Castlemaine GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
22 Kerry Co. Co.	**Rivers:**.Groin, Glanageenty, Glanshearoon, Maine, Shanowen, Brown Flesk, Longfield, Fahaduff, Croaghane.	Anna More Bog (000333) ?	146

Topography		This GWB occupies the lowlands that curve around the eastern inland end of the Dingle Peninsula and Slieve Mish Mountains (Dingle GWB), from Castlemaine Harbour in the south to Ballydwyer (southwest of Tralee) in the north. Ground elevations range from 10-100 m OD. The lowest ground (≤10 m OD) occurs in the west of the body along the Maine River and around Castlemaine Harbour and along the inner western boundary with the Dingle GWB. Most of the rest of the body has ground elevations of 20-50 mAOD gently increasing in elevation towards the outer boundary of the body, to the south, east and north. In the eastern half of the body elevations rise more steeply towards the body boundary to the south, east and north. The highest ground in the body (100 m OD) occurs on the northeastern boundary of the body, northeast of Castleisland. Around the boundary of this body to the south, east and north is a terraced escarpment of shales and sandstones of Namurian age. This escarpment ranges in elevation from 60 to 180 m OD.
Geology and Aquifers	**Aquifer categories**	**Rkd**: Regionally important karstified aquifer dominated by diffuse flow. **Ll:** Locally important aquifer, moderately productive only in local zones.
	Main aquifer lithologies	Dinantian Pure Unbedded Limestones with some Dinantian Upper Impure Limestones. *A tiny area of Dinantian Lower Impure Limestones (<1 km^2) is also included in the body.*
	Key structures	The Variscan Orogeny compressed rocks in South Munster from the south into a series of folds on east west axes, and created an extensive network of fractures (often predominantly north-south), which in the pure limestones were subsequently enlarged by karstification. The rocks of this GWB form part of the limb of a large fold (Slieve Mish Anticline). Major faults cut through the body trending NNW-SSE. The rocks are well jointed. A study in the nearby Maine River Basin shows that about 80% of joints are orientated NNE-SSW. The open nature of the joints allows groundwater movement and facilitates conduit development by solution (Scanlon, 1985).
	Key properties	The pure unbedded limestones of this GWB are highly productive. Faults and joints were enlarged by karstification as groundwater moved through the limestones. There are numerous surface karst features in these limestones, (e.g. swallow holes, collapse features and closed depressions), large caves (e.g. Crag Cave), sinking streams draining the surrounding shales, and large springs (e.g. Tobermaing Spring). In the past, sea level is estimated to have been approximately 50-60 m below present day O.D., the level to which the now infilled channel of the River Lee was eroded (Farrington 1959) enabling karstification at depth. When the sea level rose again, the large voids created by karstification were flooded and now constitute very substantial groundwater storage. There is a strong structural influence on the development of karstification (vertical N-S joints dominate). Transmissivity in the pure unbedded limestones can range up to a few thousand m^2/d. Pumping tests in the same rock type in similar conditions (Waulsortian Limestone) in the Cloyne GWB gave a range of transmissivity of 200 to over 2000 m^2/day. A study of the Maine River basin by Scanlon (1985) highlighted some variations in hydrogeological properties observed within the pure unbedded limestones in this body. The Cloonagh Limestone/Cracoean Reef which occurs on the eastern side of the body, differs from the Waulsortian Limestone in that it has lower well yields, attributed in the study to lower permeability. Groundwater level hydrographs are much flashier in the Cloonagh/Cracoean Reef than in the overburden or Waulsortian Limestone (Figure 2). Water level fluctuations are abrupt and the response to recharge is rapid. The Cloonagh Limestone/Cracoean Reef is highly karstified and it is thought that recharge from sinking streams draining the surrounding shales may be concentrated in enlarged conduits poorly connected to the main groundwater reservoir, therefore not fully benefiting the aquifer, but emerging directly as large springs. High wells yields can be expected if conduits are drilled, but the probability of locating a conduit is low. Failed wells have been reported in both types of pure unbedded limestones in this region reflecting a nonuniform porosity in these rocks (Scanlon 1985). Groundwater gradients will be low in the Waulsortian Limestones (0.001-0.005). Steeper hydraulic gradients occur towards the northern and eastern margins of the body where impure limestones and high recharge occur. In the impure limestones, transmissivities will be lower; generally in the range 5-20 m^2/d but may be higher where karstification has occurred. Overlying sand and gravel deposits which are in continuity with the underlying limestone provide additional storage to the bedrock aquifer.

