COILLTE TEORANTA

Report on the Hydrogeological Study of the Flush system in Shanvolahan, Co. Mayo

Consultancy Report

MEL Doc. Ref.: 1423-258.doc

7th September, 2006

Confidential Report To:

Caroline White
Coillte
Government Buildings
Cranmore Road
Sligo

Report submitted by:

Minerex Environmental Limited

Taney Hall,
Eglinton Terrace,
Dundrum
Dublin 14
Ireland

Tel.: +353-(0)1-2964435
Fax.: +353-(0)1-2964436
Website: www.minerex.ie

Prepared by:

Eileen McCarthy M.Sc.
Director & Senior Hydrogeologist

Minerex Environmental Limited

Contents

1. INTRODUCTION……………………………………………………………………………………………..1

1.1 Background…………………………………………………………………………………………… 1

1.2 Purpose of Study……………………………………………………………………………………1

1.3 Work Schedule…………………………………………………………………………………………1

2. METHODOLOGY………………………………………………………………………………………………2

2.1 Desk Study……………………………………………………………………………………………..2

2.2 Site Investigations……………………………………………………………………………………..2

2.3 Monitoring Network Produced…………………………………………………………………………..3

3. BASELINE HYDROGEOLOGICAL CONDITIONS……………………………………………………………..3

3.1 Physiographic Setting………………………………………………………………………………3

3.2 Geological Setting……………………………………………………………………………………..4

3.2.1 Bedrock Geology…………………………………………………………………………………...4

3.2.2 Soils and Subsoils Geology……………………………………………………………………….5

3.3 Hydrological Setting…………………………………………………………………………………..6

3.3.1 Catchments…………………………………………………………………………………………6

3.3.2 Drainage……………………………………………………………………………………………6

3.3.3 Surface Water Chemistry…………………………………………………………………………6

3.4 Hydrogeological Setting……………………………………………………………………………7

3.4.1 Aquifer Classification………………………………………………………………………………7

3.4.2 Water Table………………………………………………………………………………………7

3.4.3 Piezometric Levels and Vertical Gradients……………………………………………………...7

3.4.4 Groundwater Chemistry…………………………………………………………………………..8

4. CHANGE IN HYDROGEOLOGICAL CONDITIONS……………………………………………………………10

5. CONCLUSIONS AND ONGOING PHD RESEARCH…………………………………………………………11

6. REFERENCES…………………………………………………………………………………………………12

Tables

Table	**Title**	**Page No.**
Table 1	Bedrock Geology Formations and Stratigraphic Sequence	4
Table 2	Bedrock Aquifer Classification	7
Table 3	Summary of Dominant Vertical Hydraulic Gradients at Shanvolahan (Feb-03 to Aug-06)	8
Table 4	Peat Water Type Results from October 2003 & November 2004	9
Table 5	Mineral Subsoils Water Type Results from October 2003 & November 2004	10
Table 6	Monitoring Points that register or might register water level change as a function of Restoration	10 & 11

Appendices

Appendix A1	Site Location Map	1 x A4	1423-008.wor
Appendix A2	Vegetation Map	1 x A4	1423-008.wor
Appendix A3	Habitats Map	1 x A4	1423-008.wor
Appendix B1	Bedrock Geology Map	1 x A4	1423-008.wor
Appendix B2	Subsoil Geology Map	1 x A4	1423-008.wor
Appendix C1	Hydrological Catchment Map and GSI / MCC Well Database Search Results	1 x A4	1423-008.wor
Appendix C2	Bedrock Aquifer Classification Map	1 x A4	1423-008.wor
Appendix D1	Site Investigation Peat Distribution Map (OSI Basemap)	1 x A4	1423-008.wor
Appendix D2	Site Investigation Peat Distribution Map (Aerial Photograph)	1 x A4	1423-008.wor
Appendix D3	Site Investigation Mineral Subsoil Distribution Map	1 x A4	1423-008.wor
Appendix E1	Monitoring Network (OSI Basemap)	1 x A4	1423-008.wor
Appendix E2	Monitoring Network (Aerial Photograph)	1 x A4	1423-008.wor
Appendix E3	Monitoring Network (Vegetation Mapping)	1 x A4	1423-008.wor
Appendix F1	Summer Phreatic Contour Map (20/08/03)	1 x A4	1423-008.wor
Appendix F2	Winter Phreatic Contour Map (04/02/04)	1 x A4	1423-008.wor
Appendix G1	Summer Piezometric Contour Map (20/08/03)	1 x A4	1423-008.wor
Appendix G2	Winter Piezometric Contour Map (04/02/04)	1 x A4	1423-008.wor
Appendix H1	Summer Electrical Conductivity Map (20/08/03)	1 x A4	1423-008.wor
Appendix H2	Winter Electrical Conductivity Map (04/02/04)	1 x A4	1423-008.wor
Appendix I1	Summer pH Map (20/08/03)	1 x A4	1423-008.wor
Appendix I2	Winter pH Map (04/02/04)	1 x A4	1423-008.wor
Appendix J1	Location of Detailed Hydrogeological Cross Sections	1 x A4	1423-008.wor
Appendix J2	Hydrogeological Cross Section at XS-1	2 x A3	1423-008.wor
Appendix J3	Hydrogeological Cross Section at XS-2	1 x A3	1423-008.wor

