Banagher GWB: Summary of Initial Characterisation.

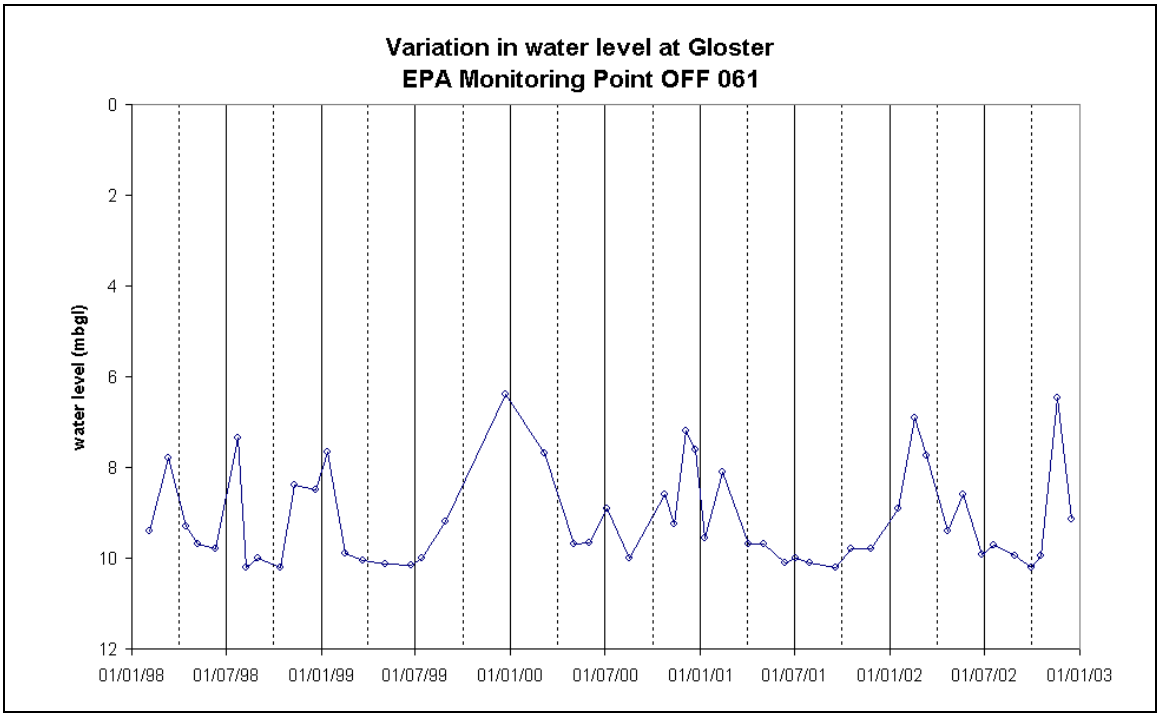
Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
25 - Little Brosna catchment North Tipperary and Offaly Co. Co.'s	Rivers: Shannon, Little Brosna, Pallas, Rapemills. Loughs: Derg.	River Shannon Callows (000216), Little Brosna Callows; New Bridge - River Shannon (000564), Killeen Bog (000648), Ballyduff/ Clonfinane Bog (000641), Arragh More Bog (000640), Dovegrove Callows (00010), Cloghan Demesne Bog and Wood (001613), All Saints Bog And Esker (000566).	197

Topography	The groundwater body is roughly like a square tilted slightly on its side. There is a small spur leading from the NW corner down to Lough Derg. The topography is undulating to gently hilly. Elevation within the GWB ranges from 30 mAOD where the GWB reaches Lough Derg, to just over 100 mAOD along parts of low ridge that runs WSW from the centre of the GWB towards Lough Derg. Over nearly all of the GWB, elevations are between 30 and 60 mAOD. Overall, elevation decreases into the centre of the GWB and northwestwards. Rivers follow the topography, generally flowing northwards to the Lower River Shannon.	
Geology and Aquifers	Aquifer categories	All aquifers within the GWB are **Ll:** Locally important aquifers which are moderately productive only in local zones.
	Main aquifer lithologies	Dinantian Pure Unbedded Limestones and Dinantian Upper Impure Limestones are the major rock unit groups within the GWB. Dinantian Lower Impure Limestones are also present in the area.
	Key structures	The major structures affecting the distribution of rock types are large folds and major faults. A large synclinal fold orientated ENE-WSW and plunging to the WSW occurs down the centre of the body. The Upper Impure Limestones are in its core and on either side are the Pure Bedded Limestones. The Lower Impure Limestones occur in small areas in the cores of minor anticlines. Major NW-SE normal faults downthrown to the NE cross-cut the fold axis almost at right angles. There is also a major ENE-WSW fault (part of the Ferbane fault) running through the very north of the GWB.
