Table 5.2: Summary of 7 day / 11 day multi-well test data

	Well	Average Pumping Rate	Drawdown	Recovery
7 day multi-well test Nun's Cross wellfield	**TW2A**	694 m^3/day	27.98m	24 hours to recover back to within 3.2m of static water level
	TW3	415 m^3/day	29.99m	24 hours to recover back to within 10.01m of static water level
	TW3A	252 m^3/day	18.39m	24 hours to recover back to within 0.55m of static water level
7 day multi-well test Ashford wellfield	**TW4**	1940 m^3/day	3.5m	22 hours to recover back to within 0.83m of static water level
	TW4A	1195 m^3/day	6.38m	22 hours to recover back to within 0.77m of static water level
7 day multi-well test Milltown wellfield	**TW15**	523 m^3/day	37.94m	24 hours to recover back to within 15.85m of static water level
	TW16	240 m^3/day	31.76m	24 hours to recover back to within 3.98m of static water level
11 day multi-well test Ashford wellfield (May 2007)	**TW4A**	1255 m^3/d for first phase Dropped back to 1077 m^3/d for second phase Cut back again to 955 m^3/d for end of test	5.92m (max) 5.12m (end of 2nd phase) 4.6m (end of test)	48 hours to recover back to within 0.36m of static water level
	TW17	1830 m^3/d for first phase Dropped back to 1420 m^3/d for second phase	3.49m (max) 2.81m (end of test)	48 hours to recover back to within 0.7m of static water level

6. INTERPRETATION OF SUSTAINABLE YIELDS

6.1 Methodology

The pumping tests (72 hour, 7 day and 11 day duration) were undertaken to stress the trial wells to provide an indication of the maximum yields. However, an estimate of the sustainable yield of each well, over a longer term and based on the available resource in the various aquifers to be exploited, was also required to provide long term projections of the operational pumping rates for the proposed water supply.

Estimates of aquifer transmissivities and well specific capacities were obtained from the 7 day pumping test data. The data gathered was analysed using a variety of numerical methods, to determine aquifer characteristics. For each set of data, the "Logan Approximation" was used to estimate an approximate transmissivity (T) value for the relevant aquifer, using the formula

$T = Q/s$

where Q = average pumping rate
and s = maximum drawdown recorded during the 7 day test.

Further analysis of the time versus drawdown (semi-log) plots (included in Appendix 4) was used to determine further estimates of aquifer transmissivities (for the middle and later parts of the test), using the formula

$T = (2.3*Q) / (4\Pi*\Delta s)$

where Q = average pumping rate
and Δs is the drawdown per log cycle

The range of aquifer transmissivity values estimated using the various analytical methods was assessed and a representative value chosen based on available data on aquifer characteristics from the GSI Groundwater Protection Scheme for Co. Wicklow.

The specific capacity of each borehole, which indicates how productive the well is as opposed to the overall aquifer characteristics, was calculated using the formula

Specific Capacity = Q/s

where Q = average pumping rate
and s is total drawdown

The aquifer and well values for each trial well are shown on the data calculation sheets in Appendix 4.

However, in most cases the water levels were still falling by the end of the 7 day tests and it is considered that in some cases the aquifers had not reached equilibrium conditions. It is considered that these wells were pumped at rates higher than what they are capable of over a longer term. A method to determine the sustainable long term discharge from each well was required. Ideally, long term operational data on pumping rates (from a supply which has been in use) are used to estimate reliable long term sustainable yields from groundwater supplies. In shallow, unconfined, fissure flow-aquifers, such as encountered in the bedrock wells (TW2A, TW3, TW3A, TW15 and TW16) the actual well performance may vary considerably from that predicted based on theoretical considerations (Misstear & Beeson, 2000). If water levels have been recorded over time, drought levels of water in the aquifer may be available which will allow reliable yields to be estimated.

No information on drought conditions in these aquifers in the vicinity of the proposed water supply wells is available. Rainfall events during the pumping tests, undertaken between September 2005 and September 2006 were not recorded. Information available from Met Eireann indicates that most of the 7 day pumping tests undertaken in 2006 were undertaken in relatively wet months (August to September 2006) although they followed a couple of dry months (June and July 2006). The extended (72 hour and 11 day) tests undertaken on TW17 and TW4A in May 2007 were undertaken following a very dry April (just 5.4mm at Casement) and average May (39mm). However, this data does not provide any correlation with the water levels in the aquifers. It is considered that although the gravel aquifer (TW4, TW4A and TW17) may respond rapidly to rainfall events, it is unlikely that fluctuations in the water levels in the bedrock aquifers would be noticeable over the course of the pumping tests.