Appendix J4	Hydrogeological Cross Section at XS-3	1 x A3	1423-008.wor
Appendix K	Site Investigations Database / Inventory	5 x A3	1423-011.xls
Appendix L1	Field Monitoring Results Database	50 x A4	1423-011.xls
Appendix L2	Hydrometric Charts	20 x A4	1423-011.xls
Appendix M	Graphical Logs of Monitoring Network Installations	36 x A4	1423-024.ppt
Appendix N1	Laboratory Analysis of Water Samples Taken from Selected Network Points	1 x A3	1423-010.xls
Appendix N2	Piper Plots for Water Samples	2 x A4	1423-010.xls

1. INTRODUCTION

1.1 Background

Coillte Teoranta (Irish Forestry Board) contracted Minerex Environmental Limited (MEL) to undertake a hydrogeological assessment of the 'flush' and lowland blanket bog system at Shanvolahan, Co. Mayo. This work was executed under the LIFE Blanket Bog Restoration Project in Ireland under Action Code **F02EF5** "Gain a scientific understanding of points of ground water discharge 'flushes' and their surrounding ecology." (Ref. 1).

The Shanvolahan site is partially covered by forestry and is site no. 11 in the restoration scheme. Approximately 76 hectares of forest has been planted at the site (Appendix A1). The Bellacorrick complex in which Shanvolahan is located, represents some of the best examples of flush ecology in Ireland. This highlights the opportunity and significance of effective conservation and restoration of the Shanvolahan site to enhance flush diversity at this location.

1.2 Purpose of Study

The purpose of Minerex's hydrogeological study of flush hydrogeology is:

(a) To understand why and how the flush ecology at Shanvolahan occurs.
(b) Generate a conceptual model / understanding of the relationship of flush ecology with groundwater movement and groundwater / surface water chemistry relationships.
(c) On the basis of evaluation of the hydrogeological model developed from the study, provide recommendations for improvements in understanding and where possible appropriate engineering measures for flush protection, restoration and enhancement.

1.3 Work Schedule

The following work schedule has been completed for this report.

A1: Monitoring Network Installation:

- 12th September 2002 – Field examination of candidate sites with Coillte and NPWS Personnel. Selection of Shanvolahan as suitable site for detailed hydrogeological flush study. Decision to focus on one site in detail rather than two in less detail to provide a detailed and comprehensive study of "flush hydrology". Initiation of study with field discussion of objectives and methodologies.
- 10th to 13th October 2002 – Gouge coring, peat and subsoils logging, drainage and terrain mapping including preliminary hydrochemical measurements of surface water runoff. Initial field characterisation and selection of suitable locations for permanent monitoring points.
- 6th to 10th November 2002 – Site walkover with project botanist (John Conaghan of Enviroscope) to agree joint botanical and hydrological locations for monitoring network installations. Installation of monitoring network which includes piezometers, phreatic tubes, staff gauges, surface water hydrochemical points at selected locations for detailed cross section profiles and overlay with flora investigations.
- 29th to 30th January 2003 - Detailed topographical survey using Differential Global Positioning System (D-GPS) along hydrogeological cross section transects including elevation survey of groundwater and surface water monitoring points.
- 13th to 16th February 2003 – Hydraulically powered percussion window sample drilling (Cobra) for characterisation of deep mineral subsoil substrates. Installation of deep piezometers (OB Series) to couple with adjacent peat installations (P and PH Series) to provide a full depth sampling suite of water levels, pressure heads and groundwater chemistry.

A2: Monitoring Network Monitoring:

- 17th February 2003 to 4th February 2004 – Baseline Monitoring Programme over 12 months under contract of Brief A2. This involved measurement of water levels (monthly), field hydrochemistry (every

2 months) and laboratory analysis of selected ground- and surface waters (twice annually). Flow gauging was also undertaken on a high, and low flow basis to produce a stage discharge curve on the two main drains D1 and D3 that exit the hydrological catchment.

- 5th February 2004 to on-going (2006) – Continuation of Monitoring under PhD Research Programme (independent of Coillte) funded by the National Parks and Wildlife Service (NPWS) and supervised by Trinity College Dublin (TCD). Extension of monitoring programme to capture immediate impact (if any) of felling of commercial forestry at Shanvolahan from February 2004 to Current. This involved measurement of water level and field hydrochemistry every 2 months over a 12 month period.

2. METHODOLOGY

2.1 Desk Study

- Acquire and compile all maps from Coillte for the proposed study site. This includes forestry zonations with database properties in ArcView.
- Overlay Ordnance Survey of Ireland (OSI) Discovery Series 1:50,000 and 1:10,560 (6”) basemaps and Aerial Photographs in MapInfo GIS.
- Overlay Geological Survey of Ireland (GSI) Geology maps (1:100,000) to determine site bedrock geology and the presence of any major faults or other anomalies at / near the site.
- Overlay Geological Survey of Ireland (GSI) Quaternary maps (1:10,560) and Teagasc / EPA updated subsoils maps (1:50,000) to determine regional distribution of subsoils and associated geomorphology relative to the study site.
- Overlay Geological Survey of Ireland (GSI) aquifer classification and vulnerability maps, and GSI well database results to determine bedrock hydrogeology and the number and proximity of groundwater abstractions relative to the study site.
- Overlay vegetation maps provided by John Conaghan (Enviroscope) outlining baseline flora and habitats zonations for purpose of comparison with hydrogeological results.
- Acquire and overlay the results of intrusive investigation results comprising peat probes, gouge cores and cobra drill holes and assessing their hydrogeological significance in the context of subsoil type, distribution, permeability and chemistry.
- Consultation with National Soils Survey of Ireland (An Foras Taluntais) on the soils of Co. Mayo.
- Consultation with Met Eireann for meteorological service records for the period 1961 to 1990 of the closest pertaining synoptic and rain gauge sites
- Selection of transect locations in consultant with project botanist (John Conaghan) for the purpose of developing detailed hydrogeological cross sections.
- Update existing graphics with new layers of information arising from field and laboratory analysis of groundwater and surface water chemistry and hydraulics.
- Produce detailed hydrogeological cross sections along selected eco-hydrogeological transects. The purpose of which is to illustrate hydrogeological functioning in cross section as well as assisting in the development and illustration of a hydrogeological conceptual model(s) for the origins and functioning of flush ecology.
- Use all acquired data to provide a detailed and comprehensive Hydrogeological Assessment Report of research findings of the baseline hydrological conditions and controls on flush ecology at Shanvolahan.

