Note: there is an EPA Water Quality and Water Level monitoring point at Charleville RWS (CON026) drilled through the Ballysteen Limestone of the Mitchelstown GWB but drawing water from the confined portion of the Ballyhoura Kiltorcan GWB. Hydrograph and Durov plot for this data need to be added.

Ballyhoura Kiltorcan GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
18 Limerick, Cork and Tipperary Co. Co.	**Rivers:** Funshion, Sheep, Castlepook, Ogeen, Farahay, Geeragh, Attychrane, Behanagh, Bregoge, Awbeg.	Mountrussell Wood (002088) ?	29.3

Topography		At ground surface the GWB is represented as a narrow strip (300-1500 m wide) that winds around the southern, western and northwestern lower slopes of the Ballyhoura Mountains and the southern lower slopes of the Galtee Mountains. This body occurs at the transition from the uplands of the Ballyhoura and Galtee Mountains to the flat lowing valley of the Mitchelstown Syncline. The change in topography is linked to changes in the underlying geology. The topography is generally steeply sloping with a transition to some more gently sloping low lying areas at the outer margins of the body. Ground elevations range from 80-180 m AOD. The topography of the land surface is at times tightly incised by gullies of streams flowing off the mountains.
Geology and Aquifers	**Aquifer categories**	**Rf:** Regionally important fissured aquifer
	Main aquifer lithologies	Devonian Kiltorcan-type Sandstones.
	Key structures	The regional structural deformation of the Variscan (Hercynian) Orogeny (mountain building episode) created the characteristic South Munster sandstone ridge (anticline)-limestone valley (syncline) topography. The Devonian Kiltorcan-type Sandstones of this GWB are the uppermost unit of the Devonian Old Red Sandstone succession. They occur on the margins of the sandstone ridge that forms the Ballyhoora and Galtee Mountains. The outcrop area of the Kiltorcan-type Sandstones is limited (approx. 300-1500 m wide) however this GWB must be viewed in three dimensions. The Kiltorcan-type Sandstones dip underneath the overlying shales and limestones of the Mitchelstown GWB (Figure 1). Down-dip towards the middle of the synclines, the aquifer becomes progressively more confined by an increase in thickness of the overlying beds. Numerous north-south faults cross cut the GWB. As deformation is likely to be most intense along the fold axis of the anticline (Churchtown Anticline) the Kiltorcan-type Sandstones are likely to be most productive in the west of the body at the 'nose' of the anticline.
	Key properties	Results of aquifer testing undertaken in the Devonian Kiltorcan-type Sandstones throughout the country are very variable. Estimates of transmissivity range from 20-1850 m^2/day, the highest values likely to be associated with low-lying areas close to anticlines or faults. The permeability of these sandstones varies from 0.5 to 20 m/day, increasing up to 80m/day in localised areas (Daly 1988). It is expected that the permeability will be greatest in the upper part of the Kiltorcan Formation. Transmissivity will be reduced at depth, where the Kiltorcan Formation is thinner in the centre of synclines and permeability is reduced by the deep burial. Borehole yields of 50-4000 m^3/d have been encountered in the Kiltorcan Sandstone (typical yield of 500 m^3/d) with specific capacities of 5-400 m^3/d/m. Storage values range from 0.01-0.1; the higher storage coefficients are a result of a limited amount of intergranular porosity (the sandstone is susceptible to weathering). Boreholes drilled in this GWB as part of groundwater investigations for Charleville WSS at Ballynageragh (O'Sullivan 1980) 9km south of Charleville were artesian in nature and had well yields of 4582 m^3/d (BH1), 5673 m^3/d (BH2), and 1811 m^3/d (BH3). Specific capacities ranged from 200-400 m^3/d/m, transmissivity was estimated at 450 m^2/d and the storage coefficient was estimated at 2.4-5.6 x 10^{-4}. The aquifer can be tapped where it is confined and at considerable pressure. The resulting artesian flows can be quite large.
	Thickness	In drilling that has been done for water wells and core retrieval it has been established that productive fractures in the Kiltorcan Sandstone extend to depths of over 100 m (Dal, 1988). Where confined, active groundwater circulation is expected to be much more limited, but some deep flow has been inferred from mineral exploration boreholes at depths of over 200 m (Daly 1985). It is probable that the Kiltorcan Formation will be thinner in the centre of the synclines (e.g. in the Nore River Basin the Kiltorcan Formation is less than 40 m thick) and permeability will be reduced by the deep burial. In boreholes drilled at Ballynageragh.
Overlying Strata	**Lithologies**	This GWB is primarily covered by glacial till. The matrix is predominantly sandy but also contains some silt and clay. Subsoil permeability has not been mapped in detail in the North Cork region. Small amounts of alluvium deposits occur along some streams crossing the body and some small isolated areas of rock outcrop and shallow rock also occur. *Subsoil Types identified in Ballyhoura Kiltorcan GWB by Teagasc Parent Material Mapping (Draft): Alluvium (A); Rock outcrop and rock close to surface (Rck); Till – Devonian Sandstone Till (TDSs).*

