractured bedrock aquifers in both Ireland and Northern Ireland in the long-term. The present WFD monitoring of water levels focuses on five wells in the Dartry and Ballyshannon Formations. Accordingly, it is recommended that transducers be fitted in selected wells in each of the other key bedrock formations associated with potential UGEE activity, especially the Bundoran Shale, Mullaghmore Sandstone and Benbulben Shale Formations of the Tyrone Group, as well as the Meenymore and Glenade Sandstone Formations of the Leitrim Group.

11.4.3 Streams/rivers

In Section 10.4, hydrometric data gaps were identified in the Swanlinbar, Arigna and Feorish catchments. Following the same approach that was described in Section 11.4.1, temporary, project-specific gauges can be established at appropriate locations relatively inexpensively and quickly for project purposes.

11.4.4 Lakes

Lake level monitoring is carried out in all of the major lakes within the study area, thus further lake level gauging stations are not considered necessary as part of the UGEE JRP.

Loughs Glenade and Glencar are hydrologically significant, and related water levels were flagged as data gaps in Section 2. However, both are throughflow lakes and removed from areas that are likely to be targeted for future UGEE activity. They are, accordingly, assigned a lower priority, and lake level gauges are not considered necessary.

11.5 Stream Sediments

In the NCB, 30 stream sediment samples are recommended for gross alpha and gross beta activity screening, and further radium isotope analyses if relevant screening thresholds are exceeded. Other NORM and metals have been characterised in the NCB (Gallagher, 2015a,b) as part of the Tellus Border research initiative, and are not proposed to be repeated or duplicated in the UGEE JRP.

Sampling locations would broadly correspond with surface water stations but final locations would factor in the need to sample in low-energy flow environments, i.e. locations where sediments settle. The locations would, to the extent possible, also be coordinated with the known Tellus Border sample locations, although sediment sampling tends not to be ‘repeatable’ (thus, past gross alpha and beta data would not be useful with the new radium data).

The stream sediment sampling and analysis is a once-off sampling event for baseline characterisation purposes. The radium isotopes are considered particularly important to document as they were not included in the Tellus Border project, and radium is an identified contaminant of concern in sediments associated with UGEE activity. Combined with the gross alpha and beta screening data, the information gained on radium isotopes would also inform if other radionuclides may be present.

12 Recommended Baseline Monitoring – CB

This section provides a recommended baseline monitoring programme for the NCB. The information is presented in the same order as the discussion on design approach in Section 10.

12.1 Groundwater Quality

Wells that were deemed suitable for groundwater quality monitoring, and are thus recommended for baseline sampling purposes, are shown in Figure 12.1 and summarised in Table 12.1. Analytical parameters and frequencies of sampling are presented in Section 13. Wells that are not already equipped for pumping (e.g. Kilmaley-Inagh GWS trial wells) would have to be sampled using portable equipment which includes a submersible pump and generator.

12.1.1 Former abstraction wells

From the ground-truthing survey of groundwater abstraction points, two former abstraction wells (Lacken/Kilmahil and Kilrush Creamery) were identified in the CB study area as candidate wells to be included in the recommended sampling programme. Further inspection of these is needed and recommended to verify if they can be used for sampling purposes. Preliminary information indicates they are suitable for sampling, and are tentatively included in the sampling programme. However, the details of each wells and their physical integrity have to be verified through inspection and basic rehabilitation measures. If inspection confirms that they are not usable, then alternative wells in the same areas would have to be located or additional new monitoring wells would have to be drilled.

The wells in Figure 12.1 that are indicated as “pending verification” are wells that have been identified but where follow-up with owners about details and permission to sample is still needed. There are also other candidate wells that may be secured for sampling, where visits are still needed. Accordingly, the finer details of the sampling programme in the CB still need to be finalised, requiring limited additional field effort and follow-up with well owners. The related activity would have to be concluded before any subsequent tendering for sampling and analyses.

12.1.2 New monitoring wells

At this time, data gaps exist with respect to spatial representation of existing wells that could be used for baseline sampling purposes, whereby suitable wells have not yet been located towards the central and south-eastern parts of the UGEE licence area in the CB. Accordingly, it is recommended that two new monitoring wells may be needed to be drilled to address the identified gap in spatial coverage. One would be located in vicinity of Cooraclare, the other towards the Mountshannon peninsula. Contacts that were made during the ground-truthing survey of abstraction points are not yet exhausted, and further effort would be made to try and confirm additional existing wells that may be candidates for sampling purposes before final conclusions about drilling are made: a) to verify the “pending verification’ locations in Figure 12.1; and b) to inspect other known candidates that have not yet been visited. Even though recommendations on final locations are pending, it is expected that the recommended sampling programme would be similar in scope/extent to that presented in the current report.

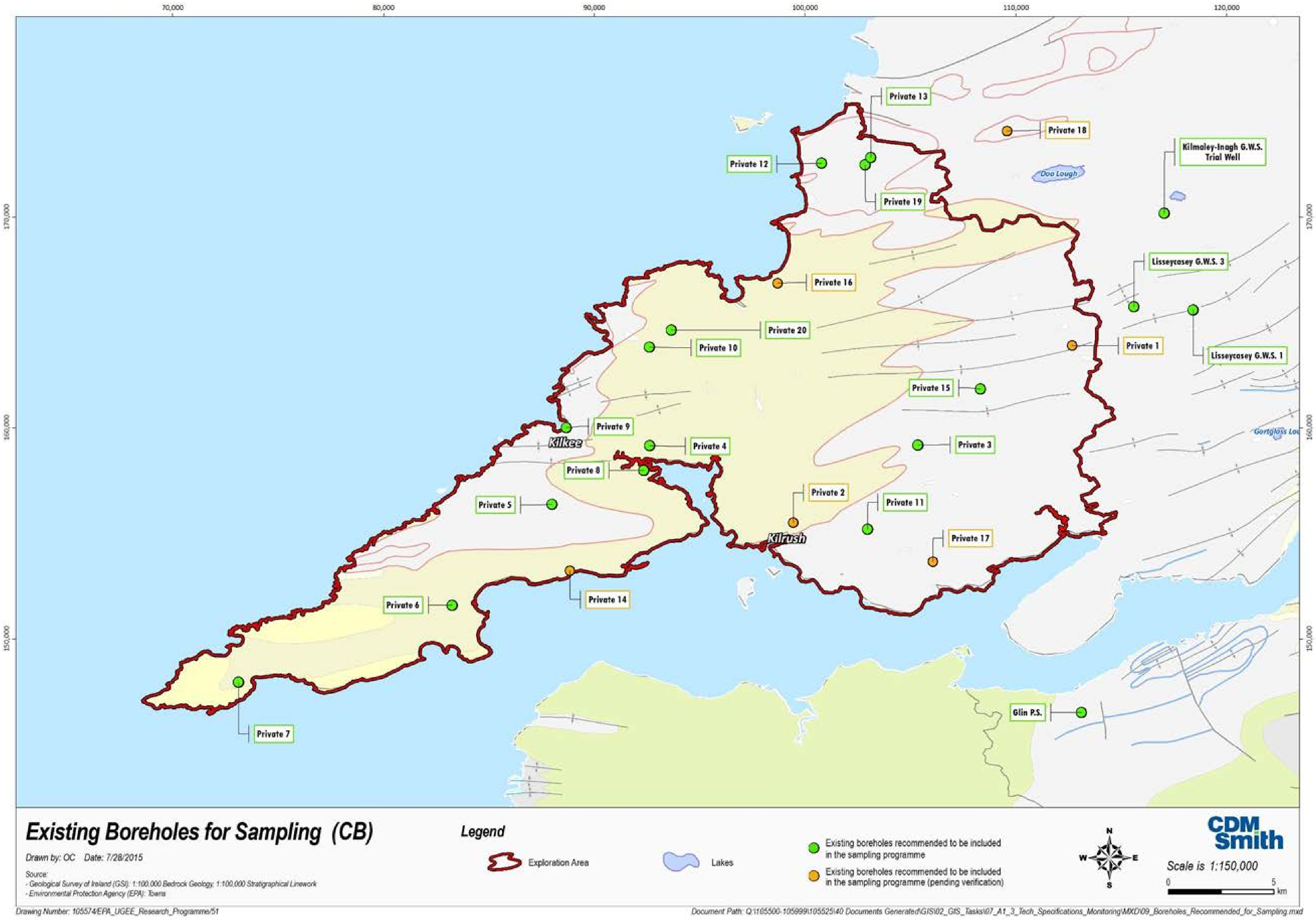


Figure 12.1. Existing wells recommended for sampling – CB study area.