2.2 Site Investigations

- Site walkover and assessment of drainage, recharge and discharge zones and likely groundwater flow characteristics.
- Peat depth probing transverse and parallel to the main axes of the wetland complex to illustrate range of peat depths and the composition of subsoils beneath the wetland complex.
- Description and logging of sediments to BS 5930 (Ref. 2) and to Von Post Humification scale (Ref. 3) to determine peat and mineral subsoils texture and permeability characteristics.
- Overburden drilling using hand operated gouge corers and a cobra hydraulic (hammer percussion) rig to install coupled piezometers and single standpipes to measure water levels, hydraulic gradients and chemistry at various depths and spatial locations in the wetland (e.g. recharge and discharge zones).

- Differential GPS and Total Station surveying of all investigation points and monitoring installations to provide accurate location co-ordinates and height elevation relative to metres above Ordnance Datum Malin (mOD Malin).
- Installation of surface water monitoring points for repeated hydrochemical measurements over the schedule of the monitoring programme and installation of staff gauges to measure water levels in drainage and correlate against discharge measurements for stage-discharge curves.
- Flow measurements in the main drain (D1 and D3) at exit points from the local wetland catchment to determine baseline flow capacity and range (high / low) and loss of water balance by drainage discharge from the site.
- Creation of canalised channels for purpose of manual flow gauging at FG1 and FG2. Calculations of dimensions suitable for flume / weir installations for automated discharge measurements.
- Frequent (every 2 months) hydrochemical measurements of surface water and groundwater (electrical conductivity, pH and temperature) to determine source and ionic concentrations of waters present on site.
- Twice annual detailed laboratory analysis of groundwater and surface water samples taken from the monitoring network for detailed hydrochemical assessment (major ions, nutrients and redox metals).
- Acquire digital photographs of all items of significance and reference for illustration in report and to third parties.

2.3 Monitoring Network Produced

Following completion of the field survey and site investigations, the following groundwater and surface water monitoring network was installed and provides site-specific data for this hydrogeological assessment (Appendices K, E and M).

- 16 Surface Water Hydrochemistry Points (SW Series)
- 6 Surface Water Staff Gauge Points (SG Series)
- 2 Surface Water Flow Gauge Points (FG Series)
- 18 Groundwater Phreatic Water Table Points (PH Series)
- 49 Groundwater Piezometer Points (P Series)
- 5 Groundwater Deep Mineral Suboils Piezometer Points (OB Series)
- 21 Couples of the above combined groundwater installations (C Series)

3. BASELINE HYDROGEOLOGICAL CONDITIONS

3.1 Physiographic Setting

Shanvolahan study site is located in North Co. Mayo c.7km west-northwest of Crossmolina and c.2.5km northeast of Eskeragh, a small village located on the N59 National Secondary Road. The centre of the site is located by Irish Grid Co-ordinates E106,900 - N320,400. The extent of the study site as defined by its local hydrological catchment is c.4.36km^2 (Appendix C1), while the central study area as defined by flora and habitats of significance is 1.53km^2 (Ref. 4).

The study site is located on lowland terrain between 95 and 60mOD Malin. Within the hydrological catchment, the highest ground is located to the west of the mature forestry plantation with an local hill apex of c.95mOD. Elsewhere, the highest ground is defined by the hydrological catchment (Appendix C1) and occurs to the north, to the west and the east (70-80mOD). From site-specific ground surveys, the lowest ground occurs in the southeast of the site adjacent to D1 (near SG5) at 63.4mOD and 64.9mOD at c.E107,097 – N319,832. The Ordnance Survey of Ireland (OSI) has indicated that lowest elevations of c.60mOD exist at the very south of the site proximal to the Shanvolahan River which acts as the discharge zone or capture zone for all waters emanating from the study site. An additional complexity to the topographic composition of the site is the presence of a number of “upland intrusives” within and peripheral to the lowland blanket bog.