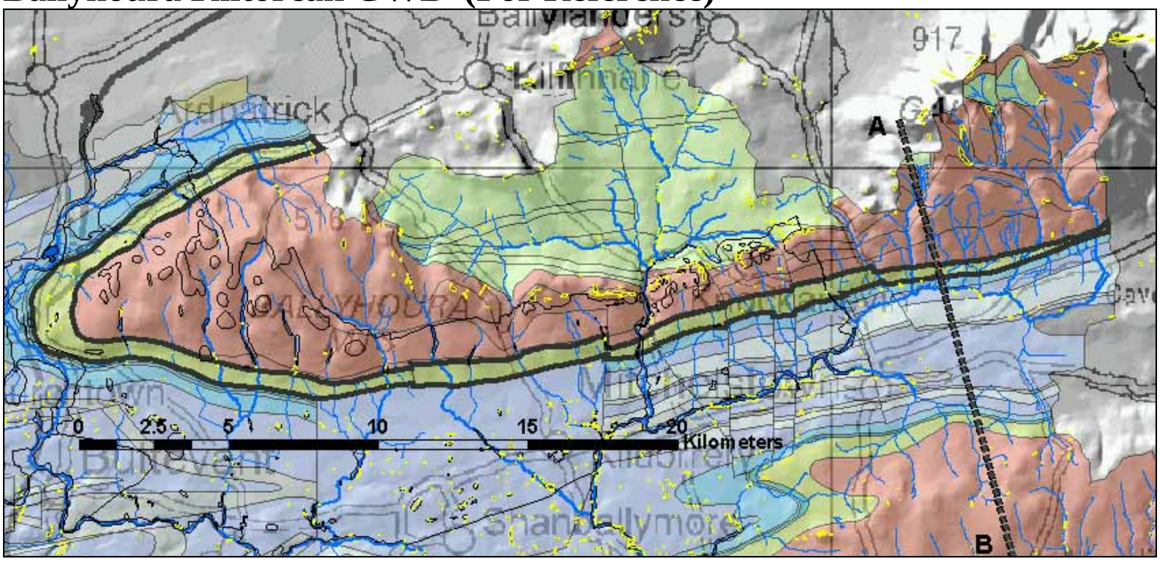
	Thickness	Few depth to rock data are currently available for this GWB. Subsoil depths are likely to be variable as this GWB lies in a transitional landscape from mountains to river valley. It is expected that subsoils will be thinner on the more elevated, steeply sloping parts of the GWB and along incising streams flowing across the GWB. Subsoil thickness is likely increase towards the more low-lying areas of the body in the valleys. At Ballynageragh, south of Charleville subsoil depths of 9-12 m were recorded.
	% area aquifer near surface	
	Vulnerability	A Groundwater Vulnerability Map is not currently available for the North Cork area. Based on data from similar areas in South Cork it is likely that most of this body will be of Extreme and High Vulnerability, however fully categorising areas of Extreme High, Moderate and Low Vulnerability is not possible at this time.
Recharge	**Main recharge mechanisms**	The Ballyhoura and Galtee Mountains to the north and east of this GWB (Ballyhoura GWB) provide abundant runoff which supplies recharge to this GWB. A small amount of groundwater may also cross as through-flow from the sandstones of the Ballyhoura GWB into this GWB. Diffuse recharge will occur over the entire GWB via rainfall percolating through the subsoil. Due to the steep gradients that occur in some parts of this GWB, recharge to the body may be reduced due to rapid discharge to surface watercourses via the upper layers of the aquifer. Most of the recharge to the aquifer will take place in the unconfined portion of the GWB, where the subsoil cover is <5 m. In the confined portion of the GWB thick subsoils and low permeability shales and impure limestones will restrict recharge to the aquifer.
	Est. recharge rates	
Discharge	**Large springs and high yielding wells (m^3/d)**	*Note: Data on groundwater sources and abstractions needs to be updated and checked by RBD Project Consultants.* Data from GSI Well Database: Charleville (Rathluirc) Water Supply Scheme Ballynageragh No. 1 (4582 m^3/d); Ballynageragh No. 2 (5673 m^3/d); Ballynageragh No. 3 (1811 m^3/d).
	Main discharge mechanisms	In the unconfined portion of the GWB a large proportion of the recharge is likely to be discharged again quite rapidly to the many small effluent streams which cross the aquifer. Where the subsoil cover is thicker discharge will take place where the streams have cut down to bedrock or where the subsoil is of high permeability. Where the aquifer is mostly confined, artesian boreholes are common. Where the Kiltorcan Sandstones are overlain by low permeability shales, the aquifer is generally confined, and discharge can only occur near the 'sandstone'/shale boundary. Further down dip into the syncline where the Kiltorcan Sandstones are confined by an increasing thickness of strata there is no obvious outlet for deep groundwater movement. In studies of a similar situation in the Nore River Basin, it was concluded that the discharge of groundwater circulating at depth in the Kiltorcan Sandstones, via large faults and complex pathways, into groundwater of shallower aquifers, was the most likely mechanism (Daly 1988).
	Hydrochemical Signature	Groundwater from the Kiltorcan-type Sandstones is mainly a calcium/magnesium bicarbonate type water. In the recharge areas where the Quaternary deposits are absent or derived from non-Carboniferous strata the water is quite soft (<150 $CaCO_3$ mg/l). Where the aquifer is overlain by limestone derived drift the total hardness normally ranges from 150 – 250 $CaCO_3$mg/l. As the water moves down dip there is some evidence to suggest that ion exchange takes place with a decrease in hardness and the concentration of sodium bicarbonate increasing (Daly 1988). Iron and manganese levels are generally low although occasional high levels can be recorded. Hydrochemical analysis of groundwater from Charleville WS boreholes at Ballynageragh showed total hardness ranging from 176-196 mg/l as $CaCO_3$, total alkalinity 178-192 mg/l as $CaCO_3$, conductivity at 20^o, 362-372 µS/cm.