	Thickness	The Dinantian Pure Unbedded Limestones (Waulsortian Limestone) is approximately 600m thick in the Castleisland–Tralee-Ardfert area (Pracht 1997). Most groundwater flow may occur in an epikarstic layer a couple of metres thick and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 30 m below this. However deeper flows also occur and boreholes can intersect fissuring and karstification at depths of down to 60 m below OD. In the Impure Limestones that occur at the margins of this GWB, most groundwater flow may occur in an upper weathered layer of a few metres and a zone of interconnected fissures often not extending more than 15 m from the top of the rock, although occasional deep inflows associated with major faults can be encountered. Impure limestones are also much less susceptible to karstification.
Overlying Strata	**Lithologies**	Most of this GWB is covered by glacial till. Tills derived from the Namurian Sandstones and Shales to the east of the GWB dominate while tills derived from Limestone occur in the northwest and between Castlemaine and Farranfore. Undifferentiated Alluvium is found along the Maine and Flesk rivers and other smaller streams. Several areas of cutover peat also occur. Areas of karstified limestone bedrock at surface occur south of the Maine River, northwest of Farranfore and northwest and southwest of Castleisland. Small areas of rock outcrop and shallow rock occur throughout the body. *Subsoil Types identified in Castlemaine GWB by Teagasc Parent Material Mapping (Draft): Alluvium (A); Cutover peat (Cut); Karstified rock outcrop and rock close to surface (KaRck); Lake sediments undifferentiated (L); Made Ground (Made); Estuarine sediments (silts/clays) (Mesc); Rock outcrop and rock close to surface (Rck); Till – Devonian Sandstone Till (TDSs), Limestone Till (TLs), Namurian Sandstone and Shale Till (TNSSs).*
	Thickness	Available data indicates that subsoil thickness ranges 0-34m. It is impossible to give a typical thickness, but the general impression is of subsoils ≤ 6 m in most areas, with thinner subsoils near outcrops and thicker subsoils near the river courses. Scanlon (1985) in the Maine catchment indicated that subsoils are thicker over the impure limestones than on the pure unbedded limestones as the impure limestones were eroded more easily by glaciers, with resulting thicker subsoils infilling the topographic lows. Where the underlying limestone is highly karstified it is likely to a very irregular bedrock surface. Subsoil depths in these areas can therefore be highly variable within short distances.
	% area aquifer near surface	
	Vulnerability	A Groundwater Vulnerability map is not currently available for Co. Kerry. It is probable that many areas of Extreme vulnerability are present around the frequent areas of rock outcrop and shallow rock, but fully delineating areas of Extreme, High, Moderate and Low vulnerability is not possible at this time.
Recharge	**Main recharge mechanisms**	Surrounding uplands provide abundant runoff which supplies recharge to the limestone aquifer. Swallowholes and collapse features provide the means for point recharge to the karstified aquifer. Some streams running off low permeability rocks in the northeast of the body sink on reaching the karstified limestone. A small volume of groundwater may cross into this GWB as through-flow from the lower permeability aquifers in adjacent GWBs. Diffuse recharge will occur via rainfall percolating through the subsoil and areas of outcropping rock. The proportion of the effective rainfall that will recharge the aquifer is determined by the thickness and permeability of the subsoil. In this highly productive aquifer there may be some low-lying areas with a high water table, where a proportion of the effective rainfall is rejected due to lack of storage space in the aquifer.
	Est. recharge rates	
Discharge	**Large springs and high yielding wells (m^3/d)**	*Note: The following data need to be checked and updated by RBD Project Consultants.* Data from GSI Well Database: Dromore, Kerry Co Co (873 m^3/d), Carrow/Ranalough Creamery (655 m^3/d) Tobermaing Spring (Kerry Co. Co.) (25,920 m^3/d) Data from EPA Groundwater Sources List: Milltown WS (290 m^3/d)
	Main discharge mechanisms	Groundwater discharges to large springs within the GWB and to the rivers and streams crossing the GWB. The Maine River is the primary discharge line.