Table 12.1. Details of existing wells recommended for sampling – CB study area

Site name	Supply type	Easting	Northing	Aquifer type	Bedrock code	Bedrock formation[a]	Comments	Minor works
Glin PS	PWS	113117	146507	LI	CCG	Central Clare Grp	Public supply well – already part of EPA's national groundwater monitoring network.	None
Lisseycasey GWS 1	GWS	118418	165605	LI	CCG	Central Clare Grp	New supply well drilled in 2014. "High yield" (est. 70 m^3/hr). Also known as 'Frure 2′ ('Frure 1′ being the old supply well at the same site, which is equipped for pumping) or 'Martin Kelly's well'. Pumps to main reservoir. C. 120 m deep.	None
Lisseycasey GWS 3	GWS	115608	165751	LI	CCG	Central Clare Grp	Back-up well. Also known as 'Frure 3′ or 'Johnny Kelly's well'. Old but equipped with pump. Is less likely to be used in future, as GWS has plans to use lake water to supplement Lissacasey 1. Engineered to pump straight into mains.	None
Kilmaley-Inagh GWS Trial Well	GWS	117049	170185	LI	CCG	Central Clare Grp	Trial well – Kilmaley-Inagh GWS. C.110 m deep.	Minor fence or bollards around wellhead. Will require lowering of pump
Private 1	Private	112673	163928	LI	CCG	Central Clare Grp	Old Lacken PWS. Video log and total depth measurement would have to be carried out to examine integrity of well which has not been operational since approx. 1990.	Investigation and potential rehabilitation required
Private 2	Private	99434	155516	LI	GI	Gull Island Fm	Located outside the museum of Irish rural life (formerly the Kilrush creamery). Well has been covered up with flagstone and rubble on top, but is reportedly in good condition.	Investigation and potential rehabilitation required
Private 3	Private	105363	159195	LI	CCG	Central Clare Grp	Glass recycling facility. Well has "low yield" and is used for onsite sanitation.	Sample tap, concrete wellhead protection, bollards, extend HDPE pipe carrying wastewater effluent further away from well
Private 4	Private	92627	159163	LI	GI	Gull Island Fm	Reportedly a "high-yielding well" (according to driller) approx. 60–70 m deep. Was not operational at time of visit – maintenance issue with filtration unit (clogged). Serves pub/B&B.	Sample tap on HDPE discharge line in shed
Private 5	Private	87996	156384	LI	CCG	Central Clare Grp	Dairy farm. Well is located in field used by horses. Well is in below-ground chamber with steel plate covers.	Sample tap on HDPE discharge line in shed, fence around well in field
Private 6	Private	83257	151595	LI	GI	Gull Island Fm	Caravan site. Well is below ground in parking area. Pump operates on demand, can pump >400 m^3/d during summer. Submersible pump was installed with 20 pieces of 18 ft long steel discharge pipe – i.e. 360 ft pump setting.	Exclude parking on top of well access lid
Private 7	Private	73116	147952	LI	GI	Gull Island Fm	Dairy farm. Well drilled in 2014, artesian at time of drilling and at time of site visit.	Sample tap, concrete wellhead protection
Private 8	Private	92346	157984	LI	GI	Gull Island Fm	Dairy farm. 380 ft deep. 6-inch steel, 4-inch PVC liner with vertical slots. "Great water" according to owner.	Sample tap on HDPE discharge line above ground near bridge crossing
Private 9	Private	88679	160021	LI	CCG	Central Clare Grp	Hotel in Kilkee. Enclosed in main building. C. 120 ft deep. Has never gone saline. Used for all hotel purposes.	Sample tap
Private 10	Private	92616	163846	LI	GI	Gull Island Fm	Owner has a domestic well to supply home, but also a deeper and larger yielding well at a farm c. 6 kms to the N towards Doonbeg. This will require a follow up visit.	Sample tap
Private 11	Private	102968	155196	LI	CCG	Central Clare Grp	Recently drilled 2012. In underground chamber which needs repair work.	Sample tap, reinforce wellhead chamber
Private 12	Private	100791	172561	LI	CCG	Central Clare Grp	Well is in below ground vault in field, and covered over by steel plates	Sample tap, fencing around vault in field
Private 13	Private	103120	172835	LI	CCG	Central Clare Grp	150 ft well, poor wellhead construction	Sample tap, wellhead reinforcement
Private 14	Private	88848	153225	LI	GI	Gull Island Fm	Caravan site. Approval for sampling pending.	Sample tap, concrete wellhead protection
Private 15	Private	108330	161846	LI	CCG	Central Clare Grp	Dairy farm. Approval for sampling pending. Reportedly a "high-yielding" well.	Not yet defined
Private 16	Private	98700	166880	LI	GI	Gull Island Fm	Hotel and golf club. Trial well not yet equipped or operations. Approval for sampling pending.	Not yet defined

Site name	Supply type	Easting	Northing	Aquifer type	Bedrock code	Bedrock formation[a]	Comments	Minor works
Private 17	Private	106067	153668	LI	CCG	Central Clare Grp	Dairy farm. Well is reportedly 120 ft deep. Backup well in case others in area are not found. New monitoring well in this area would be preferred.	Sample tap on HDPE discharge line above ground
Private 18	Private	109594	174094	LI	CCG	Central Clare Grp	Approval received to sample, but well has yet to be visited. Dairy farm. Location approximate.	Not yet defined
Private 19	Private	102854	172489	LI	CCG	Central Clare Grp	Dairy farm. Met owner, and approval was received to sample, but well has yet to be inspected.	Not yet defined
Private 20	Private	93660	164646	LI	GI	Gull Island Fm	Large dairy farm. Two wells – one on the farm visited, and the other on farmland approx. 4 kms away. The well on the farm visited is only approx. 40 ft deep, and was reportedly just drilled into bedrock, where sufficient water was developed for demands of farm – possibly a transition zone well beneath deep till. The second well is approx. 300 ft deep, but needs to be visited.	Not yet defined

[a]As indicated by published geological maps of the GSI.

12.1.3 Abandoned gas exploration wells

Two past gas exploration wells, Doonbeg-1 and IPP-1, were located and inspected visually during the ground-truthing survey. The Doonbeg-1 well has potential to be used as a monitoring point, and further checks and inspection according to Section 10.1.3 is recommended.

The location, existing condition and potential use of IPP-1 is on a preliminary basis considered to be less promising, but further inspection/investigation is recommended if only to rule it out definitively.

12.2 Surface Water

Figure 12.2 and Figure 12.3 show the locations of recommended stream and lake monitoring stations, and their locations within respective surface water catchments. Analytical parameters and frequencies of sampling are presented in Section 9.

Table 12.2 presents the WFD protected areas associated with each of the 7 proposed river monitoring locations and provides a description of each site. The main sensitive receptors within CB are the pearl mussel waters of the Doonbeg River, the West Shannon area shellfish waters, and coastal and transitional SACs/SPAs.

Table 12.3 documents two lakes, Doo Lough and Lough Acrow, which are proposed for sampling. Both are located marginally outside of the UGEE licence area but are nonetheless relevant as Doo Lough is the main drinking water supply source for western Co. Clare and Lough Acrow is part of Lisseycasey GWS and used to augment the supply from the GWS production wells during period of high water demand.

12.3 GWDTEs

Sub-regional baseline monitoring of groundwater-dependent habitats within the CB study area is not being recommended as they are few in numbers, occur in isolated pockets, and are of types that require prior investigate study to truly understand their supporting conditions, i.e. to be able to guide or direct appropriate baseline monitoring. Future case- and location-specific monitoring is considered more appropriate if or when details about future planned UGEE activities become known.

12.4 Hydrometric Monitoring

12.4.1 Groundwater levels

It is recommended that transducers for automatic monitoring of groundwater levels be installed in a subset of wells throughout the study area, including wells that are not equipped for pumping (notably the Kilmaley-Inagh GWS trial well and the former Kilrush Creamery wells if the latter can be made accessible through minor rehabilitation works). Similar to the situation described for the NCB, the presence of submersible pumps and discharge lines in existing abstraction wells may prevent access for transducer installations.

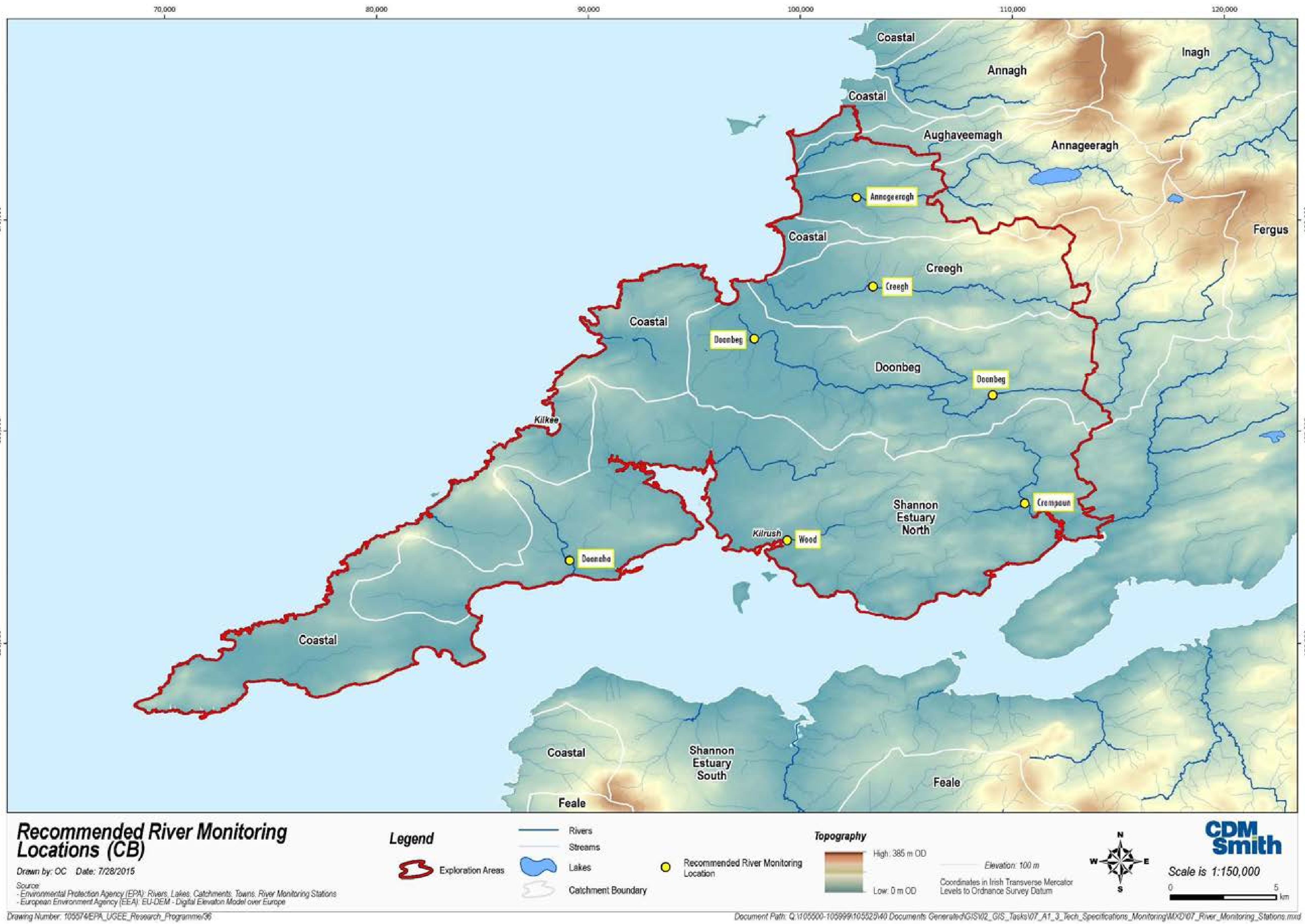


Figure 12.2. Recommended stream monitoring locations – CB study area.