	Key properties	A pumping test in the Dinantian Pure Unbedded Limestones at Shinrone, in the GWB just to the south, indicated a transmissivity of approximately 27 m^2/d. Most of the flow was through a fault zone at more than 50 mbgl. At Tulla in Co. Clare, transmissivity in the same rock unit is estimated as 13 m^2/d. These values are probably at the middle to higher end of the range of transmissivities for this rock unit group in this area. A pumping test at Lorrha WS in the adjacent Nenagh GWB indicates an aquifer permeability of 5 m/d in the Upper Impure Limestones. The borehole there intercepts a large fissure, so this value is at the high end of what would be expected for this rock unit group, which typically has transmissivities in the range 2-20 m^2/d. The Banagher WS has similar characteristics: a single large fault zone supplies the source, resulting in a transmissivity estimate of 45-70 m^2/d, but a flowing interval permeability estimate of 20 m/d. Within the Dinantian Lower Impure Limestones, transmissivities are likely to be in the range 2-20 m^2/d, with most values towards the lower end of the range. Within all rock units, storativities are low. In this generally low-lying area, groundwater gradients on the order of 0.002 to 0.02, but may be slightly steeper in the highest areas of the GWB. *(data sources: Rock Unit Group Aquifer Chapters, GWPS Reports, Source reports, see references)*
	Thickness	The Dinantian Pure Unbedded Limestones, and the Dinantian Lower and Upper Impure Limestone aquifers are more than several hundreds of metres thick. However, permeability tends to decrease rapidly with depth. Most flow occurs in the upper ≤ 15 m, in the zone that comprises a weathered layer and a connected fracture zone below this, although deeper flows may occur along faults or significant fractures, or occasionally bedding-parallel dissolution planes within the Pure Unbedded Limestones. At Banagher WS, in the Upper Impure Limestones, borehole logs indicate an intersection with a large fault at about 30-35 mbgl. In the Pure Unbedded Limestones east of Lough Derg, epikarst has been observed that has a thickness of up to 1-2 m. There is likely to be epikarst in the region of this GWB also.
Overlying Strata	Lithologies	*[Information to be added at a later date]*
	Thickness	Depth to bedrock data are very limited for this GWB. This area was near the ice margin during the Ice Age, hence subsoil thicknesses can vary widely across the GWB. Where there are extensive gravel deposits – particularly along the Little Brosna and Rapemills Rivers – subsoil thicknesses are probably up to 15-20 m. Elsewhere, subsoil thicknesses are probably in the range 2-6 m, although thicker deposits will be encountered. Outcrops and areas of shallow rock are generally concentrated in the higher ground in the W, NW and SW of the GWB, and also in the north of the GWB in the area between the Little Brosna and Rapemills Rivers. There are isolated outcrops elsewhere in the GWB.
	% area aquifer near surface	*[Information to be added at a later date]*
	Vulnerability	Vulnerability ranges from Extreme to Moderate in Co. Offaly (the NE part of the GWB) and from Extreme to High-Low in North Co. Tipperary (the SW part of the GWB). Areas of Extreme vulnerability occur on the higher ground between rivers. Areas of High vulnerability surround the Extreme areas, and occur where there are gravels; Moderate vulnerability areas occupy the low-lying areas where drainage is poor.