Groundwater Flow Paths	Groundwater flow occurs through faults and joints. The Kiltorcan-type Sandstones been found to be slightly friable due to weathering and may have a minor component of intergranular porosity, although there is no evidence that this occurs in this GWB. In general groundwater flow is concentrated in the upper 30 m of the aquifer, although deeper inflows can be encountered. Where the sandstones outcrop the aquifer is unconfined but becomes confined as it dips beneath increasing thickness of glacial till and the Dinantian (early) Sandstones, Shales and Limestones, Dinantian Lower Impure Limestones and Dinantian Pure Unbedded Limestones at the margins of the synclinal valleys. Groundwater flow is influenced by topography and groundwater flow will be to the south and west away from the higher ground towards the valleys. In studies of a similar occurrence of Kiltorcan Sandstones in the Slieve Bloom area Daly (1988) divided groundwater flow conditions into four zones (Figure 2). Groundwater circulation is most active in the more elevated parts of the GWB where the overburden cover is < 5 m and the aquifer is unconfined (Zone I). Moving down dip where the GWB is covered by increasing thickness of till the aquifer is mostly confined and artesian boreholes are common. There is not much groundwater movement (Zone II). Where the aquifer is overlain by low permeability shales (Dinantian (early) Sandstones, Shales and Limestones, the aquifer is generally confined and not much natural groundwater circulation takes place (Zone III). In the final zone (Zone IV) the aquifer is capped by an increasing thickness of strata. Significant artesian flows have been hit in this zone which means that groundwater can be induced to move at reasonable depth (over 100 m) in this aquifer. Evidence from temperature logs run in deep mineral exploration boreholes suggests that there maybe movement in reasonable quantities down to 200m and possibly 300 m. It has been suggested that groundwater circulating at depth in the Kiltorcan Sandstone aquifer may be the vehicle for carrying heat from depth to some of the warm springs active in the overlying Carboniferous limestones (Daly 1988), with faults feeding warm groundwater to some of the warm springs. However the link between groundwater circulating in the Kiltorcan Sandstones at depth, and geothermal springs and boreholes has yet to be conclusively proven. Large faults may also retard the circulation of groundwater in the Kiltorcan Sandstones, either by isolating all or part of one block of the aquifer another (fault at right angles to the strike of the aquifer) or by isolating the recharge area from the deeper parts of the aquifer (fault parallel to the outcrop) (Daly, 1988).
Groundwater & Surface water interactions	Based on data from other areas with similar rock type the aquifer is expected to contribute a relatively high baseflow to streams and rivers directly underlain by rock.

Conceptual model	• This GWB occurs as a narrow strip on the ground surface (300-1500 m wide) that winds around the southern, western and north-western flanks of the Ballyhoura and Galtee Mountains. The body occurs at the transition from the uplands of the Ballyhoura and Galtee Mountains to the generally flat low-lying Mitchelstown Syncline. The topography is generally steeply sloping with a transition to some more gently sloping low lying areas to the south and west. Ground elevations range from 80-180 mAOD. • The GWB is composed of productive fissured sandstone classed as a regionally important fissured aquifer. • The GWB is bounded to the north and east by the contact with the low permeability sandstones of the Ballyhoura GWB. The Kiltorcan-type Sandstones of this GWB dip to the west and south and become confined beneath the low permeability shales and impure limestones of the Newtown Butler GWB (west), and the base of the karstic Mitchelstown GWB (south), which forms the southern and western boundary of the body at ground level. At either end of this elongated GWB there is a groundwater divide that coincides with the SWRBD boundary. • The GWB is made up of an unconfined portion where the Kiltorcan-type Sandstones outcrop, and a confined portion where the sandstones become confined beneath thick glacial till and the overlying shales and impure limestones of the Mitchelstown Syncline. Where the aquifer is mostly confined, artesian boreholes are common. The aquifer is expected to be most productive in the west of the body along the axis of the anticline, where deformation is likely to have been most intense. • Groundwater flow generally occurs through faults and joints. • In general groundwater flow is concentrated in the upper 30 m of the aquifer, although deeper inflows can be encountered. The upper half of the Kiltorcan Sandstones is generally the most permeable. Groundwater flow is influenced by topography and groundwater flow will be to the south and west away from the higher ground towards the valleys. • The GWB is recharged diffusely via rainfall percolating through the subsoil over the GWB and by runoff from the Ballyhoura and Galtee Mountains to the north and east. Most of the recharge to the aquifer will take place in the unconfined portion of the GWB, where the subsoil cover is <5 m and where the aquifer is most vulnerable to pollution. In the confined portion of the GWB thick subsoils and low permeability shales and impure limestones will restrict recharge to the aquifer. • It has been suggested that groundwater circulating at depth in the Kiltorcan Sandstone aquifer may be the vehicle for carrying heat from depth to some of the warm springs active in the overlying Carboniferous limestones (Daly, 1988), with faults feeding warm groundwater to some of the warm springs. However the link between groundwater circulating in the Kiltorcan Sandstones at depth, and geothermal springs and boreholes has yet to be conclusively proven.