3.2 Geological Setting

3.2.1 Bedrock Geology

The study site is underlain by the following bedrock formations:

Table 1: Bedrock Geology Formations and Stratigraphic Sequence

Age	Formation	Map Code	Lithological Description
Lower Carboniferous "DINANTIAN " (c.360-330 Ma) Older → Younger	Ballina Limestone Formation (Upper)	**BU**	Succession of cleaner limestone interbedded with thin shale. Fully marine deposition on carbonate shelf. Main litho-unit: Cleaner LIMESTONE
	Ballina Limestone Formation (Lower)	**BL**	Interbedded dark grey fine-grained muddy limestone and calcareous shale. Fully marine deposition on carbonate shelf. Main litho-unit: Muddy LIMESTONE
	Unconformable Contact		
	Downpatrick Formation	**DK**	Sequence of interbedded rock types comprising: • Near-shore marine mudstones and siltstones. • Alluvial and deltaic sandstones. • Fully marine bioclastic limestones interbedded with calcareous shales. Main litho-unit: Calcareous SANDSTONE and SILTSTONES

The Downpatrick Formation (**DK**) is the oldest bedrock formation present at the study site. This formation occurs to the south of the site and is defined by a linear northwest-southwest fault (labelled **Fault 1**) that crosses the central part of the site, through the forestry plantations (Appendix B1). The Downpatrick Formation is a sequence of inter-bedded rock types comprising of <u>near-shore</u> marine mudstones and siltstones, <u>alluvial</u> and <u>deltaic</u> sandstones and siltstones and fully <u>marine</u> bioclastic limestones inter-bedded with calcareous shales. This Formation represents the encroachment of the Lower Carboniferous Sea onto the earlier coastal plains and "Old Red Sandstone" terrestrial lands from the Devonian period between c.345 to 395 Mya (Ref. 5). No direct evidence of the occurrence of the Downpatrick Formation was identified from field investigations due to significant field cover by peat and soft subsoils deposition.

The Ballina Limestone Formations occur in the north of the study site, and thus north of the northwest-southwest fault that bisects the study site in two. These formations (upper and lower) represent the fully established sea and thus a change to fully marine conditions with deposition on a carbonate shelf at the study site. The Lower Ballina Limestone Formation (**BL**) occurs over the majority of the northern study area and in fact **<u>underlies the flush complex</u>** at the site. It is bordered to the west by a large regional fault, which like the local fault across the central site, brings it in unconformable contact with the Downpatrick Formation. The Lower Ballina Limestone Formation consists of interbedded dark grey fined-grained muddy limestone and calcareous shale. It passes up gradationally to the Upper Ballina Limestone Formation (**BU**), which consists of cleaner limestone interbedded with thin shale. Chert and possibly fossil corals may be common near the top of the formation. The Upper Ballina Limestone Formation occurs over a minority area in the central and north-eastern part of the site.

Structurally, the most conspicuous and significant feature is that of the local fault which runs through the site in a west-northwest and east-southeast direction. This fault dissects the centre of the site; the northern part made up of slightly alkaline to alkaline muddy limestones and calcareous shales, with some local clean limestones in the northeast, and the southern part consisting of slightly calcareous sandstones and shales to slightly acidic siltstones and mudstones.

3.2.2 Soils and Subsoils Geology

Pleistocene – Mineral Subsoils

North Mayo is particularly rich in Quaternary Deposits that are typical of glaciated areas. Ice movements in the North Mayo region was one of the most complex anywhere in Ireland. Two major sources of ice were in West Galway-South Mayo, and an area between Leitrim and Lough Neagh. The ice streaming towards North Mayo from these two ice centres combined to flow northward through the Lough Conn Corridor.

Regional mapping of subsoils in North Mayo has recently been revised (Ref. 6). The results are presented in Appendix B2, and aside from the predominance of peat, the more significant items are:

- Limestone Till of Carboniferous parent origin occurring in the western and north-western part of the site.
- Sandstone Till of Devonian-Carboniferous parent origin occurring in the southeast corner of the site.
- Sandstone Sands and Gravels of Devonian-Carboniferous parent origin occurring in the southwest of the site within the hydrological catchment to Shanvolahan.

It appears that most of subsoils mapped particularly from deep overburden drilling (OB Series) appear to initially be sandy / gravelly CLAY but all passing into significant thickness of clayey SAND and sandy GRAVELS with depth. The field evidence thus indicates that while CLAY and SILT occur at shallow depths beneath the peat, from the deeper subsoils drilling, these units pass into coarser SANDS and GRAVELS rather quickly with depth. This suggests that the subsoils that occur underneath the site were deposited by fluvio-glacial meltwater activity, thus imparting greater permeability to the subsoils (Appendix D3).

Holocene - Peat

The peat soils or subsoils occur over all but the extremities of the study site, where upland areas consist of mineral subsoils. Lowland Blanket Bogs are found over extensive areas of flat ground below 150mOD in the west of Ireland (mainly Mayo and Galway) where precipitation exceeds 1,250mm/year. Blanket bogs grew and are largely dependent on the Quaternary subsoils that form its base. Secondly it is poor drainage (low flow gradient) and high daily and annual rainfall patterns that sustain its growth in excess of level of decay and hence the upward accumulation of un-decayed organic matter.

Direct site investigations of the study site indicate that the peat accumulated up to depths of 7.6m at the north-central part of the site at GC11 (Appendix D2). The highest peat contour of 7m is co-incident with the occurrence of flush flora in the north central part of the site (Schoenus/Potamogeton and Molinia dominated). Here an elongate basin of between 0.3-7.6m peat depth has been outlined with a long axis in a northwest-southeast direction. The boundary of this basin is controlled by topography in the north and by peat harvesting in the northeast (indentions in contour levels).

While undertaking field investigations, Minerex observed direct evidence of large in-situ wood trunks and ‘fossilised’ branches in cutover blanket bog in north-eastern part of the site between and east of GC63 and GC48. In association with this direct observation of ancient fen woodland or “carr” at the study site, detailed logging of peat probe points indicates that wood tissue and fragments coinciding with a more reddened hue generally occur within 2m of the base of the peat unit, in those locations where peat is <4m in total depth.