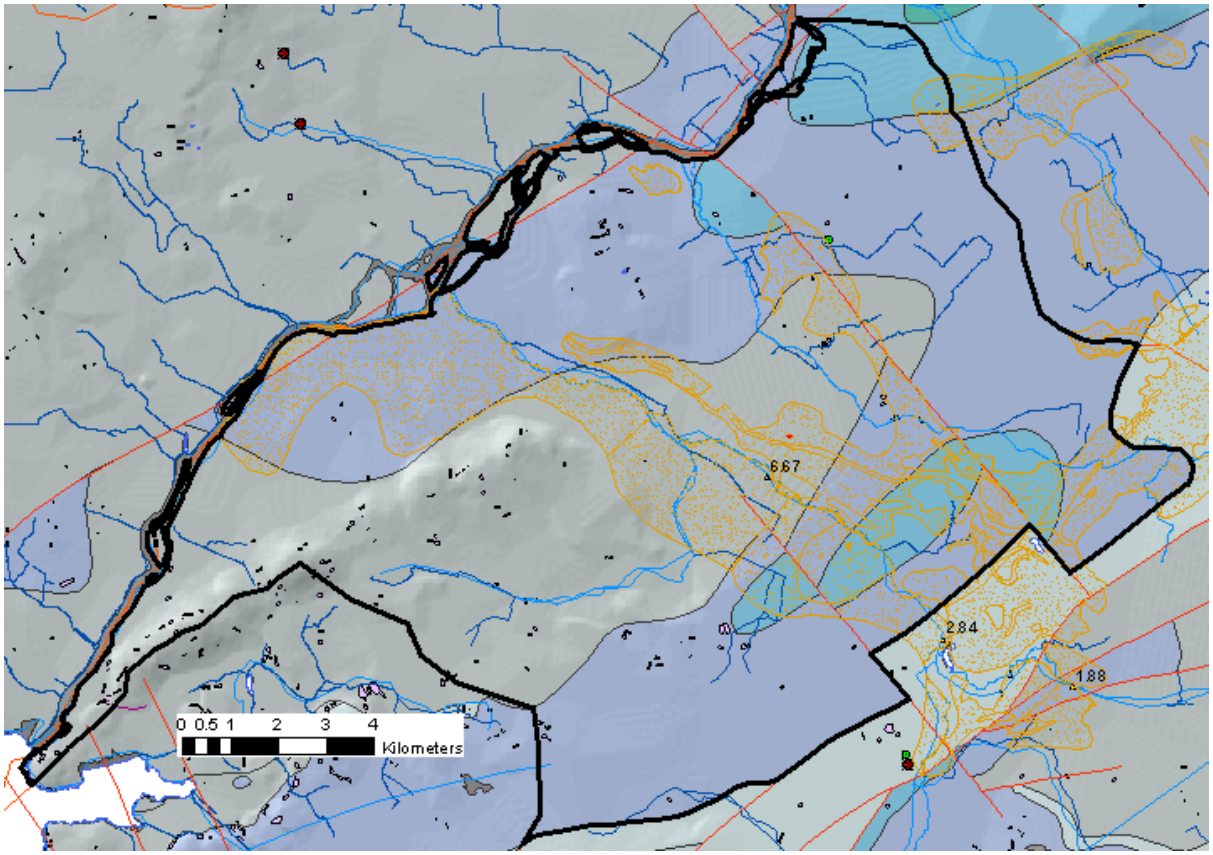
Recharge	Main recharge mechanisms	Diffuse recharge will occur via rainfall percolating through the subsoil. The proportion of the effective rainfall that recharges the aquifer is largely determined by the thickness and permeability of the soil and subsoil, and by the slope. In general, due to the generally low permeability of the aquifers within this GWB, a proportion of the recharge will discharge rapidly to surface watercourses via the upper layers of the aquifer, effectively reducing further the available groundwater resource in the aquifer. However, the permeable gravelly subsoils covering large parts of the aquifer will act as a 'store' of groundwater and somewhat mitigate this rapid through-flow. The one known swallow hole in the area accepts point recharge from surface waters.
	Est. recharge rates	*[Information to be added at a later date]*
Discharge	Important springs and high yielding wells (m^3/d)	There are two Excellent (>400 m^3/d) yielding boreholes in this GWB – at Banagher/ Lusmagh WS (yield 1,000 m^3/d, GSI database), and at the Distillery (Midland Maltings at Montcarteret, near Banagher) (1000 m^3/d – EPA database). These boreholes abstract groundwater from the Upper Impure Limestones. At Banagher WS, groundwater is abstracted from a single large fault about 35 mbgl. The yield is not sustainable in dry weather. The remainder of the known boreholes in the area have yields of less than 100 m^3/d (GSI Poor or Moderate yield categories). *[More information may be added at a later date]*
	Main discharge mechanisms	Groundwater discharges to gaining streams and rivers crossing the GWB, and to a few small springs. The specific dry weather flow of a river (Little Brosna) crossing GWB is very high (6.67 $l/s/km^2$). This is due to the presence of the overlying Birr Gravel Aquifer, which the river also crosses. The bedrock aquifers have low specific yields and are not capable of sustaining summer baseflows.