Attachments	Figure 1 Schematic Cross Section through the Mitchelstown Syncline; Figure 2 Conceptual Model of Groundwater Flow in the Slieve Bloom area; Daly EP (1988) *The Kiltorcan Sandstone Aquifer*. Paper presented at the 8th Annual Groundwater Seminar held in Portlaoise, on: The future of Groundwater Development in Ireland. Published by: IAH (Irish Group).
Instrumentation	**Stream gauges:** none **EPA Water Level Monitoring boreholes:** (CON026) Charleville RWS The borehole is drilled through the Ballysteen Limestones of the Mitchelstown GWB but draws water from the confined portion of the Ballyhoura Kiltorcan GWB **EPA Representative Monitoring points:** (Note (CON026) Charleville RWS The borehole is drilled through the Ballysteen Limestones of the Mitchelstown GWB but draws water from the confined portion of the Ballyhoura Kiltorcan GWB.
Information Sources	Daly EP (1985). *Groundwater Resources of the Nore River Basin: Hydrogeology of the Kiltorcan Aquifer System*. Unpublished internal GSI report Daly EP (1988) *The Kiltorcan Sandstone Aquifer*. Paper presented at the 8th Annual Groundwater Seminar held in Portlaoise, on: The future of Groundwater Development in Ireland. Published by: IAH (Irish Group). Daly EP (1994) "*Groundwater Resources of the Nore River Basin*" Internal Report Series, Geological Survey of Ireland. Duffy S (1994) "*The Protection of Groundwater Resources in County Waterford*" unpublished MSc Thesis for University College Galway. Hudson M (1996) Cappoquin Public Supply, Groundwater Source Protection Zones. Final report to Waterford County Council. Geological Survey of Ireland. Hudson M, Daly D, Johnston P, Duffy S (1998) *County Waterford Groundwater Protection Scheme*. Main Report. Final report to Waterford County Council. Geological Survey of Ireland, 87pp. O'Sullivan MC (1980) Report on the Investigation of Underground Sources for Rathluirc (Charleville) Water Supply Scheme for Cork County Council. Sleeman AG, McConnell B (1995). Geology of East Cork - Waterford. A geological description of East Cork, Waterford and adjoining parts of Tipperary and Limerick, to accompany the Bedrock Geology 1:100,000 scale map series, Sheet 22, East Cork - Waterford. Geological Survey of Ireland.
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae

Ballyhoura Kiltorcan GWB (For Reference)



List of Rock units in Ballyhoura Kiltorcan GWB

Rock unit name and code	**Description**	**Rock unit group**
Kiltorcan Formation (KT)	Yellow & red sandstone & green mudstone	Devonian Kiltorcan-type Sandstones

Figure 1: Schematic Cross Section through the Mitchelstown Syncline
(From Geology of East Cork – Waterford Sheet 22. 1:100,000 Bedrock Map Series, Geological Survey of Ireland.)