	Hydrochemical Signature	The groundwater in this body is dominated by calcium and bicarbonate ions. Hardness can range from moderately hard to very hard (200 to >400 mg/l (as $CaCO_3$). Spring waters tend to be softer as throughput is quicker and there is less time for the dissolution of minerals into the groundwater. Groundwater alkalinity is high, up to 400 mg/l (as $CaCO_3$). Alkalinity is generally less than hardness, indicating that ion exchange (where calcium or magnesium are replaced by sodium) is not significant. These hydrochemical signatures are characteristic of clean limestone. Like hardness and alkalinity, electrical conductivities (EC) can vary greatly. Typical limestone water conductivities are of the order of 500-700 µS/cm. Lower values suggest that the residence times of some of the sources are very short reflecting a karstic system with rapid flow velocities. Chloride levels in groundwater in this body can be elevated near the coast. Due to the high level of interaction between groundwater and surface water in karstic aquifers, microbial pollution can travel very quickly from the surface into the groundwater system. The normal filtering and protective action of the subsoil is often bypassed in karstic aquifers due to the number of swallow holes, dolines and large areas of shallow rock. The hydrochemical signature of groundwater from wells in the pure bedded limestone in this GWB is demonstrated in an expanded Durov plot in Figure 1 below.
Groundwater Flow Paths		These rocks have no intergranular permeability. Groundwater flow occurs in the many faults and joints, enlarged by karstification. North south jointing appears to be the primary control on groundwater flow. It is likely that at least part of the groundwater flow may be through enlarged conduits within the limestone (particularly in the Cloonagh Limestone/Cracoean Reef) however overall groundwater flow in the Waulsortian Limestone is generally thought to be diffuse rather than focussed due to the high frequency fractures and jointing. Within the pure unbedded limestones, the water table is shallow, generally within 10 m of the surface. Groundwater is generally unconfined, with surface water features in hydraulic continuity with the water table. Annual water table fluctuation of 2-4m is observed in the Maine (Scanlon 1985). Hydrographs from wells in the Maine River Basin are shown in Figure 2 below and the EPA hydrograph for Castlemaine WS is shown in Figure 3. Groundwater gradients are relatively flat in the Waulsortian Limestones in the centre of the body. Hydraulic gradients are steeper at the margins of the GWB where the impure and less permeable limestones occur. Groundwater flows down gradient to the Maine River which serves as the primary line of discharge. Comparison of water table and geological maps indicates that water flows along north-south joints in directions opposite to the regional dip of the beds (Scanlon 1985). The highly permeable aquifer supports a regional scale flow system. Groundwater flow paths can be up to several kilometres long, but may be significantly shorter in areas where the water table is very close to the surface.
Groundwater & Surface water interactions		The nature of the karstic system leads to rapid interchanges of water between surface and underground. Swallow holes and caves receive surface water, and groundwater is discharged to surface as springs or as baseflow to rivers crossing the groundwater body.