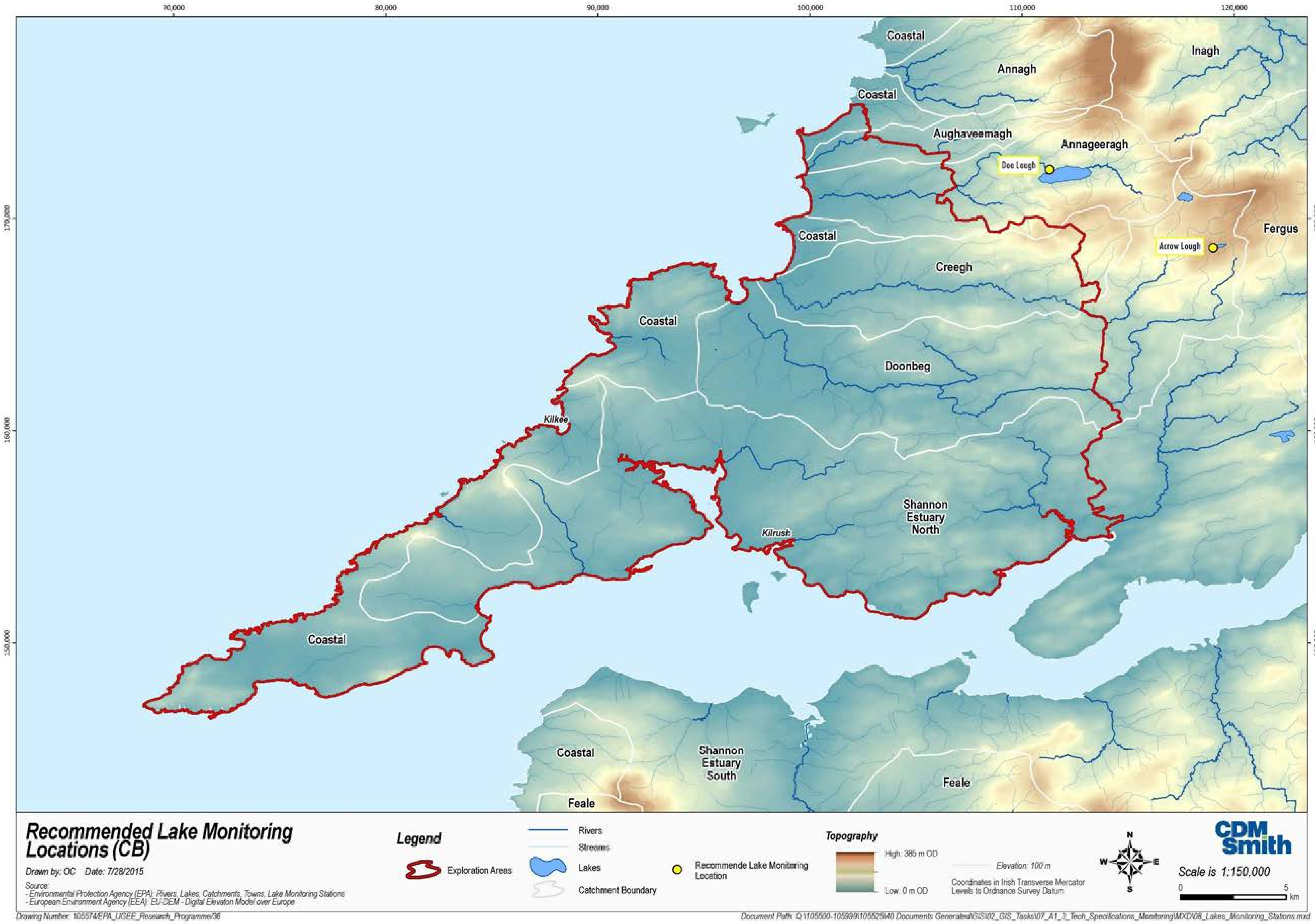


Figure 12.3. Recommended lake monitoring locations – CB study area.

Table 12.2. Details of Recommended River Monitoring Locations – CB Study Area

Water body name	WFD station ID	Station name	Catchment name	WFD Protected Areas						Protected species	Description	Easting	Northing
				Drinking water	Salmonid	Shellfish waters	Bathing waters	WFD SAC	WFD SPA	Pearl mussel			
Crompaun (West)	RS27C051200	Br Nr Carroniska	Shannon Est Nth	N	N	Y	N	N	N	N	DS Campaun, West shannon area shellfish waters	110599	156604
Doonaha	RS27D010100	Br N.E. Of Doonaha	Shannon Est Nth	N	N	Y	N	Cycle 2	Cycle 2	N	DS Doonagh, West shannon area shellfish waters	89118	153906
Wood	RS27W010200	Kilrush: 100 M U/S West Br	Shannon Est Nth	N	N	Y	Y	N	N	N	DS Wood, West shannon area shellfish waters, Cappagh Pier, Kilrush bathing waters	99373	154857
Annageeragh	RS28A020400	Lissyneillan Bridge	Annageeragh	N	N	N	N	Cycle 2	N	N	DS Annageeragh	102653	171046
Creegh	RS28C021400	Bridge At Creegh	Creegh	N	N	N	N	N	N	N	Creagh Catchment	103427	166836
Doonbeg	RS28D020500	Derrycrossaun Bridge	Doonbeg	N	N	N	N	N	N	Y	Mid Doonbeg catchment, pearl mussel river	109079	161695
Doonbeg	RS28D020770	Br 1Km D/S Br Nr Mountrivers	Doonbeg	N	N	N	N	N	N	Y	DS Doonbeg catchment, pearl mussel river	97831	164373

Table 12.3. Details of Recommended Lake Monitoring Locations – CB Study Area

Water Body Name	WFD Station ID	Station Name	Catchment Name	WFD Protected Areas						Protected Species	Description	Easting	Northing
				Drinking Water	Salmonid	Shellfish Waters	Bathing Waters	WFD SAC	WFD SPA	Pearl mussel			
Doo Lough	SH_28_82	Doo Lough	Annageeragh	Y	N	N	N	N	N	N	Source of West Clare Regional WS	111310	172304
Lough Acrow	–	–	Doonbeg	N	N	N	N	N	N	N	Source for Lisseycasey GWS	118418	165605

Continuous groundwater level monitoring using transducers in the CB study area would be of considerable added value nationally, specifically to the hydrogeological characterisation of Namurian rocks. The recommended monitoring would target dominantly sandstone formations which are used for both public and private water supply in western Co. Clare.

12.4.2 Spring discharge records

Springs in the CB study are small (generally <10 l/s) and discharge monitoring is not considered a priority for water balance quantification purposes.

12.4.3 Streams/rivers

The gauging station which is operated by the Office of Public Works (OPW) on the Doonbeg River is considered sufficient to characterise stream flows in the study areas since all catchments are of similar physiographic and hydrogeological characteristics. Thus, no additional or temporary gauging stations are recommended. Manual spot-measurements are also not considered necessary. Flows in ungauged catchments can be estimated from Doonbeg data and from application of the EPA web-based HydroTool.

12.5 Sediments

In the CB, 15 stream sediment samples would be collected and analysed for radium isotopes at locations that would broadly correspond with surface water sampling stations. Actual sample locations would be adjusted for low-energy flow environments where sediments settle and accumulate. Gross-alpha and gross-beta screening would be undertaken to document the overall radioactivity baseline in the stream sediments, with further analysis for radium isotopes based on exceedances of screening levels. The sampling and analysis is a once-off event for baseline characterisation purposes. As described in Section 9.4, radium isotopes are particularly significant as the principal contaminant of concern in stream sediments associated with UGEE activity.

13 Specification for Sampling, Analysis and Other Baseline Monitoring Requirements

13.1 Water Quality Analysis and Sampling

13.1.1 Parameters for analysis

13.1.1.1 Field parameters

Field parameters should be measured using multi-parameter water quality probes (or similar) for both surface water and groundwater, and field parameters should include:

- pH
- Specific Electrical Conductance (SEC) (mS/cm)
- Dissolved Oxygen (DO) (% and mg/l)
- Temperature (°C)
- Oxidation-Reduction Potential (ORP) (mV)

Field parameters would be measured at the time of sampling activity using protocols that are applied for EPA sampling programmes. For surface water or springs, the relevant probes would be placed directly in the flowing water and measurements recorded. For groundwater, field measurements would be taken using a water quality probe placed in a flow-through cell so that it is not exposed to air. The field parameters should be recorded at regular intervals during purging to determine when the parameters stabilise. These measurements would be taken as the final results after the parameters have stabilised. After this, samples can be collected for laboratory analysis. Stabilisation would be judged following a minimum of four readings with the difference of the two final readings not exceeding:

- 0.2 °C for temperature;
- 3% for specific conductance; and
- 0.1 pH unit.

13.1.1.1 Laboratory analysis

Table 13.1 lists the parameters that are recommended for laboratory analysis of both groundwater and surface water samples. The recommended parameters are based on review of international best practice and published impact studies. The parameter set is comprehensive. Analysis would be carried out consistently between successive sampling rounds, but an approach of “adaptive monitoring” is recommended, whereby certain parameters are only analysed when associated screening levels are exceeded. This applies to NORM (surface water, groundwater) and dissolved methane gas (groundwater only).

Table 13.1. List of recommended parameters for analysis of groundwater and surface water

Parameter	Groundwater	Surface water	Frequency
Dissolved natural gas components			
Dissolved methane	✓	×	Quarterly
Dissolved CO_2	✓	×	Quarterly
Hydrocarbon gases (C2 to C5)	✓	×	Quarterly
Nutrients and general chemistry			
Ammonia	✓	✓	Quarterly
Ammonium	✓	✓	Quarterly
Nitrite as N	✓	✓	Quarterly
Nitrate as N	✓	✓	Quarterly
Orthophosphate as P	✓	✓	Quarterly
Total Phosphorus	✓	✓	Quarterly
Total Organic Carbon	✓	✓	Quarterly
Total Dissolved Solids	✓	✓	Quarterly
Total Suspended Solids	×	✓	Quarterly
Major ions			
Alkalinity	✓	✓	Quarterly
Chloride	✓	✓	Quarterly
Fluoride	✓	✓	Quarterly
Sulphate	✓	✓	Quarterly
Sodium	✓	✓	Quarterly
Potassium	✓	✓	Quarterly
Magnesium	✓	✓	Quarterly
Calcium	✓	✓	Quarterly
Iron	✓	✓	Quarterly
Manganese	✓	✓	Quarterly
Boron	✓	✓	Quarterly
Trace elements			
Aluminium	✓	✓	Quarterly
Chromium	✓	✓	Quarterly
Nickel	✓	✓	Quarterly
Copper	✓	✓	Quarterly
Zinc	✓	✓	Quarterly
Arsenic	✓	✓	Quarterly
Cadmium	✓	✓	Quarterly
Antimony	✓	✓	Quarterly
Barium	✓	✓	Quarterly
Lead	✓	✓	Quarterly
Uranium	✓	✓	Quarterly
Mercury	✓	✓	Quarterly
Cobalt	✓	✓	Quarterly
Molybdenum	✓	✓	Quarterly
Strontium	✓	✓	Quarterly
Silver	✓	✓	Quarterly
Beryllium	✓	✓	Quarterly
Bromide	✓	✓	Quarterly
Vanadium	✓	✓	Quarterly
Descriptors of carbon sources			
Dissolved organic carbon (DOC)	✓	✓	Quarterly
Dissolved inorganic carbon (DIC)	✓	✓	Quarterly

Parameter	Groundwater	Surface water	Frequency
Trace organics			
Polyaromatic hydrocarbon (PAH) – full suite	✓	✓	Semi-annually (including low flow conditions)
Volatile Organic Compounds (VOCs) – full suite	✓	✓	Semi-annually (including low flow conditions)
Stable isotopes in dissolved methane			
Hydrogen (δD)	✓	×	Quarterly (if methane detected)
Carbon ($\delta^{13}C$)	✓	×	Quarterly (if methane detected)
Oxygen ($\delta^{18}O$)	✓	×	Quarterly (if methane detected)
Naturally occurring radioactive materials (NORM)			
Gross alpha/beta	✓	✓	Quarterly
Ra-226/Ra-228	✓	✓	Quarterly (if a gross alpha/beta threshold exceeded)
Rn-222	✓	✓	Quarterly (if a gross alpha/beta threshold exceeded)

Regarding NORM, initial screening for radioisotopes should be carried out by analysing for gross alpha and beta activity in surface water and groundwater to determine whether radioisotope-specific analysis is warranted. The proposed approach is that adopted by the former Radiological Protection Institute of Ireland (RPII), which applies a gross alpha screening limit of 100 mBq/l and a gross beta screening limit of 1000 mBq/l (RPII, 2013). The limits are linked to a “total indicative dose” (TID), which is a public health metric related to exposure to radioactivity (RPII, 2013). Where a screening level is exceeded, further analysis of Radium –226, Radium-228 and radon is recommended (radon being a breakdown product of uranium, which in turn is a gross alpha emitter). Radium is the documented main radioisotope of concern in flowback waters, and measurements of both Radium-226 and Radium-228 can be used to fingerprint the source (Vengosh *et al.*, 2014).