Where there is no operational information available, an analytical approach to reliable yield estimation is required. A methodology is outlined in Misstear & Beeson (2000) and requires a number of elements based on the data from the Step Tests, where the wells were pumped at various pumping rates. These elements are (1) calculation of short term pumping water levels from step-test data and (2) extrapolation of longer-term pumping water levels based on the Cooper-Jacob equation (see below).

The short term, step test drawdown levels for the trial wells tested as part of this assessment have already been calculated (summarised Table 6.1). Longer term drawdown values are estimated by extrapolating the short-term values using the following formulae (i) and (ii), based on the Cooper-Jacob equation

Formula (i) $\Delta s = (2.3*Q) / (4\Pi*T)$

where Δs is the drawdown per log cycle of time,
Q = pumping rate for the step being assessed
and T is the transmissivity value for the aquifer (calculated previously using the 7 day test data)

Formula (ii) $s^a = L*\Delta s$

where s^a = the additional long-term drawdown (to be added to the short-term drawdown) and L = number of log cycles of time between the end of the step (step duration = 100 minutes) and the time for which the yield estimate is to be made (in this case 200 days) (i.e. 3.46).

The total drawdown (sum of the short-term and extrapolated long term drawdowns) is added to the static water level to obtain a long term pumping water level. This is plotted against the discharge rate for that step and an extrapolated step test curve is produced (included in Appendix 4).

The potential / reliable yield is taken from the intersection of this extrapolated curve and the Deepest Advisable Pumping Water Level (DAPWL). Where there are no records on the lowest recorded water levels in the aquifer, it is considered prudent to choose a DAPWL, which may be defined as, for example, the level below which undesirable effects, such as dewatering and/or sand pumping may occur. The borehole logs for each of the trial wells were assessed and the main water entry levels were noted. The DAPWL for the wells is taken as the level of the main water bearing fissure.

This methodology is summarised in Appendix 4. The characteristics of the individual wells and the cluster groups which form 3 different well-fields are discussed below.

6.2 Nun's Cross Well Field (TW2A, TW3 and TW3A)

Using the methodology outlined above the maximum potential yield for Well TW2A, which would draw the water levels down to the DAPWL is considered to be 740 m^3/d. However, given the poor aquifer classification for the aquifer from which this borehole is abstracting, it seems unlikely that this yield is sustainable. In this case, a figure of 500 m^3/d is considered to be more conservative and realistic estimate of the sustainable yield.

The methodology was also applied to the step test data for TW3. The yield at which the water level reaches the first of the fissures in TW3 is considered to be 330 m^3/d. It is considered that this yield is sustainable in the long term for this well as there are a number of fissures below the first which will also support the planned abstraction.

The step test data for TW3A was also assessed using the methodology described above. This well is less productive than the other two in this well field as its sustainable yield is considered to be 180 m^3/d.

These wells are abstracting from the Devil's Glen Formation which is classified as a Poor Aquifer. The water supplying these wells is coming from individual fracture / fissure zones at depth and it is considered that there will be little if any interconnectivity between the fissure zones supplying each individual well. The static water levels in TW3 and TW3A are at different levels even though they are located relatively close to each other (within 250m) and at a similar elevation. Flow paths in low permeability rock types such as these greywackes and shales, will be short (in the order of a few hundred metres) and as such it is considered unlikely that there will be any interference effects between the wells in the Nun's Cross Well field as each well will have its own separate sub-catchment.

Therefore the total sustainable yield for this well field together is considered to be equal to the sum of the individual well yields, i.e. 1010 m^3/d.

6.3 Ashford Well Field (TW4, TW4A and TW17)

Using the methodology outlined above the potential yield for well TW4, which would draw the water levels down to the DAPWL is considered to be up to 2500 m^3/d. The methodology was also applied to the step test data for TW4A. This well appears to be less productive, with a potential yield between 1000 m^3/d and 1200 m^3/d. The methodology was also applied to the step test data for TW17 and DAPWL is considered to be up to 2800 m^3/d.