<table>
<tr><td>Conceptual model</td><td colspan="2">

This GWB occupies the lowlands that curve around the eastern inland end of the Dingle Peninsula. Ground elevations range 10-100 m OD, rising toward the outer boundary of the body, to the south, east and north.
The GWB is bounded to north, east and south by the contact with the poorly permeable Namurian rocks of the Scartaglin GWB. The inner western boundary is formed by the contact with the low permeability impure limestones of the Dingle GWB. The northwestern boundary is formed by the surface water catchment boundary and groundwater divide between the Maine and Lee catchments.
The GWB is composed mainly of diffusely karstified, highly productive pure limestones with some less permeable impure limestone around the southern, eastern and northern margins of the body. Surrounding this body to the south, east and north is a terraced escarpment of low permeability shales and sandstones of Namurian age (Scartaglin GWB)
The rocks in this body are intensely fractured and jointed, and subsequent karstification of these openings has significantly enhanced the permeability of the pure limestones. Karst features are common and karstification extends well below present day sea level, contributing to groundwater storage in the aquifer. Groundwater flow occurs in the many faults and joints, enlarged by karstification. North south jointing appears to be the primary control on groundwater flow. It is likely that at least part of the groundwater flow may be through enlarged conduits within the limestone (particularly in the Cloonagh Limestone/Cracoean Reef) however overall groundwater flow in the Waulsortian Limestone is generally thought to be diffuse nature due to the high frequency fractures and jointing.
Most groundwater flow may occur in an epikarstic layer a couple of metres thick and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 30 m below this. However deeper flows also occur and boreholes can intersect fissuring and karstification at depths of down to 60 m below OD.
Within the pure unbedded limestones, the water table is shallow, generally within 10 m of the surface. Groundwater is generally unconfined, with surface water features in hydraulic continuity with the water table and an average annual water table fluctuation of 2-4 m. Groundwater gradients are relatively flat in the Waulsortian Limestones in the centre of the body. Hydraulic gradients are steeper at the margins of the GWB where the impure and less permeable limestones occur
The highly permeable aquifer supports a regional scale flow system. Groundwater flow paths can be up to several kilometres long, but may be significantly shorter in areas where the water table is very close to the surface. Groundwater flows down gradient to the Maine River which serves as the primary line of discharge.
Recharge to this GWB is both point and diffuse. Swallow holes and collapse features provide the means for point recharge to the karstified aquifer. Some streams running off low permeability rocks in the northeast of the body sink on reaching the karstified limestone. A small volume of groundwater may cross into this GWB as through-flow from the lower permeability aquifers in adjacent GWBs. Diffuse recharge will occur via rainfall percolating through the subsoil and areas of outcropping rock.
There is a high degree of interaction between surface water and groundwater in this GWB. Swallow holes and caves receive surface water, and groundwater is discharged to surface as springs or as baseflow to rivers crossing the groundwater body.

</td></tr>
<tr><td colspan="2">Attachments</td><td>Hydrochemical Signature (Figure 1); Groundwater Hydrograph (Figure 2)</td></tr>
<tr><td colspan="2">Instrumentation</td><td>Stream gauges: 22014
EPA Water Level Monitoring boreholes: Castleisland WSS (KER 69)
EPA Representative Monitoring points: Old Castleisland WSS (KER 69), Currow WSS (KER 98)</td></tr>
<tr><td colspan="2">Information Sources</td><td>Conlon V, Wright G (1998) County Kerry Aquifer Classification (draft). Geological Survey of Ireland Report to Kerry Co. Co., 18 pp.
Scanlon B (1985) A Groundwater Study of the Maine River Basin, Co. Kerry. Geological Survey of Ireland Report Series, RS 85/1. Geological Survey of Ireland, Dublin.
Farrington A (1959) The Lee Basin Part one: glaciation. Proc. R. Ir. Acad. 60B (3), 135-166.
Pracht M (1997) Geology of Kerry-Cork: a geological description, to accompany bedrock geology 1:100,000 scale map, Sheet 21, Kerry - Cork. Geological Survey of Ireland. 70pp
Wright G (1979) Groundwater in the South Munster Synclines. In: Hydrogeology in Ireland, Proceedings of a Hydrogeological Meeting and associated Field Trips held in the Republic of Ireland from 22 to 27 May, 1979. Published by the Irish National Committee of the International Hydrological Programme.</td></tr>
<tr><td colspan="2">Disclaimer</td><td>Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae</td></tr>
</table>

Figure 1: Hydrochemical signature
(EPA Representative Monitoring)