Regarding the analysis for dissolved natural gas (methane) in groundwater, further detailed analysis of samples to fingerprint the chemical-isotopic composition and origins of the gas would be triggered if the methane concentrations exceed the relevant screening concentration, as guided by existing baseline monitoring experiences in England, Scotland and Wales by the British Geological Survey (BGS). The concentration of methane required to perform the isotope analysis would likely depend on the individual capabilities of the laboratories. Based on experience of BGS, the dissolved methane concentrations could actually be quite low in groundwater and therefore it is desirable that stable isotopes were able to be measured in concentrations of dissolved methane as low as 0.5 µg/l, as is the case for BGS laboratory capabilities (Darling and Gooddy, 2006).

As the baseline sampling programme progresses, opportunities to expand adaptive monitoring may arise from review of results. For example, results may suggest that spatial aspects of sample locations or analytical rigour should be adjusted, or even that parameter sets should be amended as new information (e.g. from published research) becomes available. As described in Section 9, impact identification associated with UGEE is a rapidly evolving science.

In the context of adaptive monitoring, use of portable field-based equipment may further guide sampling and analysis. Use of such equipment as part of sampling protocol was describe above. Additionally, and according to geochemical principles, methane should not develop in systems containing significant dissolved oxygen or elevated redox conditions. Thus, field screening of these parameters could, in theory, help to determine if laboratory analysis for methane of a groundwater sample is necessary. It is, therefore, recommended that this potential relationship be examined as part of the UGEE JRP monitoring, as it is easy to carry out and does not involve costs beyond a portable gas metre. In all cases, laboratory analysis for methane is recommended for the UGEE JRP, but if the derived field and laboratory data of methane, DO and redox conditions show a clear relationship, then decisions on laboratory analysis in future sampling, beyond the UGEE JRP, may be recommended based on field screening criteria. Similarly, the mobility of NORM are sensitive to redox conditions, so field measurement of redox has the potential to be used to guide the analysis of NORM in the future.

It should be noted that the analysis for methane gas is recommended for groundwater only, as dissolved gases in surface water are considered to be lost due to degassing. The same applies to springs when groundwater becomes exposed to the atmosphere. Thus, analysis of dissolved gases and associated isotopic compositions are only recommended for groundwater samples which are collected from boreholes. Sampling and results obtained from karstified limestone would need to be assessed with caution, as unconfined conditions can develop in conduits resulting in degassing. Methane gas may thus be 'lost' in vicinity of conduits but remain present elsewhere in the bedrock aquifer where confined conditions apply.

Finally, it should also be noted that the US Geological Survey has carried out research on stream-based methane monitoring to identify and quantify groundwater methane discharging to a stream in an area of unconventional gas development. The method (as reported by Heilweil *et al.*, 2015) combines "*stream hydrocarbon and noble-gas measurements with mass-balance modelling to estimate thermogenic methane concentrations and fluxes in groundwater discharging to streams*". Described by the authors as the "*first watershed-scale method to assess groundwater contamination from shale-gas development*", a review of the method indicates that it is useful and has validity at the local (sub-catchment) scale for monitoring of case-specific UGEE activity, but that it is not suited for baseline monitoring at the sub-regional scale, as the resources required to implement the method are significant, beyond what could be accomplished within the means and schedule of the UGEE JRP. The method nonetheless points to study and monitoring elements which should be considered when determining the terms and conditions of operational monitoring with any future UGEE developers. For example, if location-specific field data and/or conceptual site models indicated that there is potential for methane gas to leak to groundwater which ultimately discharges to surface water, then dissolved methane and its isotopes should be considered for monitoring in surface waters to establish baseline concentrations at a site-specific or subcatchments scale (Heilweil *et al.*, 2015). An understanding of gaining and losing stretches of the river would also need to be determined, e.g. by detailed flow measurements and tracer studies (Heilweil *et al.*, 2015). Thus, such monitoring is recommended for consideration at the site-specific scale and after detail evaluation of where specific discharges may occur close to the UGEE sites.

With regard to analysis of metals, total metals are the concentration of metals determined in an unfiltered sample (combination of metals contained in the solid sediments, colloidal particles and in the dissolved phase), while dissolved metals are those which pass through a 0.45 μm membrane filter. Dissolved metals are more biologically available than total metals and are, therefore, recommended for the baseline monitoring programme. In addition, unfiltered (total) metals should be analysed for in surface water due to the potential for metals to be contained as solid sediments.

The recommended analysis of trace organics is comprehensive, but it should be noted that the analyses may not capture all potential chemicals that might be used in a prospective hydraulic fracturing operation, as the chemical constituents of "hydraulic fracking fluids or drilling fluid chemicals"" are presently not known. Recent published research (e.g. Smith *et al.*, 2014; USEPA, 2015) on fracking-related chemicals also indicates that leaching of chemicals from cements can occur (e.g. glycols), which further influences and expands the list of trace organic chemicals that should be analysed and reported during baseline monitoring. The inference of the referenced research is that UGEE-related monitoring in the future should consider all aspects of UGEE operations, not just the chemicals that may be used routinely at a well pad or for hydraulic fracturing purposes.

13.1.2 Groundwater sampling methodology

13.1.2.1 General

Water supply wells are generally pumped on a frequent basis and purging of wells and discharge lines prior to sampling may not be required, pending verification by stabilisation of measured field parameters. Samples from boreholes/wells would be collected from raw (untreated) water sampling taps that either already exist or would be installed at appropriate wellhead locations prior to the first round of sampling.

Boreholes/wells that are not equipped with pumping equipment would have to be purged and sampled using portable pumping equipment. Ideally, such wells would be pumped at relatively high pumping rates to draw on larger volumes of aquifer, using methods in line with BS:ISO 5667 Part 11 for groundwater sampling. In some cases, yields may be low, and in such instances low-flow sampling protocols should be utilised which are consistent with protocols of EPA's national groundwater sampling programme.

Decisions about where to position portable pumps would be guided by information about where the main influx zones of groundwater are located, which is derived from drilling information, well completion reports and/or borehole geophysical logs. It is important that each sample from a given well is collected from the exact same depth interval and with the same pumping rate in successive sampling rounds.

Wherever possible, the static water level in a given well would be taken prior to pumping. The water level in the well would be measured throughout the purging process to monitor drawdown. Water quality indicator parameters would be monitored during purging using a flow-through cell, to prevent the sample interacting with the atmosphere. Stabilisation is achieved after all parameters fall within established limits as per the EPA protocol (see Section 13.1.1.1).

If a low flow pump is to be used, it is important to consider that discharge tubing would need to be filled with water so that the sample does not become aerated, as this could cause the loss of dissolved gases or VOCs from the groundwater. For this reason peristaltic pumps (suction) are not recommended. If the tubing is not filled with water, the dissolved gases and VOCs should be sampled last and the flow rate should be increased to fill the tubing (USEPA, 2010). If this is not possible for any reason the data should be qualified.

13.1.2.2 Methane Sampling

When sampling for dissolved gases, it is essential to ensure that the sample process is kept air-tight, e.g. the samples are not exposed to the atmosphere, there are no bubbles in the discharge line, and sample bottles have tight seals. The containers used must be stainless steel or non-permeable plastic or glass, and refrigeration or preservation is required to prevent bacterial degradation. Similarly the sample bottles must be filled with no exposure to air and any tubing used should be connected with an airtight seal (e.g. using standard or other hose fittings) (BGS, 2015).

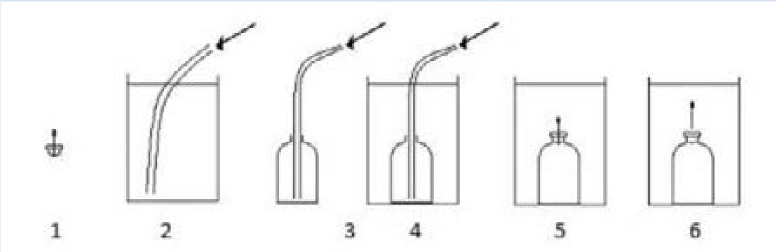
There are a few sampling methodologies for collecting dissolved gases in the field so that the concentrations of the dissolved gas per volume are quantifiable by analytical techniques used in the laboratory. A comprehensive review of methodologies is provided by Hirsche and Mayer (2009) and only sampling methodologies for above-ground access are discussed here.

Hirsche and Mayer (2009) state that the simplest methodology is the inverted bottle method. A bottle is inverted and is filled with sample water using tubing that is directed into the bottle, while the bottle is submerged in a container full of the same sample water. The bottle is flushed with at least two bottle volumes and then filled with groundwater and the tubing is slowly removed from the inverted bottle. Subsequently, the bottle is closed while it is submerged using a septum or screw cap. (Hirsche and Mayer, 2009).

Another common method that was developed by the USGS (2006) is described in the box below.