However, as the alluvial gravel deposit is limited in aerial extent to less than 1km^2, the sustainable yields need to be examined in further detail to see if they can be supported by the available recharge. The high yields achieved in the pumping tests may have been largely supported by storage in the aquifer. Storage in an unconfined coarse gravel aquifer such as this can range between 20% and 30% and it is possible that the water pumped during the pumping tests came mainly from storage. Using conservative figures of 0.5 km^2 aerial extent of gravel (1km^2 is mapped), 10m thickness of the coarse gravels (thicknesses of between 12m and 15m encountered in boreholes), a storage value of 20% and assuming that the wells may only capture one-fifth of the cross-sectional width of the aquifer, it is estimated, that there may be up to 200,000 m^3 available from storage.

The main sustainable resource of the aquifer is considered to be from the recharge it receives, both directly from effective rainfall onto the outcrop of the alluvial gravels and indirectly from the outcrop of the glacial gravels to the north which may act as further storage.

The recharge directly onto the alluvial gravel aquifer from which the TW4, TW4A and TW17 wells are abstracting is calculated using meteorological data and estimates of runoff, as follows.

Rainfall data for the area (from Met Éireann) indicates that average annual rainfall, measured at their recorder stations at Glenealy (Kilmacurragh) and Roundwood (Filter Beds) (for the period 1961-1990) was 1119mm and 1192mm respectively. Interpolation of this data indicates the site at the trial wells receives approximately 1150mm of rainfall (R) per year.

Potential Evapotranspiration (P.E.) data is also available from Met Éireann for their station in Casemount (the closest synoptic station) and is 504mm/yr. Actual Evapotranspiration (A.E.) is then calculated by taking 95% of the potential figure, to allow for soil moisture deficits. A.E. is therefore estimated as 478.5 mm/yr. Using these figures, the Effective Rainfall (E.R.) is taken to be approximately 671.5 mm/yr. This is equivalent to the Potential Available Recharge.

This potential recharge is subjected to losses from runoff. The area is considered to be covered by permeable gravels in a flat topographical setting with a gentle gradient towards the Devil's Glen River. In this case the runoff is taken to be approximately 10% based on the permeability of the soils and subsoils. A figure for actual recharge is therefore taken to be approximately 604 mm/yr as outlined below.

Average Annual Rainfall (R)	1150 mm
Potential Evapotranspiration (P.E.)	504 mm
Estimated *Actual* Evapotranspiration (A.E.)	478.5 mm
Potential Recharge (R – A.E.)	671.5 mm
Runoff Losses (10% of Potential Recharge)	67.15 mm
Estimated *Actual* Recharge	604 mm

This recharge will filter directly into the underlying sands and gravels. 604mm per year is equivalent to 1.65 X 10^{-3} m/day.

The alluvial gravels are mapped as having an aerial extent of 1km^2. If a conservative approach is taken, it is considered that perhaps only half of this area is thick enough to be considered as an aquifer and as such the aerial extent for calculations of recharge is taken as 0.5 km^2 (500,00m^2). Using the recharge rate calculated above and the recharge area, a recharge volume of 825 m^3/d can be considered to be available for abstraction directly from the alluvial gravels.

It is considered that there is additional recharge available from the glacial gravels to the north, north of Nun's Cross. These gravels were explored as part of the trial well drilling programme in this area. Although the gravels contained much less water than was originally expected (due to its classification as a Locally Important Gravel Aquifer by the Geological Survey of Ireland) and could not be exploited as a groundwater source for this scheme, it is considered that the gravels hold water in storage for the underlying bedrock aquifer and that some of this water also flows within the gravels to the south, discharging into the alluvial gravels before discharging into the river. As such, it is considered that further recharge to the alluvial gravels is available from the glacial gravels to the north.

The recharge calculations for the glacial gravels are slightly different as it is considered that there will be more slightly more runoff based on the topographical setting. The gravels themselves have a lower permeability (when compared with the alluvial gravels) due to the higher percentage of fines (silts and clays) within them. This would also lead to a higher degree of runoff. That said, the drainage density is relatively low over the outcrop of the glacial gravels. It is considered that the runoff percentage can be increased to approximately 30%. Using the rainfall, evapotranspiration figures listed above and a runoff of 30%, it is considered that the effective rainfall (recharge rate) for the glacial gravels is closer to 470mm/yr, equivalent to 1.28 x 10^{-3} m/day.