The humification rate of the peat substrate was classified using the Von Post Humificaiton scale (Ref. 3) and the composition and degree of humification of the cored peat was logged for those points where permanent monitoring couples were installed. The results indicate that humification increases sharply after 2m depth from c.H2-H5 to H7-H8. None of the investigation points indicated a humification rate greater than H8, which indicates that the humification rate overall is moderate to high, but is relatively stable in the depth column past the 2m marker horizon.

3.3 Hydrological Setting

3.3.1 Catchments

Regionally, the study site occurs within the Lough Conn hydrological catchment, and ultimately drains to the Deel River (c.3.5km down-gradient of local catchment), which flows through Crossmolina and eventually discharges to the northern shores of Lough Conn (c.9km west of the local catchment). In terms of the Water Framework Directive (Ref. 7), the site occurs within the Western River Basin District. The size of this regional catchment is 100's if not 1,000's of square km in area, and thus is greatly larger than the immediate study site which contains c.4.5km^2. As a result, the local catchment is the focus of this study, where immediate flow conditions and impacts of same can be studied and identified.

The local catchment is outlined with respect to the regional catchments of Lough Conn to the south and Cloonaghmore River Catchment to the North. The spatial distribution of the local catchment is subtly controlled by local topography with a range of 95 and 60mOD Malin. The local catchment contains an area of 4.521km^2 (Appendix C1), it is roughly rectangular in shape with its northern boundary occurring along the regional contact between the Cloonaghmore River and the Lough Conn Catchments and its southern boundary defined by relief and the margin of Shanvolahan River in the south. The Shanvolahan River is the base control on the local catchment and drains all waters from it via local drains D1, D2 and D3.

3.3.2 Drainage

Three (3) drains and one (1) river occurs within the catchment of the study site. The drains have been labelled D1, D2 and D3 in order of significance and hydraulic flow capacity, while the River Shanvolan borders the southwestern part of the catchment and ultimately drains all drainage from the study site.

D1 is the most significant drain as it traverses the centre of the site from northwest to southeast and has the longest drainage length within the local catchment. D1 appears to have originated as a natural stream, but has been heavily modified and canalised for the purpose of effective drainage of the lands in advance of commercial tree plantation. D2 is a short artificial drain along the southwestern boundary of the mature conifer plantation. It has little significance to the flush study. D3 is a natural stream that drains the southwestern catchment and ultimately discharges into the River Shanvolahan. The Shanvolahan River is the ultimate base level control on all groundwater and surface water flow at the study site. It receives all waters (bar deep groundwater throughflow) from the study site during its hydrological cycle, which for the low permeability peat can take thousands of years.

3.3.3 Surface Water Chemistry

Water chemistry taken from drainage (flowing water) within the study site indicates high variability in Electrical Conductivity (EC) and pH within the peat substrate which is largely dependent on seasonal changes in rainfall and thus recharge. The mineral subsoils on the other hand are characterised by lower EC and pH variability and thus are less influenced by seasonality, are more buffered from environmental change. In terms of inorganic analytical chemistry, the resultant water types are sodium bicarbonate ($NaHCO_3$) and sodium chloride (NaCl).

Results of water chemistry at the two bog pools sampled (T1/C7/SW1 and T5/C1/SW1) indicate lowest values recorded for both EC and pH, highlighting their dystrophic status, while inorganic testing indicates that they are strongly sodium chloride-bicarbonate ($NaCl\text{-}HCO_3$).

3.4 Hydrogeological Setting

3.4.1 Aquifer Classification

There are three bedrock aquifer types within the study type, as illustrated in Appendix C2. These bedrock aquifers are classified as:

Table 2: Bedrock Aquifer Classification

Code	**Aquifer Description**	**Yield Estimate (m^3/d)**
Pl	Poor Aquifer, generally unproductive except in local zones	<40m^3/day
Ll	Locally important aquifer, generally moderately productive in local zones	40-100m^3/day
Rk	Regionally important, karst aquifer, good development potential	>400m^3/day

The distribution of aquifer class follows the spatial distribution of the bedrock formations, with the Upper Ballina Limestone Formation (BU) being the most important aquifer, located in the eastern part of the study site; and the Downpatrick Formation (DK) being the least important aquifer, located in the south of the study site. Aquifer status boundaries follow lithological and fault contacts as defined in Appendix B1. At all times it is noted that bedrock and thus bedrock aquifer distribution is mapped at a scale of 1:100,000 and thus spatial accuracy at the study site scale should not be taken literally.

3.4.2 Water Table

In order to analyse water levels over this large site, three groups of water levels are identified as (a) high range, (b) medium range and (c) low range. These groups of water levels broadly correlate between recharge, transition and discharge areas of the blanket bog environment.

As all “phreatic” water table levels are recorded in the peat. As expected therefore, spatially highest water levels to common (mOD Malin) occur in the higher elevation parts of the site particularly in the northern fringe of the monitoring network e.g. T1/C1/PH1, and the lowest water levels to common datum occur in / adjacent to drainage, in the lower monitored reaches of D1, e.g. T6/C3/PH1. The spatial pattern of water levels are illustrated in Appendix F1 and F2 and generally highlight the strong hydraulic control of D1 and D3 on the distribution of equipotentials (contours of equal water level). The flow path of the shallow groundwater is strongly controlled by (a) topography and (b) drainage. Only in the southern intact ombrotrophic blanket bog do phreatic contours broaden out indicating a lower horizontal hydraulic gradient. It is noted that there if very little difference in the spatial location of contour lines between summer and winter baseline monitoring seasons.