Box 13.1. *USGS* methane sampling instructions

1. Insert a needle into the rubber stopper until the tip slightly exits through the stopper.
2. Fill a 2-4 litre plastic or metal beaker with raw unfiltered sample water. Sample flow rate can be between 500 ml and 4 L per minute.
3. Place the water discharge tubing at the bottom of the 150 mL sample bottle. The tubing can be C-flex, tygon, copper, Teflon, etc. After it is filled place the bottle in the water filled beaker. The water should be flowing into the bottle when it is put in the beaker. Do not filter the sample, use raw sample.
4. Make sure that no bubbles are adhering to the sides of the bottle. Shake the bottle or jiggle the tubing to dislodge bubbles if present.
5. After at least 500 mL total have flushed through the bottle, withdraw the tubing and insert the stopper in the bottle while the bottle is submerged in the water. Make sure that you push the stopper all the way down.
6. Remove the needle from the stopper while the bottle is still submerged in the water. Properly dispose of all needles or return the used needles with the samples.
7. Take duplicates of all samples.
8. Record the (a) sample name, (b) water temperature and (c) estimated recharge altitude on the label attached to the foam sleeve. Do not put a label on the bottle. The bottle with stopper is pre-weighed. Do not switch stoppers from bottle to bottle.
9. Store samples on ice / refrigerated or at least as cool as the temperature of the sampled water. This will keep the stoppers from popping up as sample warms up. Store sample bottles upside down or on their side to keep any bubble that forms away from the stopper.

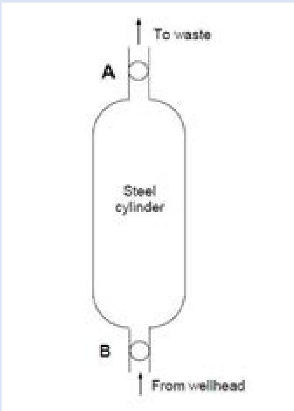


USGS (2006) and used in other countries such as Australia (Sundaram *et al.*, 2009)

Evacuated flasks can also be used to collect dissolved gas samples. This is the method used by BGS in the UK (BGS, 2014) and it is detailed in Box 13.2 below (courtesy of BGS, 2015). The sample flask is connected to the tap with tubing and several volumes of water are required to flush the flask to remove adsorbed gases. No air should be allowed to enter the tubing line or flask. The stopcock valves are then closed to provide a gas tight seal. These flasks are simple to fill and help to remove variability in sampling and therefore a duplicate for each sample is not required as it is in the USGS method.

Box 13.2. BGS steel cylinder sampling procedure

1. Connect tubing to each end of cylinder using the Swagelok® compression fittings.
2. Connect one piece of tubing to wellhead using clamped connections.
3. Allow water to flow though cylinder, which should be in a sub-vertical position, running water to waste through the other piece of tubing.
4. Ensure no air is trapped in the inlet tubing. Tap cylinder a few times with the end of a spanner (or similar) to dislodge any bubbles.
5. After flushing cylinder for a minute or two, close Tap A (outflow) firmly, followed immediately by Tap B (inflow).
6. Assuming no leaks develop under back-pressure, this will result in a sample containing dissolved gases at (or close to) pump pressure. (If closing Tap A causes tubing to blow off, better connections are required before trying again.)
7. Please try not to stick ID label over engraved serial number on cylinder.



Source BGS (2015)

Another method which is used by Bristol University alongside the BGS method in the UK baseline monitoring for methane in groundwater is using a vacuum bottle, as shown in Figure 13.1. A syringe is connected to the tubing from the sampling point so that no air is incorporated. A needle is then connected to the syringe and pushed through the septum of the bottle. The filled bottle is then stored upside down.

Figure 13.1. Methane sampling method using vacuum bottle (courtesy Bristol University).

The bubble strip method is a method used for separating the dissolved gas phase from the liquid phase in the field (Hirsche and Mayer, 2009). Groundwater is pumped through a bulb with a rubber septum. After flushing the bulb with sample, a predefined volume of an inert gas is injected through the septum into the bulb to form a headspace and this facilitates the achievement of equilibrium between the headspace gases and the dissolved gas in the sample. Once equilibrium has been reached, a syringe is inserted through the septum and a portion of the headspace gas is removed for analysis (Hirsche and Mayer, 2009). The method requires more time in the field and there is a higher possibility for error due to excessive degassing (Hirsche and Mayer, 2009).

Each of these methods are considered acceptable for sampling dissolved methane gas from groundwater in the field. The method chosen would depend on the requirements of the analytical laboratory and the sampling equipment that is available. It is noted that the steel containers used by BGS are very easy to use and the results have been found to be consistent, however the capital cost of the containers may be high. If another method is selected then it is recommended that more frequent duplicate samples are collected in the field at the start of the programme to verify the consistency of results.

13.1.2.3 Stable isotopes sampling

Sampling for stable isotopes in dissolved methane gas would depend on the requirements of the analytical laboratory. Large volumes of water (greater than 10 litres) may be required to provide sufficient dissolved methane to run the analysis.

Similarly to sampling for dissolved methane itself the water sample should not be exposed to air as demonstrated in Figure 13.2.

Above: Vacuum vile being filled using syringe and needle (after syringe was filled from tubing without exposure to air).

Left: Vacuum bag being filled by being directly connected to tubing without exposure to air.

Figure 13.2. Examples of stable isotope in dissolved methane sampling techniques (courtesy of Bristol University).

13.1.3 Surface water sampling methodology

13.1.3.1 Rivers/streams

Grab samples from surface waters (or springs) should be collected at predetermined locations using a GPS. Samples from surface waters (or springs) would be grab samples collected from a well-mixed portion of the water stream.

Bottleware and preservatives should be supplied by laboratories. To fill the container it is dipped into the surface water, with the opening facing upstream. Samplers should use a telescopic sampling pole where access to water courses is deemed unsafe. Sample bottles that require no filtering and have no preservatives can be filled directly in the stream. A sample bottle should be transported to the shore for filtering using a disposable 0.45 micron membrane filter.

13.1.3.2 Lakes

The sample sites selected for lake monitoring are located within the centre of the lake to be representative of the lakes water quality, therefore a boat would be required for most lakes. The shore and any inflows should be avoided where possible. If the lake is deep or stratified consideration to sampling at two depths should be given. Stratification should be determined in the field by measuring temperature and specific conductivity with a field probe along the depth profile of the lake, usually at one metre intervals.

Where access by a boat is not possible the sample should be collected about midway down the shoreline taking the prevailing winds into account and if there is a pier the sample can be collected from this using a telescopic sampling pole.

Bottleware and preservatives should be supplied by laboratories. To fill the container it is dipped into the surface water. Sample bottles that require no filtering and have no preservatives can be filled directly in the water. A sample bottle should be transported to the shore for filtering using a disposable 0.45 micron membrane filter.

Where a depth sample is being collected a water depth sampler should be used and the depth recorded.

13.1.4 Quality control protocol

Quality control procedures are required to monitor the effectiveness of sampling methodology and to demonstrate control over sources of error such as cross contamination. Guidance on quality assurance and quality control of environmental water sampling and handling is provided in BS ISO 5667–14 Water quality – Sampling Part 14 (ISO, 1998). The sampling personnel should be suitably qualified and trained professional. A lack of quality control procedures can lead to publishing erroneous data which can have significant consequences (USGS, 2011). Quality control procedures should be designed into the monitoring programme from the beginning and used to qualify data as necessary. The following is a list of QA/QC are samples that commonly collected during sampling and are recommended to be incorporated into the sampling programme (e.g. ISO 5667–14 and USGS, 2011):

- Duplicates: A duplicate is a sample collected at the same time as the main environmental sample, it can be achieved by splitting the sample. The analysis of duplicate samples gives an indication of sampling and analysis precision. Precision is measured by analysing two portions of the sample (sample and duplicate) and then comparing the results. The closer the results of the measurements are together, the greater is the precision. This comparison can be expressed in terms of relative per cent difference (RPD). Reimann *et al.* (2008) recommends that duplicates are carried out randomly for 5–10% of environmental samples.
- Field blank samples: Field blank samples are taken to identify errors relating to processing of identify errors due to sampling bottles, filtration equipment, sample transportation and contamination during sampling. The sample is deionized water (usually from the laboratory) that are exposed to the same conditions as the main environmental samples and are used to determine ambient contamination.
- Equipment blank or decontamination blank: Can also be taken by collecting deionised water that is poured over the sampling equipment after the equipment has been decontaminated. Analytical results are used to evaluate the adequacy of the decontamination procedure.
- Filtration blank: A filtration blank can be taken by filtering deionized water to identify errors mainly due to the sample bottles and the filtration process.
- Certified Reference Materials (CRMs): CRMs are material that has been tested and certified with a known level of uncertainty. When submitting them blind to a laboratory they can be used to assess the accuracy of analytical results.

13.2 GWDTEs

The information provided above for surface water would also apply to the turloughs and petrifying springs selected for water quality monitoring. Similarly, the information relevant to groundwater sampling applies to the existing borehole at the Roosky-Fardrum turlough.

13.3 Sediments

It is recommended that stream sediment sampling be carried out as guided by the procedures and methods applied during the Tellus Border project (Johnson *et al.*, 2005; Smyth, 2007; Milne *et al.*, 2013), for three reasons:

- The Tellus Border project was comprehensive in scope;
- Procedures are well described and tested;
- Implementation of same procedures (and analytical methods) improves the comparison of results between data sets.

Johnson (2005) describes relevant field planning, site selection, sampling methods, sample handling, and QA/QC procedures. Sample analysis would be carried out for radium isotopes by an accredited laboratory.

13.4 Hydrometric Monitoring

Hydrometric monitoring recommended for the baseline monitoring programme falls into these categories:

- Groundwater level monitoring;
- Spring discharge measurement; and
- Streamflow measurement

Groundwater level monitoring would be carried out using transducers installed in a subset of wells. The transducers should monitor changes in water level, temperature and EC. Final specifications on pressure ratings and cable lengths would need to be tailored to observed conditions at individual wells.

Spring discharge and streamflow measurements can be carried out using temporary staff gauge solutions fitted with standpipes and transducers to record changes in water level, pH, temperature and EC. Each station would be surveyed in terms of its channel cross-section, and periodic manual flow measurements would be needed to generate rating curves to convert transducer level readings to flows.

Regarding the use of transducers for continuous data collection of field parameters, these can be affected by a range of issues in the field, such as physical damage (natural, vandalism), biofouling and are subject to data 'drift'. For this reason, data have to be regularly downloaded and checked and the equipment needs periodic calibration and general maintenance or replacement, depending on field circumstances. Based on a 3-year EPA study involving continuous monitoring of selected springs, i.e. similar to what is recommended for the baseline monitoring programme, Drew and Tedd (2013) documented the value that is gained from long-term transducer installations but also cautioned that the initial level of effort that is required to establish confidence in the data being recorded should not be underestimated. The baseline monitoring programme of the UGEE JRP is, therefore, guided by the main lessons learnt from the EPA study regarding the equipment to be used, practical aspects of installations, as well as calibration and maintenance issues. Moving forward, it should also draw on lessons learnt regarding technical support from equipment manufacturers or vendors.