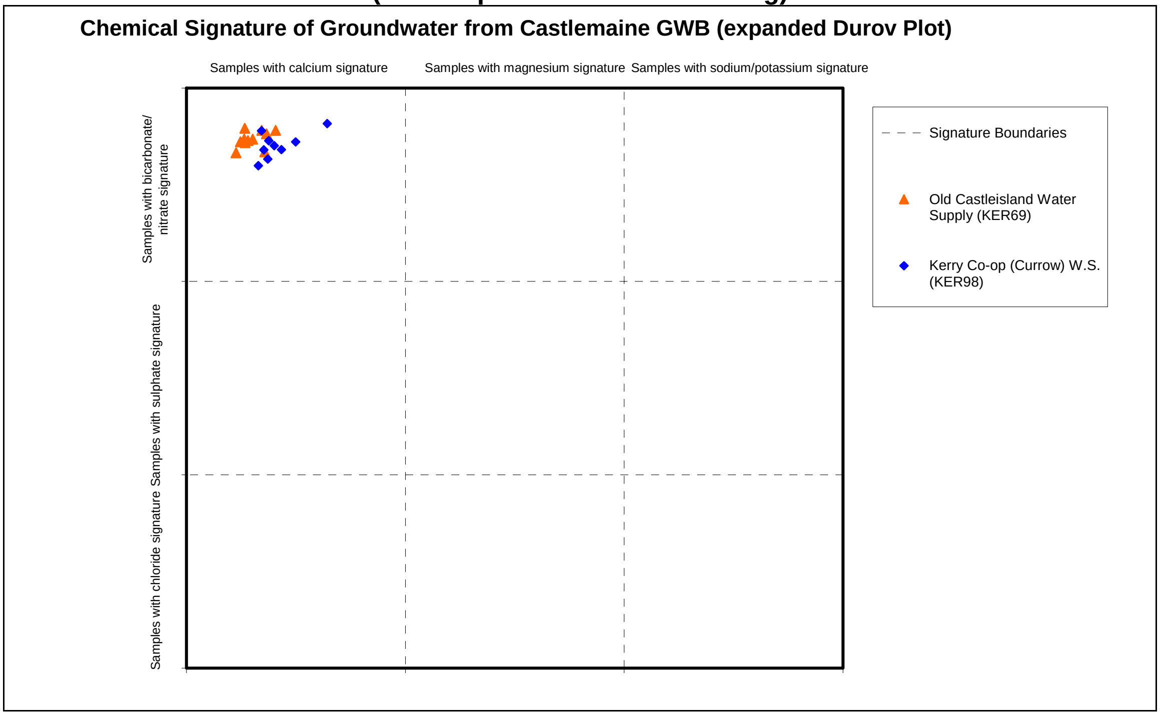


Figure 2: Groundwater level hydrographs in Dinantian Pure Unbedded Limestone in Castlemaine GWB

(Scanlon, 1985. A Groundwater Study of the Maine River Basin, County Kerry.)