3.4.3 Piezometric Levels and Vertical Gradients

It is noted that the piezometer points are installed in both peat and mineral subsoils substrates. As for the phreatic levels, in order to make sense of the large data set, piezometric monitoring points have been grouped according to elevation clustres: (a) high range, (b) medium range and (c) low range, which broadly correlate with recharge, transition and discharge areas of the blanket bog environment.

The piezometric levels generally follow the same spatial elevation pattern as the ‘free’ water table with again strong control by drainage (Appendix G1 and G2). Piezometric levels are less affected by local topography and have smoother flow lines than the phreatic surface (water table). D1 is the main interceptor of groundwater at depth in the site (peat and mineral subsoils) and is the most important hydraulic controlling factor on the ‘flush eco-hydrology’ in the northern study area. Spatially, there is more seasonal change in the piezometric contour levels compared to the phreatic levels with a net spatial adjustment in response to increased recharge in winter (contours migrate upgradient) and reduced recharge in summer (contours migrate downward).

There are some differences in the hydraulic behaviour between piezometers located in peat and mineral subsoils. The PEAT piezometers are relatively consistent with the hydrograph pattern of the shallow phreatic levels, with some minor variances arising from impact of forestry (e.g. T5/C3) and drainage (T6/C2). Those piezometer points that are installed in the underlying MINERAL SUBSOILS have been subdivided based on permeability difference into (a) Clays and Silts and (b) Sands and Gravels. There is much less frequency in fluctuation response in the clays and silts compared to the sand and gravel points which respond quicker and more frequently in changes to hydrological conditions. However, as expected the amplitude of change can be much large in piezometers located in the clays and silts (e.g. T4/C1/P1).

In terms of vertical hydraulic gradients the following table summaries the main characteristics of vertical hydraulic pressures and gradients at the study site (Appendix L).

Table 3: Summary of Dominant Vertical Hydraulic Gradients at Shanvolahan (Feb-03 to Aug-06)

Couple ID	Range of dh/dz	Average dh/dz	Dominant Gradient Direction	Dominant Gradient between Mineral Subsoil and Deep Peat?	Decoupling within Nest / Couple?	Seasonal Reversal?
T1/C1	$+4.4^{-2}$ to -9.6^{-2}	-1.77^{-2}	Downward	Downward	No	Yes
T1/C2	$+1.1^{-1}$ to -5.0^{-3}	-1.92^{-2}	Downward	N/a	Yes	Yes
T1/C3	$+3.7^{-2}$ to -1.9^{-2}	-7.77^{-2}	Downward	Downward	Yes	Yes
T1/C4	$+1.6^{-2}$ to -3.3^{-3}	-9.66^{-4}	Downward	Downward	Yes	Yes
T1/C5	$+2.7^{-1}$ to -2.7^{-1}	$+2.71^{-2}$	Upward	Upward	Yes	No
T1/C6	$+4.6^{-3}$ to -2.5^{-2}	-9.76^{-3}	Downward	N/a	No	No
T1/C7	$+3.8^{-1}$ to -1.4^{-2}	-9.16^{-2}	Downward	Downward	Yes	No
T1/C8	$+7.1^{-2}$ to -2.6^{-1}	-3.62^{-1}	Downward	Downward	No	No
T2/C2	$+3.0^{-2}$ to -6.1^{-3}	$+5.00^{-3}$	Upward	Upward	Yes	Yes
T2/C3	$+2.4^{-2}$ to -1.3^{-3}	$+2.05^{-3}$	Upward	Upward	No	No
T3/C1	$+1.4^{-2}$ to -1.1^{-2}	-1.95^{-2}	Downward	Downward	Yes	Yes
T3/C2	0.0^{0} to -1.1^{-1}	-5.63^{-2}	Downward	Downward	No	No
T4/C1	$+7.8^{-2}$ to -2.6^{-3}	-8.26^{-3}	Downward	Downward	Yes	Yes
T4/C2	$+1.9^{-1}$ to -8.5^{-3}	-1.27^{-1}	Downward	Downward	Yes	Yes
T5/C1	$+6.7^{-3}$ to -6.7^{-4}	-1.49^{-2}	Downward	Downward	No	No
T5/C2	$+3.6^{-2}$ to -9.1^{-3}	-3.66^{-2}	Downward	Downward	No	No
T5/C3	$+2.4^{-1}$ to -2.4^{-2}	-7.63^{-2}	Downward	N/a	No	No
T6/C1	-6.7^{-1} to -4.4^{-1}	-5.5^{-1}	Downward	Downward	No	No
T6/C2	$+4.4^{-2}$ to -1.1^{-2}	$+1.3^{-2}$	Upward	N/a	No	Yes
T6/C3	$+1.9^{-1}$ to -3.7^{-2}	$+1.4^{-2}$	Upward	Upward	Yes	Yes

The table highlights that with exception of those monitoring points installed adjacent or within drainage such as D1 (T1/C5, T2/C2, T2/C3, T6/C2 and T6/C3), the lowland blanket bog environment is dominated by a downward hydraulic gradient through most of the year with only a short seasonal upward gradient following the winter / spring recharge months.