Despite the practical challenges that accompany the use of automatic data logging equipment, their application is regarded as a more feasible and appropriate response to the needs of the UGEE JRP compared to extensive and engineered gauging installations. The alternative would be to conduct all flow and monitoring of field parameters manually, but this would be significantly more labour-intensive. Continuous records of change are important to document, especially in dynamic karst flow systems.

13.5 Management and Reporting

In respect to the management and reporting on the baseline monitoring the following recommendations are made.

- A monitoring plan should be developed and kept updated as a live document. The monitoring plan would specify:

  - Field procedures/detailed standard operating procedures, including equipment decontamination in the field and sample custody, handling and transport procedures;
  - Proposed QA/QC protocols which should be robust in order to assess the quality of the data;
  - Project organisation including laboratories, management;
  - Analytical methods to be used, accreditation status, detection limits and holding times.
- Environmental monitoring reports should be comprehensive and include the following:
  - Sampling procedures used and any deviation from the Monitoring Plan;
  - Analytical methods used and any deviation from the Monitoring Plan;
  - Maps and GPS coordinates for all sampling locations and photographs;
  - Evaluation of data quality including evaluation of accuracy and precision using both field and laboratory QA/QC sample results;
    - Comparison of field measurement to laboratory (pH, conductivity, etc.) and evaluation that the arrived in satisfactory condition (no changes);
    - Evaluation of duplicate, CRM and field blank results;
    - Evaluation of sample decontamination procedures using decontamination blanks; and
    - Evaluations of the water quality data to make sure that the analyses are internally consistent and accurate and that major ions are not missing.
  - Comparison of validated results to appropriate environmental standards and background concentrations;
  - Recommendations concerning changes in the monitoring programme.
- Laboratories conducting the analysis would also be required to be transparent and supply details of their QA/QC protocols and results of specific QA/QC analysis run with the environmental samples, such as method blanks, CRMs and duplicates etc.
- It would be important that the person responsible for managing the data generated is experienced with environmental data and data validation techniques;
- The data generated should be stored in a central database in a consistent format for both Ireland and Northern Ireland;
- Validated baseline monitoring data and final environmental monitoring reports should be made publically available for trust and transparency.

14 Summary and Conclusions

Risks of environmental impact from UGEE operations are well described in international literature. Principal risks are associated with: a) the potential for stray gas migration of natural gas constituents from hydraulic fracturing operations; and b) the potential for spills, leaks and discharges associated with routine day-to-day UGEE operations at individual well pads and construction/transport across a wider area.

Potential surface sources of contamination are many and can, in most cases, be mitigated against with proper planning, enforcement and monitoring. Potential subsurface sources of contamination are related to hydraulic fracturing and are more difficult to mitigate against due to limited knowledge and inherent uncertainty about geological and hydrogeological conditions underground. Accordingly, risk mitigation requires prior characterisation of the physical–chemical systems involved at appropriate scales, in addition to employing best practice methods. The scale and content of such investigations depend on the scale and nature of proposed UGEE operations. For this reason, the prior characterisation must be tailored to case- and location-specific circumstances, for example where UGEE activity is proposed, how many drill pads are proposed, and what potential receptors of contaminants are present. Such items have to be specified and reviewed in context of licensing. Thus, case- and location-specific investigation and monitoring requirements are specified and established as part of the licensing process.

The key to risk identification, mitigation and monitoring is to develop an understanding of source–pathway–receptor relationships for any given site and proposed operation. For the two case study areas which have been examined as part of the UGEE JRP, these relationships are conceptually well understood. However, firm plans for UGEE activity at individual locations are not yet known. Therefore, case- and location-specific risks cannot be judged until such a time when details of plans for UGEE activity are presented.

From a broader, sub-regional perspective, the characterisation and knowledge of deep geological and hydrogeological conditions represent the principal data gaps associated with both case study areas, notably:

- Whether open natural fractures are present in deeper bedrock formations, including those that separate the unconventional gas target formations from shallow potential receptors;
- Whether, and the extent to which, deeper groundwater flow systems are present and may be hydraulically connected to shallow aquifers; and
- The chemical characteristics of deeper formation waters beneath the currently exploited shallow aquifers.

On the basis of existing data and information, potential pathways and hydrogeological connections between the deep unconventional gas target formations and shallow receptors are inferred rather than proven. Deep hydrogeological data are sparse. Although conceptual models inform about likely processes and associated risk factors, the hydrogeological characterisation of both case study areas would benefit from deep hydrogeological investigation. The data gaps associated with the hydrogeological characteristics of deeper formations and water resources can only be addressed by a combination of surface geophysical surveys (e.g. fault identification), drilling, borehole geophysical logging, hydraulic testing, sampling and monitoring of deep wells. The objective would be to gather data about water levels and water quality, hydraulic properties and potential pathways across the intervening formations that separate the unconventional gas target formations from shallow aquifers and associated (other) receptors. Future investigation (exploration) boreholes could be converted and installed as monitoring wells, which would subsequently be used as “sentinel” wells (CCA, 2014), or “warning wells”, provided their locations and positions are geographically relevant to future UGEE sites.

Prior baseline monitoring is a requirement of planning for UGEE activity, and are embodied in the European Parliament resolution on the “Environmental impacts of shale gas and shale oil extraction activities” [2011/2308(INI)]. Baseline monitoring applies to both the sub-regional and site scales. Sub-regional baseline monitoring programmes have been designed for the two case study areas – the Northwest Carboniferous and Clare Shale Basins. Following best practice guidelines in international literature, a precautionary approach has been adopted which is comprehensive in scope and extent, and would be capable of: a) describing general environmental pressures; and b) distinguishing impacts of UGEE-related activity from general environmental pressures. Importantly, baseline monitoring at the sub-regional scale should also be capable of addressing cumulative impacts across catchments.

Experiences from other countries are useful in guiding how baseline monitoring should be conducted, specifically the decisions about what should be monitored for and the methods of monitoring. However, information on baseline monitoring programmes in other countries cannot guide where monitoring should be undertaken in the two case study area, as the monitoring programmes have to be designed according to the hydrogeological systems and potential receptors that are present.

The sub-regional baseline monitoring networks that have been designed as part of the UGEE JRP are receptor-focussed and are based on conceptual hydrogeological models that define source–pathway–receptor relationships to the extent that data and information are available. The monitoring networks encompass groundwater, surface water and aquatic ecosystems in both case study areas, and provides recommendations for approaches, methods and potential new infrastructure that would be needed for implementation.

Baseline monitoring is a longer-term commitment and the resulting datasets would inform about natural trends as well as potential impact. To be cost-effective, there is opportunity to integrate the recommended baseline monitoring programmes with existing monitoring initiatives by public bodies in both Ireland and Northern Ireland. Any new infrastructure install as part of the UGEE JRP could, in turn, benefit the same public agencies in a longer-term perspective.

A distinction is made in the UGEE JRP between recommendations for receptor-focused baseline monitoring at the sub-regional scale and recommendations for improved geological/hydrogeological characterisation. Because UGEE activity is case- and location-specific, improved characterisation work should be carried out where UGEE activity is most likely to be targeted. A sub-regional approach to characterisation, whereby drilling is conducted over the wider study areas, would provide valuable data, but findings at one location can always be questioned or challenged in the context of another location. A sub-regional approach would not necessarily produce the answers that are needed at the case- and location-specific scale. The onus for location-specific characterisation would be on the UGEE companies, under terms of legislation and conditions set forth by regulators. The same applies for siting of well pads and the monitoring day-to-day activities if or when future UGEE activity takes place.

14.1 Summary of Sub-regional Baseline Monitoring Programmes

The recommended sub-regional baseline monitoring programmes are summarised in Figure 14.1 and Figure 14.2 and in Table 14.1. The overall scope and extent of monitoring is considerably greater in the NCB than in the CB. This partly reflects the much larger UGEE licence area of the NCB (*c.* 2200 km^2) compared to the CB (*c.* 496 km^2), but also the relative complexity of the NCB with regard to its hydrogeology and range of potential receptors.

The data generated would provide a consistent and comprehensive database of environmental conditions at the catchment scale in each study area. Specifically, the recommended monitoring includes:

- Groundwater sampling of existing public and private supply wells, springs and potential new monitoring wells;
- Surface water sampling of lakes and streams, including designated protected areas under the Water Framework Directive; and
- Hydrometric monitoring of spring discharges and stream flows at a limited number of locations (in the NCB only) where particular data gaps exist.

In addition, a small number of designated groundwater dependent habitats are recommended for water quality monitoring in the NCB, as follows:

- Roosky-Fardrum Turlough;
- Loughs Augh and White (both turloughs); and
- A group of 3 petrifying springs with tufa formations in the West Fermanagh Scarplands SAC, to be selected pending field verification.