The glacial gravels (upgradient of wells TW4, TW4A and TW17) are mapped covering an area of approximately 3.65 km^2. Using the recharge rate calculated above and the recharge area, a recharge volume of 4,670 m^3/d can be considered to be available in the glacial gravels. A proportion of this will filter directly through to the underlying bedrock. However as the underlying bedrock is described as a low permeability poor aquifer, it is considered that a significant proportion of the recharge will flow south to recharge the alluvial gravels. This proportion cannot be accurately quantified but is considered to be at least 50%. As such, it is possible that up to 2,335 m^3/d is available from the glacial gravels.

A simple water budget shown below, indicates that the alluvial gravel aquifer has significant water available from both storage (available in the short term but not sustainable in the longer term) and also from recharge (sustainable in the longer term) both directly from the alluvial gravels and indirectly from the glacial gravels to the north and possible from the river at certain times of the year.

Table 6.1: Water budget of gravel aquifer

	Inputs	**Outputs**
Water Available from Storage	200,000 m^3/	
Recharge Directly onto alluvial gravels	825 m^3/d	
Recharge indirectly from glacial gravels	2,335 m^3/d	
Recharge indirectly from river at certain times of the year	*Unknown*	
Recommended maximum abstraction volume from the wells		3000 m^3/d
TOTAL	3,160 m^3/day	3,000 m^3/day

These wells are abstracting from a band of alluvial gravels associated with the Devil's Glen River. They are not mapped as an aquifer resource by the Geological Survey of Ireland but are considered by GES Ltd. to represent a Locally Important Gravel Aquifer in this area, following investigation of its resources as part of this hydrogeological assessment.

The gravels are assumed to have very high permeabilities (Transmissivity values of between 300 and 600 m^2/d were determined using the 7 day / 11 day pumping test data) and as such it is assumed that there will be a high degree of interaction between the wells (TW4A and TW17) which are abstracting from the same alluvial gravel deposit. This was seen by the effect pumping at any of the wells in this gravel aquifer had on water levels in the other nearby wells in the same gravels.

Flow paths in gravels such as these will be relatively short (in the order of 500m) but there will be interference effects between the wells in the Ashford well field. The sum of the individual wells is considered to be around 3000 m^3/d. However, it is considered that the interference effects may lower the overall combined yield by approximately 30%, thus reducing the overall yield for this well field to 2200 m^3/d.

However, it is also considered that it may be possible to exploit more from this resource in the winter when more recharge is available so allowance should be made for abstraction rates up to 3000 m^3/d.

6.4 Milltown Well Field (TW15 and TW16)

Using the methodology outlined for the Nuns Cross Wellfield the sustainable yield for Well TW15, which would draw the water levels down to the first fissure is considered to be 220 m^3/d, although more water may be available as there is another deeper fissure.

The methodology was also applied to the step test data for TW16. The yield at which the water level reaches the main productive fissure in TW16 is considered to be 180 m^3/d.

These wells are abstracting from the Maulin Formation which is classified as a Locally Important Aquifer. The water supplying these wells is coming from individual fracture / fissure zones at depth. In a Locally Important Aquifer there may be some interconnectivity between the fissure zones supplying each individual well, as could be seen by the slight effect pumping at TW16 had on the water levels in TW15. It is noted that this effect was observed at a higher pumping rate than is actually planned on an operational basis at these sources so the effect will be smaller in an operational situation. Flow paths in moderate permeability rock types such as these slates, siltstones and schists will be relatively short (in the order of 500m) and as such it is considered that there will be minimal interference effects between the wells in the Milltown well field.

Therefore the total sustainable yield for this well field together is considered to be equal to the sum of the individual well yields, i.e. 400 m^3/d.

It may be possible to drill another well in the vicinity of TW15 and TW16 to make it a more viable scheme. The Poor Aquifer and the Locally Important Aquifer are both located in this area and further investigation of sites close to the boundary of the aquifers may reveal a higher degree of fracturing and perhaps higher yields.

7. CHEMICAL AND BACTERIOLOGICAL ANALYSES

Water samples were taken towards the end of the pumping tests on boreholes TW2A, TW3, TW3A, TW4, TW4A, TW4D, TW14, TW15, TW16 and TW17. The water sampled from all boreholes was noted as clear and colourless with no obvious odours or other visual signs of contamination. Samples were also taken in sterile containers for bacteriological analysis.