3.4.4 Groundwater Chemistry

MEL undertook groundwater samples for analytical chemistry twice during its twelve (12) month monitoring contract with Coillte. Water samples were taken on the 30/10/03 (end of summer, early autumn) conditions with enough water in phreatic tubes to allow sample retrieval for analysis; and on the 04/02/04 to capture winter recharge and at the end of the monitoring contract to determine any chemical changes arising from restoration measures.

A total of thirty one (31) groundwater samples were taken in 2003 and a further twenty two (22) groundwater samples in 2004, of which seventeen (17) were repeat samples between both years. In the 2003 sampling event, the majority of the groundwater monitoring network was sampled, focusing on Transect 1 (T1) which transverses the centre of the site and is generally perpendicular to contour lines, as well as T4 which is located uphill and thus up-gradient of the flush system. One couple from each of T3, T5 and T6 were also sampled at strategic locations, such as on D1 or at bog pools. All samples were subjected to rigorous ionic balance quality assurance prior to using for final results.

Groundwater chemistry is summarised for each main litho-unit that occur at the site. These are peat and mineral subsoils.

PEAT:

The Peat unit is characterised by two main water types: Calcium Carbonate (Ca-CO_3) and Sodium-Carbonate (Na-CO_3) with secondary Chloride and in some cases Calcium. Table 2 identifies which monitoring points record each water type. The majority of points have a Ca-CO_3 water type, while T1-C4-PH1 and T5-C1-P2 have a Na-CO_3 water type with secondary Cl and Ca. As T1-C4-PH1 is the only shallow peat phreatic point within the validated data results, the replacement of Na over Ca is expected due to ion exchange and the influence of rainfall onto the sphagnum surface within birch (local flush area). It is harder to explain why T5-C1-P2 has a Na-CO_3 type signature rather than the expected Ca-CO_3 signature. It is quite shallow in occurrence with the response zone starting at 1.15m which is just 0.38m below the phreatic level, along with a downward vertical gradient (Section 3.4.3), may explain why its chemistry is more like acrotelm peat rather than catotelm peat.

Table 4: Peat Water Type Results from October 2003 & November 2004

Monitoring Point ID	**Litho-Unit**	**Water Type** (October 2003)	**Water Type** (November 2004)
T1-C4-P2	PEAT	Ca-CO3	Ca-CO3
T1-C4-P3	PEAT	*N/A*	Ca-CO3
T4-C2-P2	PEAT	Ca-CO3	Ca-CO3
T5-C3-P1	PEAT	*N/A*	Ca-CO3
T1-C4-PH1	PEAT	Na-CO3 (with secondary Cl)	*N/A*
T5-C1-P2	PEAT	Na-CO3 (with secondary Cl)	*N/A*

MINERAL SUBSOILS:

With the exception of one point, all of the mineral subsoils irrespective of whether they are sampling clay, silt, sand or gravel have a Calcium Carbonate (Ca-CO_3) water type with secondary Magnesium. The exception to this is T6-C3-P1 which is a transition installation in both peat and sand; hence it has a different water composition of Sodium Carbonate (Na-CO3) with secondary Chloride.

Table 5: Mineral Subsoils Water Type Results from October 2003 & November 2004

Monitoring Point ID	**Litho-Unit**	**Main Lithology**	**Water Type** (October 2003)	**Water Type** (November 2004)
T1-C1-P1	Mineral Subsoils	CLAY / SILT	Ca-CO3 (with secondary Mg)	*N/A*
T1-C3-OB4	Mineral Subsoils	CLAY / SAND / GRAVEL	Ca-CO3 (with secondary Mg)	*N/A*
T1-C3-P1	Mineral Subsoils	PEAT / SAND	Ca-CO3 (with secondary Mg)	*N/A*
T1-C5-OB2	Mineral Subsoils	SAND	Ca-CO3 (with secondary Mg)	*N/A*
T1-C7-P1	Mineral Subsoils	SAND	Ca-CO3 (with secondary Mg)	Ca-CO3 (with secondary Mg)
T1-C7-OB1	Mineral Subsoils	GRAVEL	Ca-CO3 (with secondary Mg)	Ca-CO3 (with secondary Mg)
T3-C1-P1	Mineral Subsoils	SAND	Ca-CO3 (with secondary Mg)	*N/A*
T4-C2-P1	Mineral Subsoils	SILT	Ca-CO3 (with secondary Mg)	*N/A*
T4-C2-OB3	Mineral Subsoils	GRAVEL	Ca-CO3 (with secondary Mg)	*N/A*
T6-C3-P1	Mineral Subsoils	PEAT / SAND	Na-CO3 (with secondary Cl)	*N/A*

4. CHANGE IN HYDROGEOLOGICAL CONDITIONS

Examination of whether restoration efforts involving de-forestation and drain blocking has resulted in a measurable impact (positive or negative) on the site's hydrogeology is one of the main purposes of this study. This is particularly relevant to the flush ecology that occurs at Shanvolahan.

From monitoring results to date, Table 4 outlines those points that suggest or clearly identify a positive water level change following restoration works at the study site.