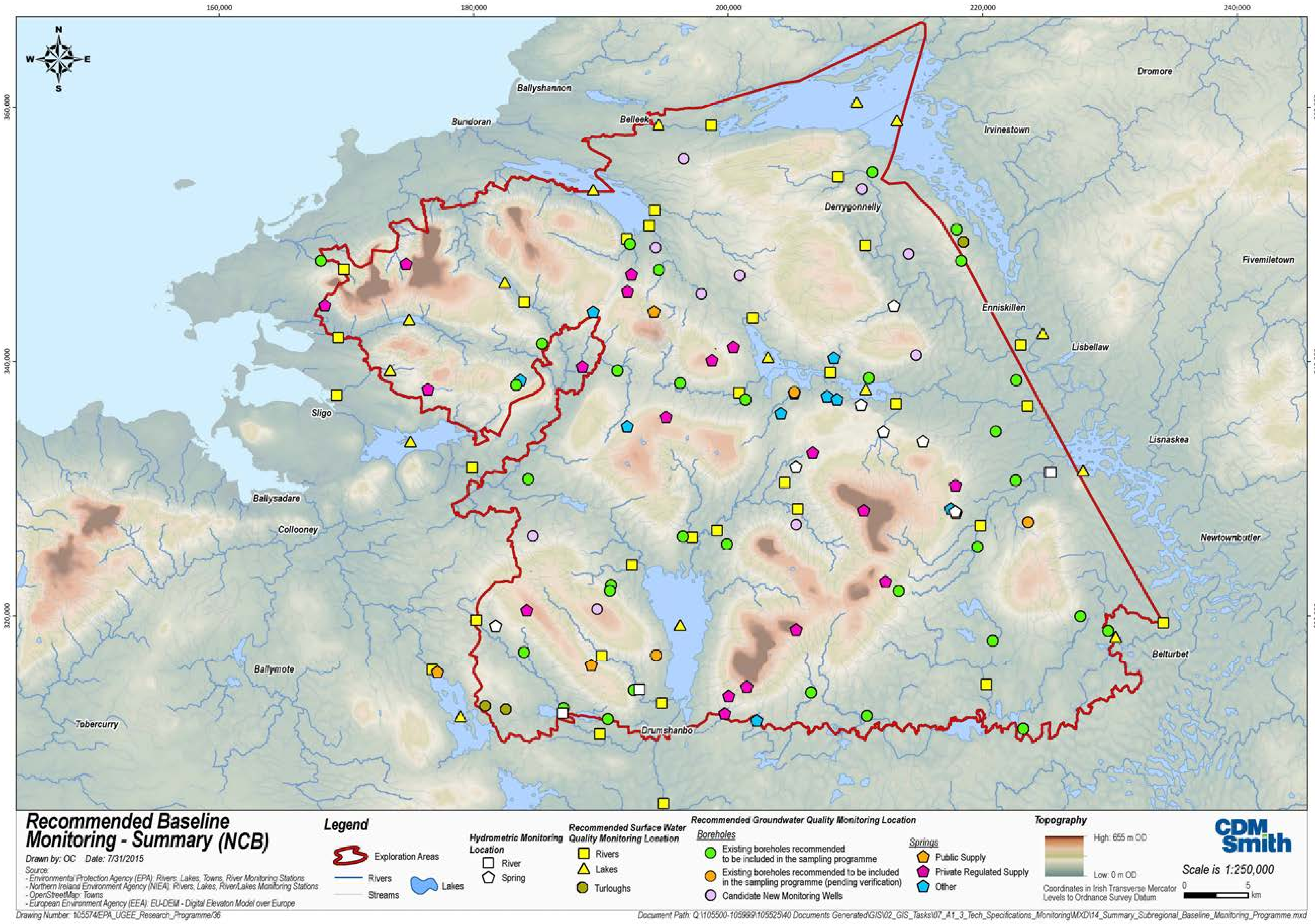


Figure 14.1. Overview of recommended monitoring stations for groundwater and surface water – NCB study area.

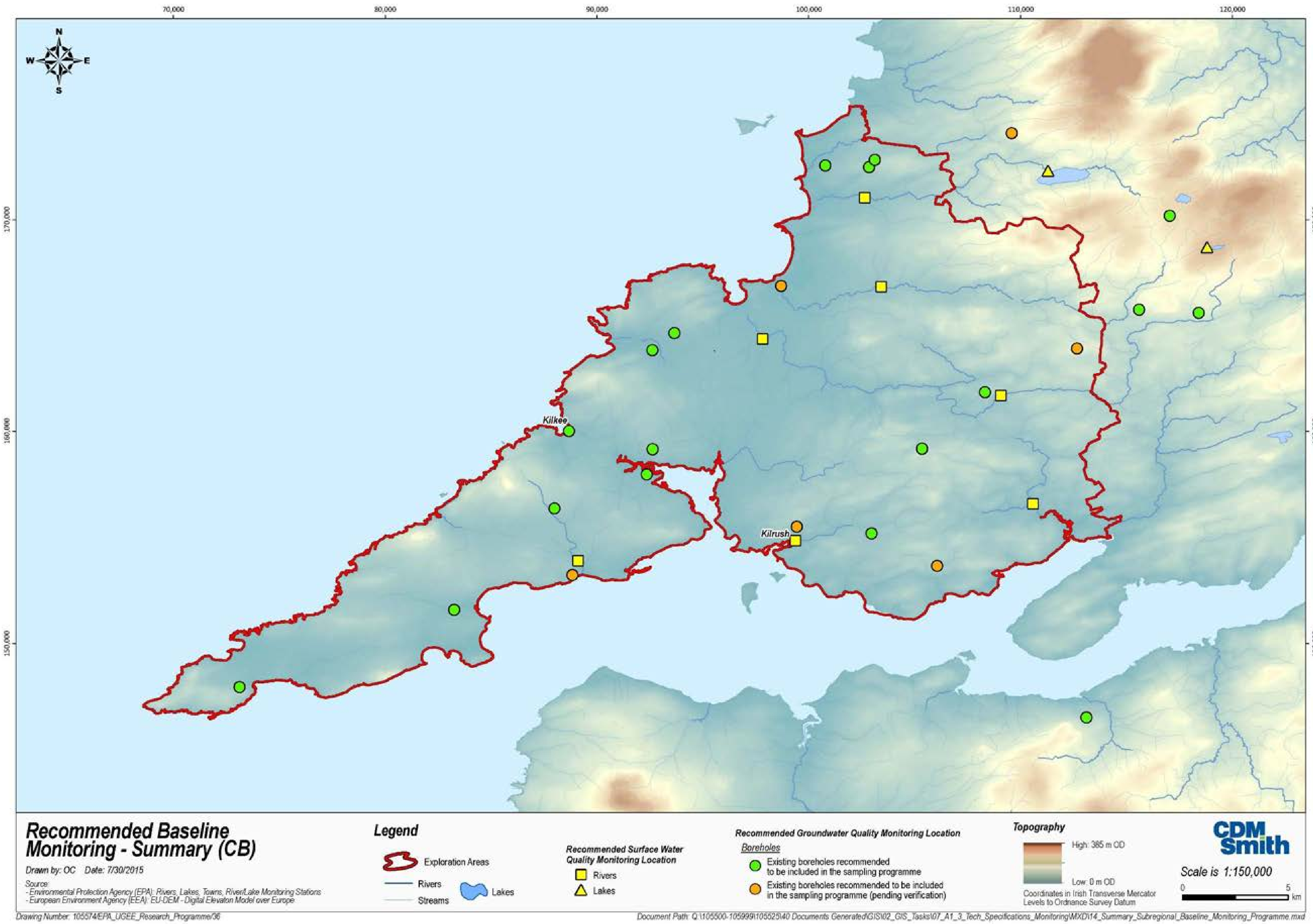


Figure 14.2. Overview of recommended monitoring stations for groundwater and surface water – CB study area.

Table 14.1. Summary of recommended baseline monitoring

	NCB No. of Stations	CB No. of Stations
Area (km^2)	**2200.40**	**495.65**
Groundwater quality – wells (PWS + GWS + private)	35	22[a]
Groundwater quality – wells (new)[b]	10	2
Groundwater quality – springs (PWS + GWS)	23	–
Groundwater quality – springs (other)[c]	10	–
Surface water quality – streams	32	7
Surface water quality – lakes	15	2
Surface water quality – turloughs	3	-
Groundwater – petrifying springs[d]	6	-
Hydrometric – stream flow	3	-
Hydrometric – spring discharge	7	-
Stream sediments[e]	30	15

[a]Estimated, to be finalised – 18 sites are accessible for sampling; a further 6 are require follow-up for verification of details or confirmation of owner agreement.

[b]New monitoring wells may need to be drilled for improved coverage in areas with data gaps. In the NCB, the emphasis is on areas where prospective UGEE activity has been flagged – Kilcoo Cross, Arigna/Drumkeeran and Dowra. New wells in the CB would be located towards the central and south-eastern part of the UGEE licence area, with final recommendations to be provided pending final verification of existing wells. Two wells is an estimated number of new wells to be drilled in the CB.

[c]Primarily large karst springs of sub-regional significance, although not used for water supply.

[d]Groundwater dependent habitats within SACs in the NCB. Two clusters of 3 petrifying springs in each cluster are proposed for monitoring to establish baseline water quality associated with these habitats.

[e]Locations not shown on figures as final locations are pending field verification of suitable sites.

Fen habitats which are present in the NCB are considered important to monitor as well, specifically to fingerprint naturally occurring (biogenic) methane. However, establishing representative baseline monitoring programmes for such environments is challenging since the majority of habitats are geographically widespread but occur as individual entities which are often disconnected from one another. The environmental supporting conditions of groundwater dependent habitats are inherently site-specific, and baseline monitoring at a given site (habitat) would only provide indications of the specific conditions that apply to that site. The generation and emissions of methane is also localised and subject to both spatial and temporal variations within individual habitats. For these reasons, baseline monitoring of priority GWDTEs/habitats requires prior study, involving site investigation and monitoring, to be able to identify and select a population of sites for longer-term baseline monitoring This may be attempted, but may also not be achievable within the timeframe of the UGEE JRP. In this regard, it is considered appropriate to recommend that such study and monitoring be conducted if or when details about future planned UGEE activities become known, as field work can be guided geographically.

Such monitoring should in all cases be considered when scoping, planning and assessing future UGEE activity at specified locations, as the habitats are ecologically significant and many are located within SACs. In such cases, the onus of prior study and monitoring should be placed on the developer with appropriate review and supervision by regulatory bodies.

14.1.1 Sampling and analysis of water quality

International best practice requires that samples be analysed for a wide range of analytical parameters. However, baseline monitoring cannot account for all potential chemicals associated with UGEE. Even if the composition of all hydraulic fracturing chemicals were constant and known in full, the totality of permutations of potential breakdown and transformation products cannot be predicted or described, as chemicals in both groundwater and surface waters are subject to what is actually used at a given site and application, as well as a range of breakdown products which result from transformation processes such as biodegradation, partitioning, and phase changes.

Thus, laboratory analysis would be guided by “chemical fingerprinting”. The recommended approach is to monitor for groups of chemicals and constituents which are representative of UGEE activity. “Fingerprinting” is best done with parameters that are rare or non-detectable in the natural settings of the case study areas, and that are distinguishable from other environmental pressures that may be present. This includes stable isotopes, radioisotopes and chemicals associated with flowback waters (e.g. barium, bromide, strontium).

The principal contaminant of concern from UGEE operations is methane in groundwater. Thus, dissolved gas monitoring in groundwater would be prioritised, along with fingerprinting techniques to define the origins of the gas, provided that dissolved gas is detected in a given sample. Because baseline data for natural gas constituents do not yet exist in the case study areas, it is recommended that the methods of current sampling by the British Geological Survey in England and Wales be adapted for Ireland and Northern Ireland.

Establishing sub-regional monitoring programmes which are capable of both documenting existing environmental pressures and identifying potential future impact from UGEE activity at the catchment scale have to be comprehensive by default. The associated burden on resources would, accordingly, be significant. For this reason, an approach of ‘adaptive monitoring’ is recommended which allows for a degree of flexibility about where and what is sampled and analysed. The BGS has adopted a tiered approach of analysis, whereby screening-type analyses for lower cost parameters inform about the need for analyses of higher cost parameters. A relevant example is the analysis of methane and stable isotopes in groundwater. If dissolved methane is absent or concentrations are below a certain threshold value, then isotopic fingerprint analysis of methane may not be not carried out. Similarly, if field-measured dissolved oxygen (DO) concentrations are high in groundwater, then the analysis for dissolved methane may be redundant.