The water samples were transported to T.E. Laboratories in Carlow for analysis. The samples taken from TW3 and TW4 in October 2005 were analysed for the full SI 439 range of parameters, while the samples taken from TW2A, TW3A, TW4A and TW15 in March 2006 were analysed for a broad range of indicator parameters (but not the full SI 439 suite). This provided information on a broad range of physical, chemical and bacteriological parameters to assess the baseline quality of the groundwater sampled at each of the sites.

Following the multi-well, 7 day tests undertaken in August and September 2006, further groundwater samples were taken from all wells tested. The samples taken from TW2A, TW3A, TW4, TW4A, TW4D, TW15 and TW16 were analysed for the full SI 439 range of parameters, while the sample taken from TW3 was analysed for a broad range of indicator parameters (but not the full SI 439 suite as this had been done previously in October 2005). These analyses provided information on a broad range of physical, chemical and bacteriological parameters to assess the quality of the groundwater following a prolonged period of pumping.

A sample was also taken from TW17, the replacement well for TW4, after the initial 72 hour test on the 17th May 2007. The sample was analysed for the full SI439 range of parameters, so a comparison could be made with the water quality from TW4 and to provide a full background water quality suite for this well.

The results of the analyses are included in Appendix 5 to this report. The results indicate good quality water from most of the trial wells (although in some cases some bacteriological contamination is indicated).

The **pH** concentrations range from **6.5 at TW4A to 7.9 at TW3**. These concentrations are within the range required by the Drinking Water Standards i.e. between 6.5 and 9.5.

The **Electrical Conductivity** concentrations in the samples range between **214 µS/cm at TW4A and 419 µS/cm at TW3A** below the EU MAC for Drinking Water, of 2,500 µS/cm.

The **ammonia** concentrations in the samples were all **<0.1 mg/l NH_4** (below the limit of detection of the analytical method used) and below the EU MAC of 0.3 mg/l NH_4.

The **nitrate** concentrations at most of the boreholes sampled are considered relatively low ranging between **<0.5 mg/l NO_3** at **TW15** to **24 mg/l NO_3** at **TW2A**, all below the Guide Level of

25 mg/l NO_3 and below the EU MAC of 50 mg/l NO_3. However, the nitrate concentration at **TW2A** is considered slightly elevated at **24 mg/l NO_3**, just below the guide level, although still below the MAC concentration. The water quality at this borehole may be influenced by the intensive tillage lands in the immediate vicinity.

The **nitrite** concentrations are considered low at **all boreholes** at **<0.2 mg/l NO_2**, below the limit of detection of the analytical method used and below the EU MAC of 0.5 mg/l NO_2.

The **chloride** concentrations are considered normal for an area within 5km of the sea, ranging from **16 mg/l Cl at TW4A** to **31 mg/l Cl at TW15**, all below the EU MAC of 250 mg/l Cl.

The **iron** concentrations in the water from all but 2 of the boreholes are considered low at **<0.05 mg/l Fe**, below the limit of detection and below the EU MAC of 0.2 mg/l Fe. However, the iron concentrations in the samples from **TW15** and **TW16** are considered elevated. The concentrations in the samples from **TW15** were **0.7 mg/l Fe** (March 2006), and **0.59 mg/l Fe** (September 2006), while the concentration in the sample from **TW16** taken in September 2006 was **0.52 mg/l Fe,** all above the EU MAC concentration. It is considered that these iron concentrations are as a result of the natural geochemistry of the clay-rich mudstones and siltstone which these boreholes encountered.

The **manganese** concentrations in the water from all but 2 of the boreholes are considered low at **<0.03 mg/l Mn**, below the limit of detection and below EU MAC of 0.05 mg/l Mn. However, the manganese concentrations in the samples from **TW15** and **TW16** are considered elevated. The concentrations in the samples from **TW15** were **0.2 mg/l Mn** (March 2006) and **0.16 mg/l Fe** (September 2006), while the concentration in the sample from **TW16** taken in September 2006 was **0.97 mg/l Mn**, all above the EU MAC concentration. It is considered that this is due to the natural geochemistry of the clay-rich mudstones and siltstones from which TW15 is abstracting.