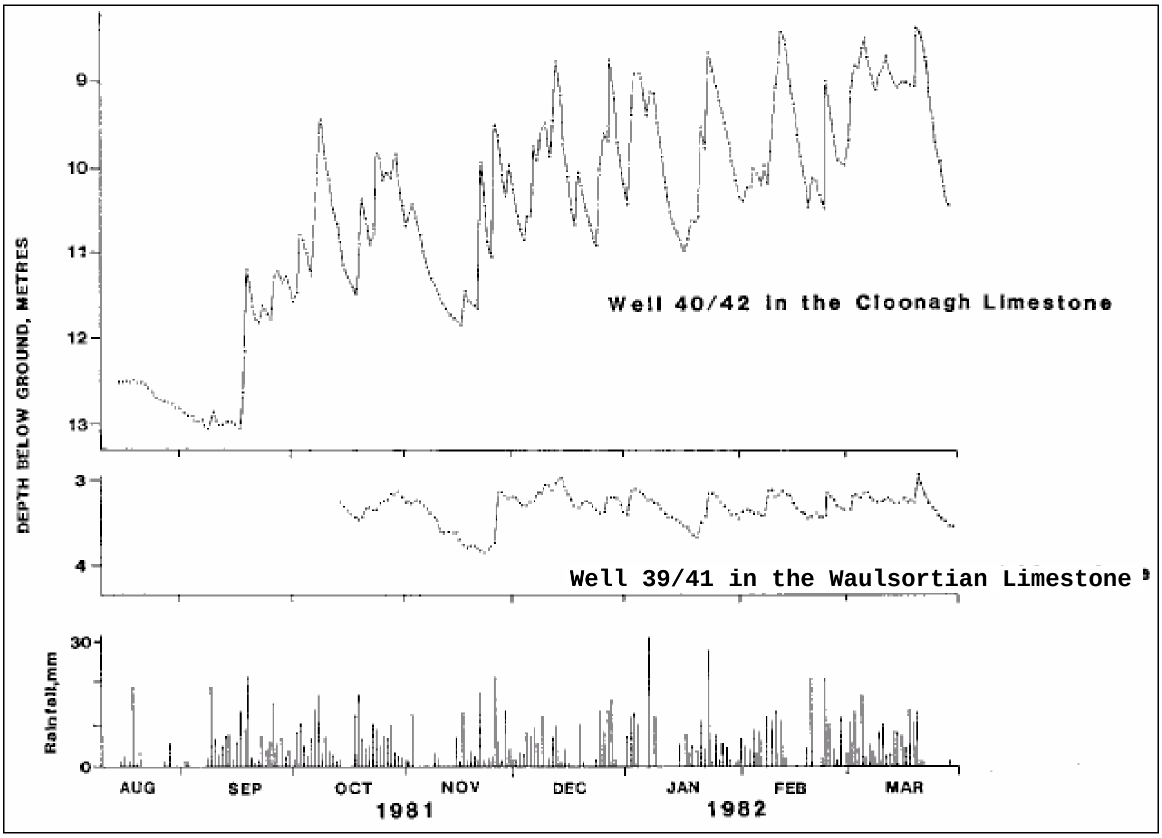
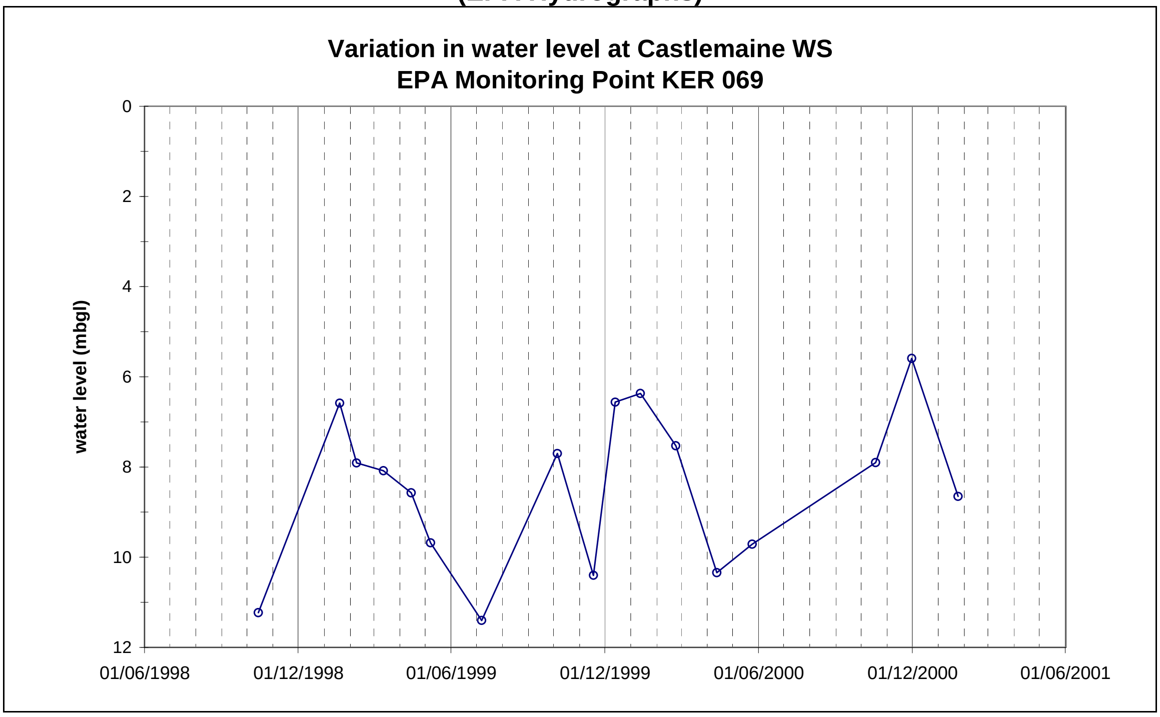
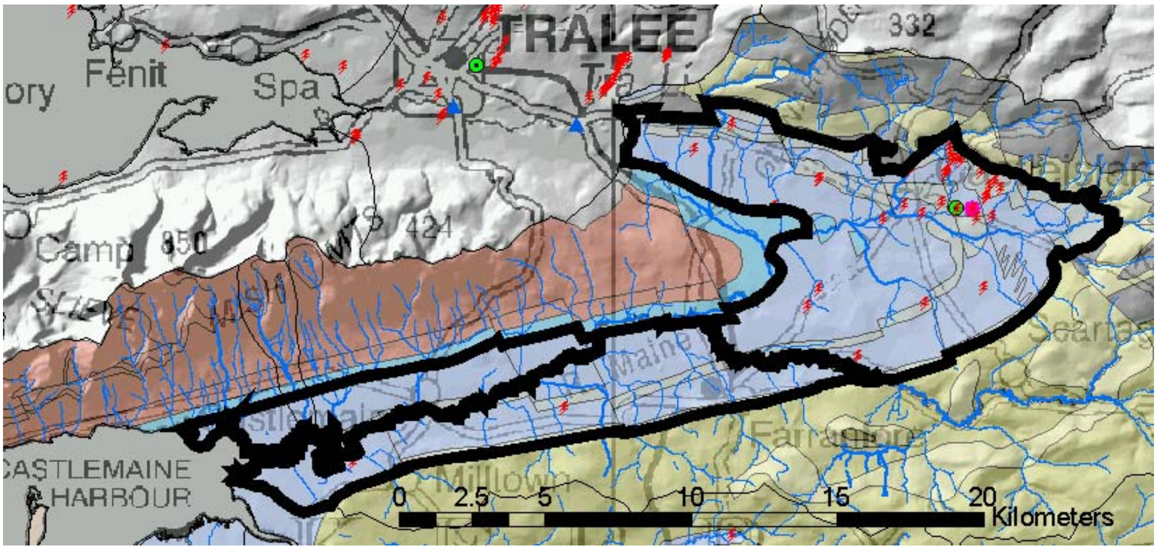