	Hydrochemical Signature	Groundwaters from all aquifers within this groundwater body have a calcium-bicarbonate signature. At Banagher WS, which abstracts from the Upper Impure Limestone aquifer, groundwater is Very Hard (>350 mg/l as $CaCO_3$) and has electrical conductivity values of 650-720 µS/cm. In the Lower Impure Limestone and Pure Bedded Limestone aquifers, groundwaters are also Very Hard (typically ranging between 380–450 mg/l), and high electrical conductivities (650–800 µS/cm) are often observed. Alkalinity is also high, but less than total hardness (250-370 mg/l as $CaCO_3$). These values are typical of groundwater from limestone rocks and typical of groundwater across Co. Offaly (Cronin, 1999). As would be expected, pH is generally neutral. At springs, or other systems where throughput is rapid, groundwaters have lower dissolved solids. Within the Impure Limestones, iron and manganese concentrations frequently fluctuate between zero and more than the EU Drinking Water Directive maximum admissible concentrations (MACs). Hydrogen sulphide can often reach unacceptable levels (E.P. Daly, 1982) in the Lower Impure Limestones. These components come from the muddy parts of these rock units and reflect both the characteristics of the rock-forming materials and the relatively slow speed of groundwater movement through the fractures in the rock allowing low dissolved oxygen conditions to develop. It has been demonstrated that at low pumping rates water does not reside long enough in the well for oxidation to occur, thereby resulting in elevated Fe and Mn in small domestic supplies (Applin *et al.*, 1989). Groundwaters in the overlying gravel deposits and gravel aquifers have similar compositions to pure limestone bedrock aquifers, but may contain less total dissolved solids if throughput is rapid.
Groundwater Flow Paths		These rocks are devoid of intergranular permeability; groundwater flow occurs in fractures and faults. In the main, the rocks are dependent on fracturing and fissuring to enhance their permeability. Zones of high permeability can be encountered near fault zones and in areas of intensive fracturing. There is evidence of limited karstification in the Upper Impure Limestones, which may occur in the slightly more pure limestone zones. The Pure Unbedded Limestones may also have had their transmissivity enhanced further by dissolution of calcium carbonate along fracture, joint and bedding planes. There is probably an epikarstic layer of 1-2 m at the top of the pure limestones. Permeabilities in the upper few metres are often high although they decrease rapidly with depth. In general, groundwater flow is concentrated in the upper 15 m of the aquifer. Significant yields can be encountered where fault zones are intercepted by boreholes. Often, these flowing intervals behave in a confined way and, when the water level falls beneath the inflow level, yields decrease and drawdowns increase rapidly. Generally speaking, these rocks are unconfined where subsoils are thin or gravelly. Groundwater may be locally confined where it flows beneath the low permeability bases of the raised bogs. In the bedrock aquifers, groundwater flow paths are generally shallow and short, on the order of 30-300 m long, with groundwater discharging to the streams and rivers that traverse the aquifer. Local groundwater flows are determined by the local topography. There is no regional flow system. Examination of data in the GSI well database shows that water levels are shallow, less than 10 m below surface, and commonly less than 3 mbgl. Next to the rivers, water levels will be closer to ground level. At Banagher WS in the Upper Impure Limestone aquifer, static water levels vary between 2-5 mgbl. Water levels in a Sand and Gravel deposit at Gloster vary by up to 4 m annually and generally range between 8-10 mbgl. This deep water table and relatively large variation for high porosity deposits may be a function of the location of the well on a local topographic high. Lower permeability lenses or disseminated clay particles may also be reducing the overall permeability of these deposits. There are several locally important <u>*potential*</u> gravel aquifers and gravelly deposits overlying this bedrock GWB: The most extensive of these are the Birr-Rapemills-Rahan (Aghall) Gravels and Birr Gravels that radiate NW and NE-wards out from Birr in the south of the GWB. These deposits generally follow the line of the Little Brosna and Rapemills Rivers. Gravel deposits overlying the bedrock aquifers can cause drainage densities to be lower than they would be for a given aquifer type, can contribute storage to the bedrock aquifers, and can also focus flow and influence the locations of springs in some cases.

Groundwater & Surface water interactions	The streams and rivers crossing the aquifer are generally gaining. Due to the shallow groundwater flow in this aquifer the groundwater and surface waters are closely linked. There are several fens and wetlands in the area that are dependent on groundwater. At the flat lowland raised bogs at Arragh More (000640) there are areas flushed with more mineral rich water. At Killeen Bog (000648) and Ballyduff/ Clonfinane Bog (000641) there are large quaking areas. At the River Shannon Callows, there is a 'petrifying stream' with associated species-rich calcareous flush and at Cloghan Demesne Bog and Wood (001613) there is a small flush to the east. All Saints Bog And Esker (000566) is a complex area. Approximately in the centre of the bog is an elongated flushed area with an outer non-wooded area surrounding a central wooded area. To the south of the bog are the fragmented remains of an esker ridge, which may have an influence on the hydrology of the flush. To conserve the site peat cutting needs to stop, drains be blocked and marginal dams built to raise the water table.