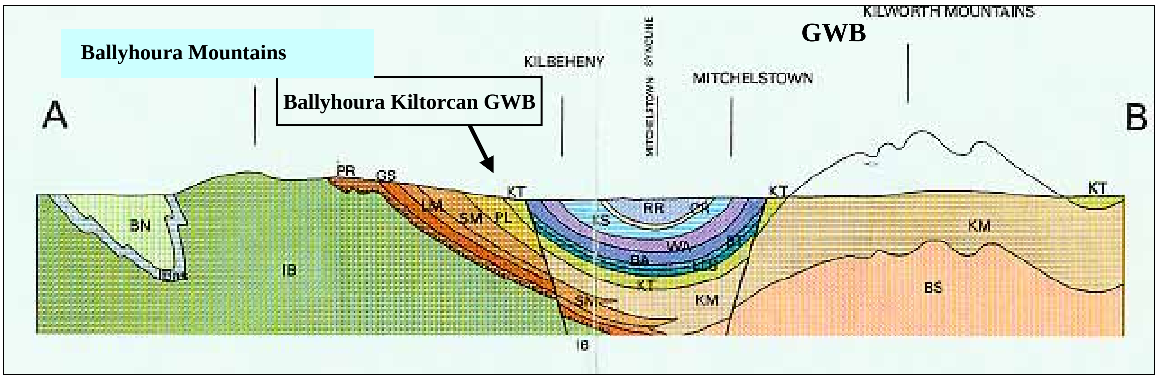
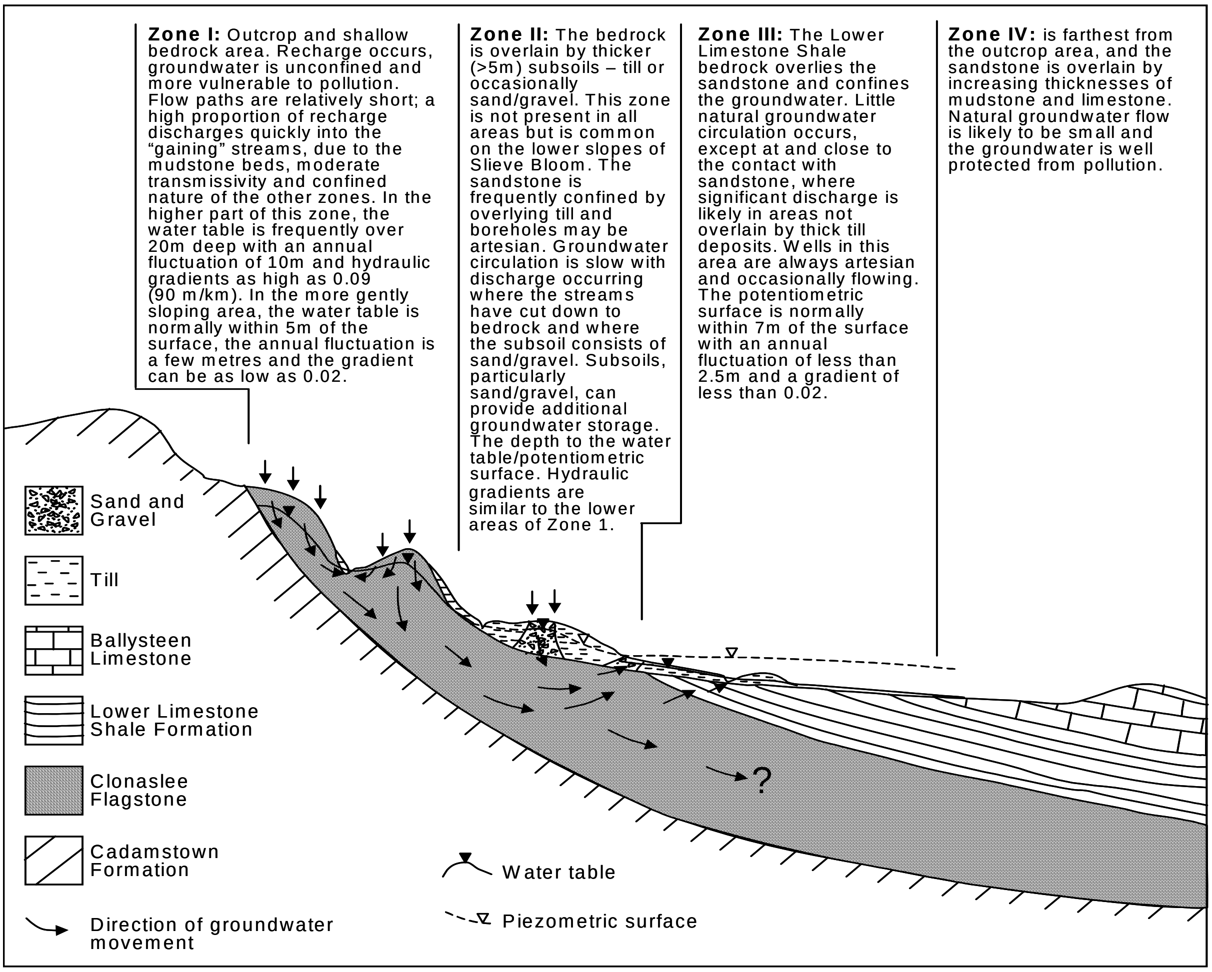


Figure 2: Conceptual Model of Groundwater Flow in the Slieve Bloom area

(From E.P Daly, 1988)



The Kiltorcan Sandstone Aquifer

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THE KILTORCAN SANDSTONE AQUIFER

1) Introduction

The Kiltorcan Sandstone Aquifer is a group of water-producing rocks which occur close to the base of the sedimentary sequence which covers much of the southern part of Ireland.

The aquifer is important when viewed from several standpoints. With exception of the Ordovician Volcanics in the southeast these are the oldest and deepest strata on this island through which groundwater is moving in quantity and which produces substantial and consistent supplies throughout its full extent. The aquifer crops out in areas where alternative sources of water are generally absent. It will be shown later that groundwater movement at depth in this aquifer may act as a conduit to bring heat, present at depth, to the surface. The general purity and range of chemistry of the groundwaters in this aquifer makes it an ideal source for a bottled water.
In the early 1970s when the Geological Survey produced the first hydrogeological maps these strata were not considered to be a significant aquifer. The principal reasons were as follows:

a) Results from wells in the Cork and Kerry region, where there are large outcrops of Old Red Sandstone, were generally rather poor.

b) Much of the aquifer crops out in upland areas where only small supplies are normally required. Very few boreholes penetrating this strata were intended for large supplies.

c) The differences between the geology of this aquifer and the underlying Devonian strata were not fully appreciated, especially the fact that it could be tapped at depth in less elevated areas.

d) The steep dips, poor exposure and complex outcrop pattern over much of the outcrop area meant that a number of boreholes which penetrate the aquifer were actually thought to be in the overlying formations.