Samples were also taken from the boreholes for **bacteriological** analysis. It is considered the bacteriological quality of the groundwater from most of the boreholes is good to fair. Initially, following disinfection of the boreholes (after drilling and prior to the pumping tests) the bacteriological quality was good in TW2A, TW3, TW3A, TW4A and TW17 with no total or faecal Coliforms detected. Low concentrations of both Total and Faecal Coliforms (at a concentration of 1 CFU per 100ml) were detected in initial samples taken from TW4 and TW15. Following a period of between 5 and 11 months, additional samples were taken from the wells between August and September 2006. During this sampling round, bacteriological contamination was detected in more of the wells, namely TW2A (>100 CFU per 100ml Total Coliforms along with an elevated colony count of 13 CFU per 100ml), TW3 (3 CFU per 100ml Total Coliforms), TW3A (Colony count of 46 CFU per 100ml, although no Total or Faecal Coliforms were detected), TW4 (5 CFU per 100ml for both Total and Faecal Coliforms), TW15 (2 CFU per 100ml Total

Coliforms and 7 CFU per 100ml Colony Count) and TW16 (10 CFU per 100ml Total Coliforms and 85 CFU per 100ml Colony Count). No bacteriological contamination was detected in the water from TW4A or TW17.

A summary spreadsheet, which illustrates the results of the main water quality parameters, is provided in the Appendix 5 to this report.

Various forms of treatment will be required on the majority of the well sources, results of the groundwater chemistry analysis are given in Appendix 5 and Figure 2 (Drawing No. 812/02/105).

The elevated iron and manganese concentrations noted in the samples from **TW15** and **TW16** in the Milltown well field are considered to be related to the natural geochemistry of the clay-rich mudstones and siltstones. It is possible that the concentrations would decrease following further pumping. However, as the concentrations are quite high (ranging from 0.52 mg/l Fe to 0.7 mg/l Fe for Iron and from 0.16 mg/l Mn to 0.97 mg/l Mn for manganese), it is recommended that iron and manganese removal treatment systems may be required for these two well sources.

Bacteriological parameters above the Drinking Water Limits were detected (albeit in relatively low concentrations) in samples from all but one of the well sources. As such it is recommended that the wells are treated to protect the bacteriological quality of the proposed drinking water source.

It is also considered that a number of the wells will require treatment for turbidity. Samples from **TW3**, **TW3A**, **TW4** and **TW4A** had levels of turbidity above the limit of 5 FTU units. It is possible that the design of the production wells and proposed pumping regime may limit the amount of sandy / turbid water from being pumped and as such turbidity levels may drop. However, if this level of turbidity is noted in samples from the production wells treatment (possibly periodically in the case of the wells in the gravels) will be required.

The turbidity levels in the trial wells at Milltown (**TW15** and **TW16**) are significantly higher (than in the wells in Ashford and Nun's Cross) and would definitely require treatment if this situation persisted in the production wells.

8. IMPACT ON, AND MONITORING OF, THE VARTRY RIVER

The Ashford Wellfield is the most productive of the 3 no. wellfields to be developed as part of this scheme. It is proposed to abstract up to 2,200 m^3/d from TW4A (PW4) and TW17 (PW5). These wells are supplied by the alluvial gravels associated with the Vartry River. Further investigation is required due to the proximity of the river to the wellfield, the level of interaction between the river and the alluvial gravels associated with it and the potential impacts that this level of groundwater abstraction may have on the river flow and its supported ecosystems.

It is considered that the groundwater abstractions in the Nun's Cross Wellfield, i.e. TW2A (PW1), TW3 (PW2) and TW3A (PW3) will not have any impact on flow in the Vartry River. The wells will be abstracting from bedrock aquifers and are not considered to have a direct connection with the River Vartry. The static groundwater levels in these wells are approximately 10m lower than the levels in the river, as can be seen from the cross sections shown in Appendix 6. The cross section is drawn from north to south and shows the levels (both topographic and water levels) at wells TW2A, TW3, TW3A, TW3B and the Vartry River. The river in this part of its catchment, to the west of the Nun's Cross wellfield, is in a steep sided valley (the lower part of the Devil's Glen) and is considered to have "flashy" characteristics (i.e. flow is dependent on rainfall and runoff from the surrounding land) and is unlikely to be dependent on the underlying groundwater system for recharge or flow. There is also likely to be little interaction between the river and the groundwater in this low permeability aquifer. The pumping water levels in the wells are also shown on the cross section and indicate that although there was significant drawdown in the water levels in some of the wells (between 22m and 50m), the Vartry River was not affected due to the river and groundwater being quite separate environments in this area.