Conceptual model	• The groundwater body is bounded on the southwestern edge by the contact between the low transmissivity rock units of this GWB and the karstified Pure Bedded Limestones of the adjacent Birr GWB. Surface water catchment divides define the SW and NE edges of the GWB, whilst the NW edge coincides with the Lower River Shannon. The terrain is generally flat-lying or gently undulating. There is a small ridge in the west of the GWB. • The groundwater body is comprised of generally low transmissivity and storativity rocks. Where gravel deposits or potential gravel aquifers overlie the bedrock aquifer, this can contribute to the storage. • Flow occurs along fractures, joints and major faults. Flows in the aquifer are typically concentrated in a thin approximately 15 m zone at the top of the rock although deeper groundwater flow in hydraulically isolated fault zones can occur. Within the pure limestones, transmissivity may have been enhanced further by dissolution of calcium carbonate along fracture and bedding planes. An epikarstic layer of 1-2 m is likely to exist at the top of the Pure Unbedded Limestones. Limited karstification has taken place in the Upper Impure Limestones. • Diffuse recharge occurs across the entire GWB, but particularly where rock outcrops or where subsoils are thin. Where the water table is close to the surface potential recharge may be rejected. • The aquifers within the GWB are generally unconfined. Areas where confined conditions occur include beneath the raised bogs and in the deeper, isolated fault zones. Depending upon the local topography, the water table can vary between a few metres up to 10 m below ground surface. Flow path lengths are short (≤ 30-300 m). Groundwater flows to the surface water bodies, with local flow directions controlled by local topography. There is no regional flow system. • Groundwater discharges to the streams and rivers crossing the aquifer and to a few springs. • Due to the shallow groundwater flow in this aquifer the groundwater and surface waters are closely linked. There are several ecosystems in the GWB dependent on groundwater, including mineralised flushes. Groundwater and surface water interactions require special attention where terrestrial ecosystems are dependant on a sustainable balance between the two. • There are several gravel aquifers or potential gravel aquifers overlying this bedrock GWB: The most extensive of these are the Birr-Rapemills-Rahan (Aghall) Gravels and Birr Gravels that radiate NW and NE-wards out from Birr in the south of the GWB.
Attachments	Groundwater hydrograph (Figure 1).
Instrumentation	Stream gauges: 25010, 25024*, 25051, 25058, 25126, 25144. *(Stations marked with * have specific dry weather flows calculated.)* EPA Water Level Monitoring boreholes: Gloster (OFF 61). EPA Representative Monitoring points: Banagher (OFF 3).
Information Sources	Applin, K. R. and N. Zhao (1989) The Kinetics of Fe (II) Oxidation and Well Screen Encrustation. *Ground Water*, Vol. 27, No 2. Cronin, C., Daly, D. (1999). *An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly*. Geological Survey of Ireland report to Offaly County Council, Daly, D., Cronin, C., Coxon, C. and Burns, S-J (1998) *County Offaly Groundwater Protection Scheme.* Geological Survey of Ireland Report to Offaly Co. Co., 54 pp. Hunter Williams, N., Motherway, K. and Wright, G. (2002) *North County Tipperary Groundwater Protection Scheme (draft)*. Geological Survey of Ireland Report to North Tipperary Co. Co., 58 pp. Kelly, C. *Banagher WS – Groundwater Source Protection Zones*. Geological Survey of Ireland Report to Offaly Co. Co., in preparation. Kelly, C. *Shinrone WS – Groundwater Source Protection Zones*. Geological Survey of Ireland Report to Offaly Co. Co., in preparation. Motherway, K., Hunter Williams, N. & Wright, G.R. (2002) *Lorrha WS, Groundwater Source Protection Zones*. Geological Survey of Ireland, 15 pp. Aquifer chapters: Dinantian Upper Impure Limestones; Dinantian Pure Unbedded Limestones; Dinantian Lower Impure Limestones.
Disclaimer	Note that all calculations and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae

Figure 1: Groundwater hydrograph



NB: this hydrograph is measured in a borehole drilled in a Sand and Gravel potential aquifer.



Rock units in GWB

Rock unit name and code	Description	Rock unit group
Ballysteen Formation (BA)	Fossiliferous dark-grey muddy limestone	Dinantian Lower Impure Limestones
Waulsortian Limestones (WA)	Massive unbedded lime-mudstone	Dinantian Pure Unbedded Limestones
Lucan Formation (LU)	Dark limestone & shale (Calp)	Dinantian Upper Impure Limestones