Figure 3: Groundwater hydrographs

(EPA Hydrographs)



Castlemaine GWB (For Reference)



List of Rock units in Castlemaine GWB

Rock unit name and code	**Description**	**Rock unit group**
Dinantian limestones (undifferentiated) (DIN)	Undifferentiated limestone	Dinantian Upper Impure Limestones
Dirtoge Limestone Formation (DI)	Bioclastic cherty grey limestone	Dinantian Upper Impure Limestones
Cloonagh Limestone Formation (CL)	Bedded bioclastic limestone	Dinantian Pure Unbedded Limestones
Cracoean Reef Member (CLcr)	Unbedded calcilutite limestone	Dinantian Pure Unbedded Limestones
Rockfield Limestone Formation (RF)	Well bedded argillaceous limestone	Dinantian Upper Impure Limestones
Waulsortian Limestones (WA)	Massive unbedded lime-mudstone	Dinantian Pure Unbedded Limestones
Ballysteen Formation (BA)	*Fossiliferous dark-grey muddy limestone*	*Dinantian Lower Impure Limestones*

NOTES
Draft Conceptual Model of Groundwater Flow in the Waulsortian Limestones in the Southern Region

Groundwater flow within the Waulsortian Limestones in the south of the country is controlled to a large extent by the regional geological structure. Rocks in the region were compressed from the south into a series of folds on an east west axis. Subsequent erosion stripped the softer more soluble limestones from the fold crests or ridges (anticlines) exposing the harder more resistant sandstones underneath. The Carboniferous limestones, including the Waulsortian, were preserved in the fold troughs which today form elongate east west trending valleys separated by the intervening sandstone ridges. The folding was accompanied by extensive fracturing and faulting which, in the Carboniferous limestones, created numerous potential pathways for groundwater movement. In pure limestones like the Waulsortian, which are susceptible to karstification, these faults and joints were opened up by solution as groundwater moved through the limestones enlarging the fissures and producing karst features.

The sandstone ridges act as regional groundwater recharge zones which supply recharge to the limestone aquifers in the valleys. There is a high density of surface drainage on the sandstone ridges indicating that the permeability of the sandstones is relatively low. (Recharge to the ridges is expected predominantly move as through flow to streams with limited percolation to bedrock.) Streams run off the sandstone ridges into the limestone valleys.

The topography of the valleys is relatively flat although there can be some topographic highs along the centre of the valleys. The ready weathering of the thin shaly limestones which separate the main limestones from the underlying sandstones is thought to be responsible for the topographic lows along the edges of the valleys. Another cause is the presence of subsidiary folding in the core of the limestones.

The valley floors are characterised by a general lack of surface drainage. The Waulsortian Limestone in the valleys is highly karstified with sinking streams, springs, numerous cave systems, sinkholes and other collapse features common. Karstification is known to extend well below present sea levels the base of karstification estimated to extend to depths of 50 to 60 m below O.D. Malin Head. Groundwater flow rates are rapid within the limestones and there is evidence for conduit flow.