Well surveys carried out by the Geological Survey and exploratory investigationsat Charleville and Clonaslee carried out by Geoex Ltd in middle and late 1970s suggested that these particular strata had the potential to provide large water supplies.

Since then development by several Local Authorities and research by the Geological Survey has confirmed these strata as a major aquifer.
Significant groundwater resources have been shown to exist in this aquifer or have been developed at Carrick-on-Suir, Ferbane, Moate, Mitchelstown, Knocktopher, Thomastown, Windgap and possibly Cappawhite as well as those areas already mentioned.

The results of some of these investigations have been presented at previous seminars by Wright (1984), Hand and Daly (1985) and Welsh (1987). Much of the data collected during the Charleville and Mitchelstown (Geoex Ltd) investigations are available in reports. Detailed work on the aquifer by the Geological Survey in the Southeast (1982), County Laois (1983) and the Nore River Basin (1985) are available at the Geological Survey. This paper is based on all of the material referred to above as well as on the results of wireline drilling carried out last year by the Geological Survey at Ballynageragh (Charleville) and Windgap (Co. Kilkenny).

As will be shown below the successful and optimal development of this aquifer is dependent on detailed knowledge of the geology and hydrogeology of the aquifer. Hence in this paper I will attempt to provide sufficient background material for those who may consider developing this aquifer at some locations in the future.

The Kiltorcan Sandstone Aquifer is defined as consisting of the Kiltorcan ('sandstone') Formation and the overlying Porter's Gate 'Shale') Formation. The upper boundary was chosen in order to optimise its development and the lower boundary was chosen on the basis of potential. The reason for doing so will become clear later on in the paper.

2) Geology

This aquifer crops out around the sides of the limestone synclines in the South of Ireland as well as around the foothills of over 20 upland areas (Palaeozoic Inliers) which occur throughout the southern part of the Central Plain.

It normally crops out at elevations of less than 200m. The Kiltorcan Formation consists of fine to medium grained pale sandstones and green or red mudstones with minor amounts of conglomerate. Quartz is the dominant mineral but varying amounts of feldspar, dolomite and mica are also present. In the Nore River Basin the sandstone units generally up about 70% of the upper part of the formation with the individual units being thickest in the middle. The mudstone units increase in thickness towards the base. A substantial proportion of the sandstone units are in excess of 5m thick.

The Porter's Gate Formation consists of thin (normally less than 2m) of interbedded sandstones, limestones, siltstones and mudstones which grade into each other both laterally and vertically. The sandstones and limestones are generally restricted to the lower part of the formation, where they account for 30-70% of the strata. The sandstone are fine grained and are calcareous or dolomitic in places. The mudstones/siltstones are dominant at the top where they act as a confining (impermeable) layer.

The Devonian strata are fluvio-lacustrine (continental) deposits and were laid down in the channels and flood plains of large southerly flowing rivers. The Lower Devonian strata were laid down in a number of small basins and the Munster Basin an area of continuous crustal subsidence (hence vary thick deposits). The Kiltorcan strata were deposited in an extensive coastal plain which covered the earlier basins which had filled up. The Porter's Gate Formation signifies the onset of marine conditions and the transgression of the Carboniferous Sea northwards.

There is a general reduction in the thickness of both of these formations from south to north and from west to east. Equivalent strata are almost absent from the north of Ireland. It is also probable that the sandstones will be much thinner in the centre of the synclines (e.g. in the Nore River Basin the Kiltorcan Formation is less than 40m thick). The thickness of the Kiltorcan and Porter's Gate Formation in the Slievenamon areas are 230m and 40m respectively. In the case of the ‘sandstone' formation the reduction in thickness is particularly marked north of Slievenamon.

The Hercynian earth movements resulted in these strata being uplifted into large mountains and being extensively deformed and broken. The steep folds of the extreme south give way to more gentle folds (e.g. Slieve Bloom), in the midlands where the effect of the Hercynian deformation is less. The area of outcrop of the aquifer is greater in the latter region with the exception of the areas where the steep folds plunge below the Carboniferous. The induration of the sediments is also likely to be less with distance from the Hercynian Front which is thought to extend from Dungarvan to Dingle.

Faulting is far more extensive than is shown on any maps particularly in the south. In South Kilkenny there appears to be a significant fault about every kilometre. The faults are generally, N/S, NE/SW and E/W in direction and they are regularly encountered in boreholes. The sandstone units are extensively jointed (vertical) in places and the joints tend to be parallel to the strike of the main faults. The amount of jointing also decreases northward. Horizontal jointing is present in the sandstone units but is much more widely spaced. The microfractures, which are not always open over their full length, can be tightly spaced and are generally parallel to the main joints.

The outcrop areas of the aquifer (especially on the north facing slopes of the uplands) frequently have a thick cover (up to 25m) of Quaternary deposits (e.g. Galty Mountains and Slieve Bloom). Till and sand and gravel are the most common type of deposit.

3) Porosity and Permeability

The porosity and permeability present in the sandstone and limestone units after deposition has been obliterated by the geological processes resulting from the increased temperatures and pressures associated with the compaction and burial of these rocks by over 2000m of subsequent strata. Hence the porosity and permeability we now see in these old and indurated strata are secondary and are the result mainly of earth movements (Hercynian and Tertiary) and to a lesser extent of weathering and possible dolomitisation.