The Ashford Wellfield, however, will be abstracting from alluvial gravels which are associated with the Vartry River and the wells are located in a different, flatter, part of the river catchment where flow may be supported to some degree by groundwater flow. Flow in the gravel aquifer is of an intergranular nature (rather than through fractures and fissures which would be the main flow mechanism in a rock aquifer). Information from the trial well drilling programme, geophysical survey and data from the pumping tests has indicated that the productive, coarse gravel layers lie between 12m and 24m depth. The conceptual model of recharge discussed in Section 6.3 above, indicates that these gravels are recharged directly from rainfall and indirectly from the glacial gravels mapped to the north of the wellfield.

The static water levels in the Ashford Wellfield trial wells are relatively high and above the water level in the Vartry River, although they can be within 3m of the river level – as can be seen on the cross sections for this wellfield, included in Appendix 6. Two cross sections were drawn, from north to south, for this wellfield, and show the levels (both topographic and water levels) at wells TW4A, TW4, TW17, TW4D and the Vartry River. The cross section indicates that the static water levels in the alluvial gravel aquifer are close to but still above the Vartry River level. In this lower part of the river catchment, the river flows along a flatter gradient and it is considered that there is likely to be some interaction between the river bed and the alluvial gravels which are closely associated with it – given that they were probably deposited by the river at various stages (during its lifetime and during various flood events). The cross section shows that the gravels possibly extend beneath the river and out to the other side of it as they are mapped on both sides. The maximum pumping water levels recorded during the pumping tests (undertaken in 2006 and 2007) are also shown on the cross section. These indicate that there was very little drawdown, for example in TW17, and in this case, the pumping water levels were still above the level of the Vartry River. It is unlikely that this pumping scenario reversed that natural groundwater gradient and pulled water back from the river towards the wells. However, on the cross section showing TW4A, it appears that the pumping water level was drawn down to a level below the Vartry River. It is not known if river water was being pumped at this point. It is considered further monitoring is required before a more definitive assessment of the interaction between the river and the alluvial gravels can be made.

The river may receive baseflow from the gravels and as such it is considered important to determine the dry weather flows (DWF) in the river and pump test the production wells at this time to see how pumping will affect the DWF. Pumping tests undertaken on the trial wells in summer 2006 (a dry summer up to August / early September) did not note any recharge effects from the river to the gravel aquifer, although no direct monitoring of the river levels was undertaken at that time.

Once the production wells are drilled, it is recommended that long term pumping tests are undertaken in conjunction with river monitoring. This river monitoring will be undertaken prior to and during the production well testing to establish the level of interaction between the river and the gravels.

Proposed Vartry River Monitoring Programme

A programme of monitoring is required prior to and during the production well testing phase, to determine the level of interaction between the river and the gravel aquifer and any potential impacts the proposed groundwater abstractions may have on the river.

Firstly, river gauges should be installed at suitable sites located upstream, in the vicinity and downstream of the abstraction point in the gravel aquifer (Ashford wellfield) to measure river flow. The suitable sites will be initially surveyed (for ease of access, measurement, proximity to wellfield and gravels etc.) and staff gauges installed. Topographical surveys of the river channel (cross sections) will be undertaken at the gauging sites and flow measurements will be taken along with levels on the staff gauges, to develop a “stage / discharge relationship” for each site. It is recommended that flow measurements are taken prior to any well testing to determine background data and to see if there are additions to the flow along the channel which may indicate the river may be partially groundwater fed.

The flow in the river will be defined during the monitoring period (prior to production well testing) and flow durations curves will be developed for upstream and downstream of the wellfield locations.

Some dye-tracing could also be undertaken, initially under natural conditions and then under abstraction conditions, between the wells and the river to establish if there is a link and the nature of the connection between the two systems.

Production wells PW4 and PW5 are drilled in close proximity to the trial wells (TW4A and TW17 respectively). These are currently being initially tested for a 24 to 48 hour period to determine if yields are similar to the trial wells. It is proposed that extended tests (possibly up to 28 days duration) will be undertaken in late summer (Dry Weather Flow conditions) and the sustainable yields of the production wells will be reviewed to give a more accurate estimate of their long term yield.

Water samples from the pumped wells and the river will be taken prior to and during the well tests and, if possible, in-line monitoring of the groundwater being pumped could be undertaken which may give information on the changing signature of the water chemistry (particularly with regard to Conductivity, pH, Dissolved Oxygen etc.) if the river water is influencing the pumped groundwater.

During the long term production well testing programme (multi-well test), the flow response of the river to the groundwater abstraction will be measured under the expected dry weather flow conditions. Large changes in the pumping rates would be made during the latter stages of the tests to see if any response is noted in the river flow. This would help derive flow accretion profiles and quantify how pumping from the boreholes at various rates impacts on these profiles.