- Groundwater gradients are steep in the lower permeability sandstones of the ridges and flow direction is towards the limestones in the valley. Groundwater gradients are flatter in the more permeable limestones and regional flow direction is to the sea or to major rivers to the east or west along the valley.
- The groundwater in the Waulsortian limestones is unconfined. There are large fluctuations in water levels between winter and summer which can be up to 4-5 m, with seasonal variations in drawdown also observed.
- Rivers within the limestone valleys have relatively high dry weather flows
- Permeability in the Limestones is highest in the uppermost few metres of intense weathering.
- Sand and gravel deposits occurring in the valleys in hydraulic continuity with the underlying limestones can supply additional storage.

Una Leader November 2002

Notes (cont.)

Table 1 Aquifer Properties

Source Name and GSI Well Number	*Transmissivity* (m²/d)	Permeability (m/d)
Northern Region		
Longwood and Summerhill areas, Co Meath	30-40	
Tulla PS, Co Clare	13	
Southern Region		
Downing Bridge, North Co. Cork	3400	10-200
Cloyne, Southeast Co. Cork	200-2000	3-30
Croom, Co. Limerick (1413NWW201)	120	4.2
Fedamore, Co. Limerick (1413NEW140)	34	0.5
Lefanta, Co Waterford (2009SWW047)	3600	
Ardmore, Co Waterford (2007SE W014)	170	26.5
Dungarvan, Co Waterford (2009SEW069-072)	900-13000	25-190 (100)

The permeability of these limestones has developed in response to structural movements and karstification to deeper drainage levels that existed in the past. They are examples of a drowned karst terrain. The limestones are unconfined. Over a significant part of the valleys the limestones are overlain by sands and gravels with which they are in continuity and which provides them with additional storage. There are numerous karst features in these limestones, i.e. caves, swallow holes, collapse features and large springs.

The potential for saline intrusion is a constraint on development near the coast.

1.3.4 Hydrochemistry

The Waulsortian Limestone is a carbonate rock type. The hydrochemistry of the carbonate rocks is dominated by calcium and bicarbonate ions. Hardness is in the range from 200 mg/l to >400 mg/l (as $CaCO_3$), i.e. moderately hard to very hard. Spring waters tend to be softer as throughput is quicker and there is less time for the dissolution of minerals into the groundwater. This is particularly true where the limestones have been karstified.

Groundwater alkalinity is high, up to 400 mg/l ($CaCO_3$). Alkalinity is less than hardness indicating that ion exchange (where calcium or magnesium are replaced by sodium) is not significant. Typical limestone water conductivities are of the order of 500-700 µS/cm. Lower values suggest that the residence times of some of the sources are very short, for example at the Dower Spring where conductivities average 396 µS/cm. This value reflects a karstic system (in the Waulsortian) with rapid flow velocities. Table 2 shows major ions and other water quality parameters from a number of locations in the Waulsortian Limestones.

Table 2: Major ions and other water quality parameters in groundwaters from Waulsortian limestone aquifers.

Source	Sample date	pH (lab.)	Total Hardness (mg/l CaCO3)	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Total Alkalinity (mg/l CaCO3)	Sulphate (mg/l)	Chloride (mg/l)	EC (µS/cm)	Iron (mg/l)	Manganese (mg/l)
Dower Spring, Co Cork	Range	7.18-8.25								34.2-46.69	219-740		
Cloyne, Co Cork (Commons East BH)	Sep 1999	7.4	317.7	114	8.2	19.3	1.7	248	18.8	33.4	596	0.16	<0.05
Cloyne, co Cork (Lissanly BH)	Sep 1999	7.3	347.3	123	9.85	19.5	2	268	19	37.4	644	<0.1	<0.05
Croom, Co Limerick	Sep 1993		373	110	24.1	13.9	2.2	332	21.4	32.5	779	<0.01	<0.005
Fedamore, Co Limerick	Sep 1993		427	111	23.7	13.9	3.1	381	18.3	31.2	802	<0.01	<0.005
Mountbolus, Co Offaly			369							16-28	634		
Ballivor, Co Meath (PW1)	Sep 1995	7.1	378	132	11.9	9.899	2.078	302	56.5	15.7	711	0.069	0.071

Note: MDLs are Method Detection Limits.