Should plans for UGEE be authorised in the future, the baseline monitoring can also be adjusted geographically as plans for UGEE activity become known. Accordingly, monitoring strategies and programmes may evolve in time, also as new data become available and new monitoring installations become active.

14.1.2 Sampling and analysis of stream sediments

It is recommended that sampling of stream sediments is included in the baseline monitoring programme, with gross alpha and gross beta screening, as well as further analysis of radium isotopes if relevant screening thresholds are exceeded. Although this is a one-time characterisation effort, it is important because radium isotopes are the principal UGEE-related contaminants of concern in sediments, and radium data from stream sediments are not available in either of the two study areas. Sample locations are not included in Figures 14.1 and 14.2 because suitable locations have not yet been identified, requiring field verification to locate low-energy environments where sediments accumulate. In the NCB, this should be coordinated as much as possible with sample locations from the existing Tellus Border datasets of other naturally occurring radioactive materials (NORM) and metals.

14.1.3 Monitoring for impact from UGEE-related abstractions

UGEE operations require water, and the highest water demands would occur during the hydraulic fracturing programmes at individual wells. As a cost-saving measure, it is expected that UGEE companies would try to source water locally.

Available water resources are represented by rainwater, lakes and reservoirs, streams and rivers, and groundwater in bedrock aquifers. There is capacity to supply water use requirements of potential future UGEE development in both study areas, but this would ultimately be conditioned and influenced by *how* and *where* the development would proceed, both spatially and temporally. Local supply options are considerably wider in the NCB study area compared to the CB study area.

Capacity would have to be judged by actual total demand, with a clear understanding of timelines of total demands. For the peak 'probable commercial' build-out scenarios defined in *Final Report 4: Impacts and Mitigation Measures* of the UGEE Joint Research Programme (CDM Smith, 2016), the total potential demand is driven by how many wells are hydraulically fractured in the same time period. Water demands would likely have to be supplied from multiple sources in parallel, and for this reason, future UGEE-related abstraction plans would have to be carefully defined to understand the timeline of total demands, individually and cumulatively, with the involvement of relevant stakeholders and regulatory bodies.

Risks of *volumetric* impacts are lower in large lakes and streams, and greater in small lakes and streams. Identifying and documenting volumetric impact is relevant in a regulatory context, but ultimately, impact from abstractions are more appropriately described by changes to *ecological* reference conditions (e.g. macroinvertebrates, hydromorphology and physico-chemical quality). In the process of licensing or granting prior authorisation of future UGEE-related abstractions, environmental reference conditions would have to be identified on a case by case basis, using site- and case-specific inputs (e.g. flow data and ecological datasets), and requiring technical judgement by specialists in related fields. The distinction between "small" and "large" abstractions is relative, depending on source, and impact assessment should be based on consideration of aquatic ecology from lines of evidence.

Existing abstraction pressures are currently considered to be low in both case study areas. Future UGEE-related abstractions would have to be considered in regards to the requirements of existing statutory instruments and efforts by the EPA and NIEA to maintain "good quantitative" and "good ecological" status of water bodies. As UGEE activity is rarely confined to single locations, abstractions could have a cumulative impact which would need to be addressed by appropriate monitoring.

14.2 Notes on the Recommended Baseline Monitoring Programmes

With regard to the sampling and documentation of naturally occurring methane in groundwater, the recommended baseline monitoring programme includes 45 sites in or near the c. 2200 km^2 UGEE licence area in the NCB, and likely 20+ sites in or near the c. 496 km^2 licence area in the CB (pending verification of a small number of sites). The sites are distributed across several bedrock formations which are used for water supply purposes and which have relevance to hydraulic fracturing activity. For purposes of comparison, the National Methane Baseline Survey carried out by the BGS (2014) in England, Scotland and Wales includes, to date, approximately 330 sites (mostly abstraction wells), with a focus on areas where aquifers are underlain by shale units that may be exploited for unconventional gas. The US Geological Survey (USGS, 2012) carried out baseline monitoring of methane in 66 private wells across a 5200 km^2 area in the state of New York. The

USGS is also carrying out a baseline survey for dissolved gases, including methane, in groundwater from approximately 50 private wells across a 200 km^2 area prior to unconventional gas exploration in North Carolina (USGS, 2015), and Warner *et al.* (2013b) describe methane analysis of samples from 127 private wells across an approximately 2200 km^2 area in Arkansas. Finally, Pinti *et al.* (2013) reported on results from a baseline survey of 130 private wells in a 14,000 km^2 area in Quebec in support of a government-supported strategic environmental assessment of unconventional gas development options.

In this context, density of sampling points is relevant but is not the main criterion by which to judge ‘adequacy’ of a monitoring network. What is principally important is that monitoring covers the range of identified potential receptors that are present within each study area.

Much of the data that would be produced from the recommended baseline monitoring programme are ‘standard’ and similar to monitoring initiatives which are presently undertaken by public bodies in both Ireland and Northern Ireland as part of WFD implementation. Where sample locations recommended for the UGEE JRP coincides with existing monitoring, e.g. stream and lake sample locations, cost savings could be achieved as sampling activities would be coordinated to avoid duplication of effort. However, significant ‘new data’ would also be generated for parameters that are not commonly sampled or analysed for, and which reflect the particular nature of UGEE operations. Principal amongst these are natural gas constituents, notably methane, and naturally occurring radioactive materials (NORM) in groundwater.

Finally, the sub-regional baseline monitoring programme focuses on receptors at the sub-regional scale and is different from the baseline monitoring that would be required of UGEE operators as part of a future planning and licensing process. The environmental risks associated with hydraulic fracturing activity are both case- and location-specific, thus baseline monitoring required of UGEE companies would have a more targeted geographic and technical focus. The monitoring would also be preceded by detailed hydrogeological characterisation and risk assessment of potential contaminant mobilisation from deeper formations to shallow receptors.

14.3 Addressing Deep Geological and Hydrogeological Data Gaps

The characterisation of deep geological and hydrogeological conditions represents the principal data gap associated with both case study areas of the UGEE JRP, notably:

- Whether, and the extent to which, deeper groundwater flow systems are present;
- Whether open natural fractures exist in deeper bedrock formations; and
- The chemistry of deeper formation waters beneath the currently exploited shallow aquifers.

On the basis of existing data and information, potential pathways and hydrogeological connections between the deep unconventional gas target formations and shallow receptors are inferred rather than proven. Deep hydrogeological data are sparse. Although conceptual models inform about likely processes and associated risk factors, the hydrogeological characterisation of both case study areas would benefit from investigative deep drilling. The data gaps associated with potential deeper water resources and open fracture networks can only be addressed by drilling, borehole geophysical logging and hydraulic testing. The objective would be to gather data about water quality, water levels and potential pathways across the formations that separate the UGEE target formations from shallow aquifers and other potential receptors.

Investigation (exploration) boreholes would be converted and installed as monitoring wells, which could subsequently be used as “sentinel” wells (CCA, 2014), or “warning wells”, if their locations and positions are geographically relevant to future UGEE sites.

A distinction is made in this report between recommendations for receptor-focused baseline monitoring at the sub-regional scale and recommendations for improved geological/hydrogeological characterisation. Because UGEE activity is case- and location-specific, improved characterisation work should be carried out where UGEE activity is most likely to be targeted. A sub-regional approach to characterisation, whereby drilling is conducted over the wider study areas, would provide valuable data, but findings at one location can always be questioned or challenged in the context of another location. A sub-regional approach would not necessarily produce the answers that are needed at the case- and location-specific scale. The onus for location-specific characterisation would be on the UGEE companies, under terms of legislation and conditions set forth by regulators. The same applies for siting of well pads and the monitoring day-to-day activities if or when future UGEE activity takes place.

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Abbreviations

AMD	Acid mine drainage
ASSI	Areas of Special Scientific Interest
ATV	Acoustic televiewer
Bbl/d	Barrels per day
BGS	British Geological Survey
Bls	Barrels
BMWP	Biological Monitoring Working Party
BOD	Biochemical oxygen demand
BPH	Barrels per hour
CB	Clare Basin
CCA	Council of Canadian Academies
CCG	Central Clare Group
CO_2	Carbon dioxide
DCENR	Department of Communications, Energy and Natural Resources
DETI	Department of Enterprise, Trade and Investment
DIC	Dissolved inorganic carbon
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DRBC	Delaware River Basin Commission
EC	European Commission
Eh	Redox potential
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EU	European Union
ft	Foot/feet
GPS	Global Positioning System
GSI	Geological Survey of Ireland
GSNI	Geological Survey of Northern Ireland
GWB	Groundwater basin
GWDTE	Groundwater dependent terrestrial ecosystem
GWS	Group water scheme
H_2S	Hydrogen sulphide
HDPE	High-density polyethylene
HMWB	Heavily modified water body
IGI	Institute of Geologists of Ireland
IW	Irish Water
JNCC	Joint Nature Conservation Committee
JRP	Joint Research Programme
LAB	Lough Allen Basin
LI	Locally important bedrock aquifer, moderately productive only in local zones

Lm	Locally important aquifers
LOC	Loss of circulation
m^3/d	Cubic metres per day
$m^3/d/m$	Cubic metres per day per metre
MAC	Maximum admissible concentration
MCPA	2-methyl-4-chlorophenoxyacetic acid
mD	Millidarcies
mOD	Metres Ordnance Datum
MRP	Molybdate reactive phosphorus
NCB	Northwest Carboniferous Basin
NHA	Natural Heritage Area
NIEA	Northern Ireland Environment Agency
NIW	Northern Ireland Water
NO_3	Nitrate
NORM	Naturally occurring radioactive materials
NPWS	National Parks and Wildlife Service
OPW	Office of Public Works
PAD	Petroleum Affairs Division
PAH	Polycyclic aromatic hydrocarbons
Pl	Generally unproductive bedrock aquifer
pNHA	Proposed Natural Heritage Area
PPA	Poorly productive aquifers
ppm	Parts per million
Pu	Generally unproductive aquifer
PWS	Public water supply
QA	Quality assurance
RBD	River Basin District
Rk	Regionally important karstified bedrock aquifer
Rkc	Regionally important karstified limestone aquifer dominated by conduit flow
RPII	Radiological Protection Institute of Ireland
SAC	Special Areas of Conservation
SEA	Strategic Environmental Assessment
SPA	Special Protection Area
S-P-R	Source-Pathway-Receptor
STRIVE	Science, Technology, Research and Innovation for the Environment
SVOC	Semi-volatile organic compounds
THM	Trihalomethane
TOR	Terms of reference
µg/l	Micrograms per litre
UGEE	Unconventional Gas Exploration and Exploitation
UKTAG	UK Technical Advisory Group
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

VOC	Volatile organic compounds
WFD	Water Framework Directive