The fractures (faults, joints and microfractures), produced by the stresses exerted on these rocks by the earth movements, are more extensive in the south. Hence the permeability will be higher here also. This is illustrated by the core from the boreholes at Charleville which is more broken than the Windgap core. Fracturing will also be more intense around major structural features such as fault zones, anticlines etc. In these formations fracturing tends to be restricted to the sandstone units. In the Kiltorcan Formation the intensity of fracturing can vary greatly over relatively short distances. Fracturing is likely to be considerably reduced at depth and may be absent in the centre of large synclines where the sandstones (at 500-1000m) are in compression. So far in the drilling that has been done for water wells and core retrieval it has been established that productive fractures extend to depths of over 100m.

Many of the minerals in these rocks e.g. calcite, dolomite, feldspar and argillaceous clasts or the matrix of argillaceous material are susceptible to chemical weathering. Along some fractures, both in outcrop and core (especially where two fractures intersect), the sandstones are friable and crumble easily. In many of the water wells drilled by air percussion the chippings resemble a fine sand. The total porosity of these sandstones is normally less than 5%, however in these heavily weathered sections the porosity is in excess of 10% in places. These weathered sections will also have an intergranular permeability. There is some evidence to suggest that this weathering effect increases to the north, possibly due to the lower degree of induration. With the decrease in the intensity of fracturing (and hence groundwater movement) at depth and to the north the volume of rock affected will be less. As the fracturing and weathering are related we know it can extend to over 100m but was not detected in a borehole that penetrated the sandstone, near the centre of the Southeast Carboniferous Basin, at 950m. Hence it must die out somewhere in between.

Dolomitisation of the limestones and sandstones does occur in certain areas of both formations and appears to be restricted to the strata close to the boundary between the 'sandstone' and 'shale' formations. The shrinkage cracks and vugs normally associated with dolomitisation will lead to an increase in porosity which will be present throughout the aquifer.

The sandstones and mudstones of the Kiltorcan Formation were deposited in a large coastal flood plain hence they interfinger both vertically and horizontally. The permeability of the different parts of the formation will depend basically on the amount of sandstone present and the thickness of the individual sandstone units and their degree of interconnection. Hence it is to be expected that the permeability will be greatest in the upper half of the Kiltorcan Formation and at the base of the Porter's Gate Formation. The permeability of these sandstones varies from 0.5-20 m/d but occasionally can be as high as 80 m/d.

4) Well yields

From the discussion above on permeability it would be expected that well yields (and hence transmissivity and specific capacity) would be greatest in the south, in the areas with major structural features and where a significant part of the upper half of the Kiltorcan Formation is penetrated.

This is shown to be generally true by the developments to date. The details of boreholes in four areas where there has been substantial development are given in Table 1, which shows the type of variation in yield, etc. that can be expected when poor locations have to be used.

In the Kiltorcan Formation the specific yield is normally about 2%, however near the surface it can be as high as 5%. Storage in the overlying Quaternary deposits can be up to 15% and can be utilised in the development of this aquifer.

Area	**Well Yields**	**Specific Capacity**	**Transmissivity**	**Storage Coefficient**
	m^3/d	$m^3/d/m$	m^2/d	
Charleville	2,700-4,000	200-400	450	$2.4\text{-}5.6 \times 10^{-4}$
Mitchelstown	1,000-2,000	1-80-120	225	6.7×10^{-6}
South Kilkenny	200-1,300 (Artesian)	30-600	75-1,800	3.9×10^{-6}
North Laois	250-1,000	14-35	20-94	8.0×10^{-4}

Table 1. Result of pumping tests on boreholes in four areas of the Kiltorcan Sandstone Aquifer.

5) Hydraulic Regime

The flow conditions in this aquifer can be conveniently subdivided into zones with different hydraulic and flow characteristics (Figure 1).

Zone I — This zone is underlain by the ‘sandstone’ formation and an overburden cover of less than 5m. The aquifer is unconfined and hence it is here that most of the recharge takes places and also where the aquifer is most vulnerable to pollution. This is the zone of the most active groundwater circulation. A large proportion of the recharge is discharged again quite rapidly to the many small effluent streams which cross the aquifer.

Zone II — This zone is also underlain by the ‘sandstone' formation but contains a thick cover (>5m) of till or sand and gravel. This is not present in all areas. The aquifer is mostly confined and artesian boreholes are common. There is not much groundwater movement. Discharge takes place where the streams have cut down to bedrock or where the overburden consists of sand and gravel.

Zone III — This is the outcrop area of the 'shale' formation the top of which is considered to be an aquitard. The aquifer is generally confined. Not much natural groundwater circulation takes place as discharge can only occur near the 'sandstone'/shale boundary.

Zone IV — Here the aquifer is capped by an increasing thickness of the strata which overlies the Porter’s Gate Formation. Significant artesian flows have been hit in this zone which means that groundwater can be induced to move at reasonable depth (over 100m) in this aquifer. In the synclines of the Central Plain there is no obvious outlet for deep groundwater movement. Hence it is difficult to tell whether deep groundwater circulation does take place naturally owing to the shortage of deep boreholes. Evidence from temperature logs run in deep mineral exploration boreholes suggests that there maybe movement in reasonable quantities down to 200m and possibly 300m.