Table 6: Monitoring Points that register or might register water level change as a function of Restoration

Monitoring Couple ID	**Possible or Definite Impact?**	**Description of Impact**	**Start of Impact**	**End of Impact (where applicable)**
T1/C6	Definite	Initial rapid water level rise in P1 and P2 but subsequent reduction in 2006. Still above baseline however.	Nov-04	Ongoing
T3/C1	Possible	Sharp rise in P2 while P1 remains at baseline. Subsequent reduction to within baseline in 2006	Nov-04	Unknown
T3/C2	Possible	Rise in P1 and P2 in Spring 2006 which is above baseline, may be explained by rainfall data.	Apr-06	Aug-06
T5/C1	Definite	Sharp rise in PH1 which is +0.4m above baseline. Water level has been maintained at this new equilibrium.	Sep-04	Ongoing

T5/C2	Possible	Rise in P2 and P3 in Nov-04, but subsequent fall within baseline in 2006	Nov-04	Unknown
T6/C2	Possible	Sharp rise in P1, P2 along with SG4 indicating impact of de-forestation on water levels. Subsequent reduction in water levels in all points in 2006 to within baseline levels. It is postulated that drain-blocking upstream may be starving this location of water source.	Nov-04	Unknown
T6/C3	Possible	Sharp rise in all points indicating impact of de-forestation on water levels. Subsequent reduction in water levels in all points in 2006 to within baseline levels. It is postulated that drain-blocking upstream may be starving this location of water source.	Nov-04	Unknown

Unfortunately some of those points closest to the conifer plantation have been destroyed during de-forestation. These include T5/C1 and T6/C1, which would have been very valuable for monitoring. The remainder of points illustrate no change outside of seasonal oscillation as a result of restoration efforts and changes at Shanvolahan since 2004.

5. CONCLUSIONS AND ONGOING PHD RESEARCH

To provide answers to the questions that were identified as the purpose of this study (Section 1.2), the following has been identified:

(a) To understand <u>why</u> and <u>how</u> the flush ecology at Shanvolahan occurs.

The flush ecology occurs at this location as a function of topography which drives the horizontal hydraulic gradient across the northern part of the site from c.70mOD in the uppermost recharge zone (e.g. T1/C1) to c.65mOD in the discharge zone (e.g. T1/C6). Without this topographic gradient, flush ecology would not occur due to ensuing stagnation and associated lowering of nutrient and ionic value of groundwater.

The second important factor that drives flush ecology is that the distribution of mineral subsoils that surround and underlie the peat at the site. At this site, it was noted how sandy the subsoils are and from mapping their distribution, there is a positive correlation between where flush ecology occurs and the distribution of sands and gravels.

The manner in which the ionised and nutrient rich groundwater from the subsoils manages to reach the surface of the bog can be explained by lateral diffuse discharge from the higher elevation terrain at the northern part of the site to the margins of the peatland (such as along the soakaway) and possibly by upward vertical seepage from the underlying gravelly sands during seasonal reversal of vertical hydraulic gradient, which appears to be sufficiently long to "mineralise" most of the main peat body within the flush zone for the remainder of the year (when otherwise downward hydraulic gradients exist). It is noted that generally downward hydraulic gradients are not very strong in the flush zone. It is also noted that a natural "drainage feature" with high pore water pressure occurs from c.T1/C4 to south of T1/C3 and is readily identified on the aerial photograph. There must be enough upward hydraulic pressure or movement of water in this part of the site to keep this feature "open" or "liquefied" and avoid build up of vegetation and deposition / consolidation of peat along this feature.

(b) Generate a <u>conceptual model</u> / understanding of the relationship of flush ecology with groundwater movement and groundwater / surface water chemistry relationships.

Please refer to detailed hydrogeological cross sections in Appendix J which illustrate the distribution and interaction of topography, geology, chemistry and vegetation zones / habitats at the Shanvolahan site.

(c) *On the basis of evaluation of the hydrogeological model developed from the study, provide recommendations for improvements in understanding and where possible appropriate engineering measures for flush protection, restoration and enhancement.*

While the main purpose of the restoration works is to remove the impact of forestry and "restore" hydrological conditions to what they were before forestation (exact condition unknown), care must be taken not to tip the balance by inducing higher than required water levels, particularly surface water levels in D1. This would have the opposite effect on the flush system, causing a reduction of topographic gradient and thus hydraulic gradient and diluting the nutrient rich waters that sustain the flush plant species. The restoration is a careful balance of taking negative impact out of the water budget and moderating the recovery of water levels that maintains the chemistry of the flush ecology. Water level monitoring results suggest that excessive raising of water levels in D1 has not occurred as a function of restoration and that water levels in the flush ecology have been unaffected by restoration.

At this site, D1 acts at the discharge zone for the flush ecology and provides a hydraulic buffer / barrier or protection line between the flush and the larger mature plantation. The younger plantation may have had a historic impact on the distribution of the flush ecology in the eastern part of the site, however extensive peat harvesting is likely to be the main culprit for the absence of flush vegetation east of T4/C2.

6. REFERENCES

1. Extract from Coillte's Funding Application for LIFE-Nature Blanket Bog Restoration. (MEL Doc. Ref. 1423-043)
2. Von Post, L. (1922) *"SGU (Seriges Geologiska Undersoknings) peat inventory and some preliminary results".* In Dann. Geol. Unders. IV Series. Vol. 3 (10)
3. British Standards Institution (1981) *"Code of Practice for Site Investigations - BS 5930".*
4. Conaghan (2005) Vegetation Survey Results and Mapping.
5. Long C. B. *et al* (1992) *"Geology of North Mayo".* Geological Survey of Ireland.
6. EPA-Teagac (2005) "Soils and Subsoils of Co. Mayo"
7. European Union (2000) "Water Framework Directive (2000/60/EC)"