If natural flow does occur then what is the mechanism that brings the groundwater back to the surface? In the Nore River Basin three possible mechanisms were considered. It was concluded that the discharge of groundwater circulating at depth in this aquifer via large faults, into or with the groundwater of shallower aquifers, is the most likely. The volumes of water returning to the surface would be quite small and it would be mixed with large volumes of other groundwaters. Hence it would be difficult to detect the presence of the deeper waters using hydrochemical methods. In these circumstances temperature measurements are likely to be more sensitive. It is possible that groundwater circulating at depth in this aquifer may be the vehicle for carrying heat from depth to some of the warm springs active in the overlying Carboniferous limestones. Burdon 1983 has concluded that faults could feed warm groundwater to some of the warm springs in this country. The presence of anomalous temperatures in the waters from springs, boreholes and dug wells in the Callan area of County Kilkenny, where there are also some major faults, gives some weight to this proposed model.

Large faults may also retard the circulation of groundwater in aquifer, either by isolating all or part of one block of the aquifer another (fault at right angles to the strike of the aquifer) or by isolating the recharge area from the deeper parts of the aquifer (fault parallel to the outcrop).

6) Hydrochemistry

The groundwaters in this aquifer are mainly calcium/magnesium bicarbonate type waters. The chemistry of these waters is quite varied. In recharge areas where the Quaternary deposits are absent or derived from non-Carboniferous strata the water is quite soft (T.H. < 150 mg/1). Where the aquifer is overlain by limestone-derived drift the Total Hardness normally ranges from 150-250 mg/l. In the Porter's Gate Formation the waters are very hard (IT.H. > 250 mg/l.). As the water moves downdip there is some evidence to suggest that ion exchange takes place with a decrease in hardness and the concentration of sodium bicarbonate increasing.

The water quality is generally excellent. Iron and manganese levels are low although one or two exceptions have been recorded.

7) Aquifer Development

Over the last ten years significant development of this aquifer has taken place. It has been developed in many areas where cheap alternative sources of supply have not been available. The principal advantages in developing this aquifer are as follows:

a) It can be developed over much of the country south of a line from Dublin to Galway.

b) It can generally be developed close to good reservoir sites.

c) The aquifer crops out in areas of moderately high rainfall.

d) The aquifer can be tapped where it is confined and at considerable pressure. The resulting artesian flows can be quite large. The implications for pumping costs are obvious.

e) The groundwaters are normally softer than those from the other major aquifers in this country.

f) The quality of the groundwater is usually good as the recharge areas are in remote areas where habitation is sparse and agricultural development is non-intensive. The confined nature of the aquifer in the areas suitable for development provides protection from pollution near abstraction sites.

g) Drilling conditions are usually good although the boreholes may need to be fully cased to protect the pumping installation. As artesian flows are common, preparations to cope with them should be made in advance casing with a threaded or flanged well head should be grouted at least 3m into bedrock. Furthermore artesian flows should be shut off when boreholes are complete.

The principal disadvantage to the development of this aquifer is the low specific capacity and storage. The low specific capacity can be offset to some extent by choosing favourable sites for development and the low storage is compensated for by the consistently high recharge for about six months of the year and the additional storage which is available in the Quaternary deposits.

In order to achieve the optimum yields from boreholes when developing this aquifer in particular areas, the following criteria should be used where possible when selecting well sites:

a) lowlying areas where the aquifer is confined and near a significant structural feature such as an anticline or fault.

b) ideally boreholes should penetrate 50-100m of the 'sandstone' formation depending on the yield required. These thicknesses may not always be available, however.

c) Areas where the piezometric surface is at least 30m above the most productive section of the aquifer i.e. the base of the 'shale' formation and the upper half of the 'sandstone' formation. This will minimise well losses and reduce the possibility of wash outs of the borehole walls. Hence boreholes should be collared at the surface near the outcrop of the top of the 'shale' formation.

d) Where very large supplies are required it would be advisable to choose a site which is downdip of either an area where the outcrop is quite extensive or where there is additional storage available from the Quaternary deposits.

With boreholes of 100-150 m deep at sites chosen in accordance with the above criteria yields of 1,000 to 4,000 m3Iiday can be expected.

This aquifer does underlie most of the limestones in the southern part of the Central Plain. How far out from the outcrop area (i.e. penetrating the aquifer downdip at greater depth) are we likely to obtain reasonable well yields? So far we have evidence of groundwater flow at depths of 100m. Beyond that we are in the unknown. For the moment it would be unwise to attempt to tap the productive part of the aquifer at depths in excess of 250 m. This means choosing sites within a kilometre of the outcrop of the top of the Porter's Gate Formation. If development proceeds in some areas at greater depths we will eventually get the required information on permeability and aquifer thickness in order to predict the effective boundary of the aquifer at depth.

In this aquifer the amount of potential recharge is far greater than the volume of water that can be taken from the aquifer in any one This and other aspects of development are topics for another day.