In addition to the groundwater abstraction and river flow data, supporting data will be required to quantify other inputs to the flow in the river, namely rainfall and the controlled overspill from the Vartry Reservoir in the headwaters of this river. It would be useful to acquire local rainfall data for the site (or very close to it) to correlate with flows in the river. Data will also be required from Dublin City Council, who operate the reservoir at Vartry, on the operation / timing schedule of overflow from the reservoir system.

Once the pumping tests and river monitoring have been undertaken, the data will be assessed to quantify the level of interaction between the river and the gravels and to determine the impact, if any, long term pumping from the wells will have on the flow in the river.

Once the relationship between the groundwater levels in the gravels and the flows in the Vartry River have been established, an assessment of the potential impacts of any reduced water levels and flows in the Vartry River may have on the fish populations and other protected species will be examined and a separate report will be prepared if necessary.

When the production wells are commissioned, it is proposed that discharge meters and data loggers are installed on the boreholes to record operational data. Regular sampling of the groundwater and surface waters would provide more information on the level of interaction between the two water systems. A long term monitoring programme of at least one year duration will be implemented in order to establish a baseline across all seasons.

9. CONCLUSIONS

Following the assessment of the investigation as discussed in this report the conclusions are as follows:

The total available sustainable yield from the 7 no. wells tested (**TW2A**, **TW3**, **TW3A**, **TW4A**, **TW15, TW16 and TW17**) is over **3,500 m^3/d**. These are conservative values of sustainable yield and it is considered that more water may be available, specifically from the gravels of the Ashford Wellfield, in the winter months. This cannot be quantified until monitoring is undertaken on the production wells, following their commissioning, for a full 12 months (over all seasons) to determine if there is any impact from pumping on the river or surrounding wells.

Low concentrations of Coliforms were detected in samples at most of the wells with the exception of **TW2A**.

Iron and Manganese concentrations at the Milltown wells (**TW15** and **TW16**) are considered elevated and related to the natural geochemistry of the aquifer from which these wells are abstracting.

Turbidity levels in the water from most of the wells are above the desirable levels for the Milltown wells (**TW15** and **TW16**), Nuns Cross Wells (**TW3** and **TW3A**) and the Ashford gravel wells (**TW4A**).

The findings are summarised in Table 8.1 and on Figure 2 (Drawing 812/02/105) overleaf.

Table 9.1: Summary of Groundwater Chemistry Results

Well Number	Sustainable Yield	Water Quality	Comment
TW2A (Bedrock)	500 m^3/d	Good, although slightly elevated Nitrate and Total Coliforms	Little or no effect noted at TW3 or TW3A when pumping
TW3 (Bedrock)	330 m^3/d	Good but with some Total Coliforms	Little or no effect noted when TW2A or TW3A pumping
TW3A (Bedrock)	180 m^3/d	Good	Little or no effect when TW3 and TW2A is pumping
Sub total Nun's Cross wellfield	**1,010 m^3/d**		
TW4A (Gravel)	770 m^3/d	Good but with slightly low pH	Slightly affected by pumping at TW4
TW17 (Gravel)	1400 m^3/d	Generally good	Slightly affected by pumping at TW4A
Sub total Ashford wellfield	**2,200 m^3/d**		
TW15 (Bedrock)	220 m^3/d	Generally good but elevated iron and manganese and traces of Total and Faecal Coliforms	Very slightly affected by pumping at TW16
TW16 (Bedrock)	180 m^3/d	Generally Good but elevated iron and manganese and traces of Total Coliforms	
Sub total Milltown wellfield	**400 m^3/d**		
TOTAL	**3,580 m^3/d**		

FIGURE 2

10. RECOMMENDATIONS

1. **TW2A**, **TW3**, **TW3A**, **TW4A**, **TW15, TW16 and TW17** are suitable for future development into production wells.

2. Any of the unsuccessful (from the Wicklow WSS perspective) trial wells which are to be retained for use as domestic and / or farm wells (e.g. TW9, TW20) should be limited in abstraction rates to just $20m^3/d$ so as not to affect any production wells to be located close to them. It is also recommended that the wellhead protection around these wells be improved so as to minimise the risk of contamination of the groundwater in the underlying aquifer. If possible the annular space between casing and liner (or drilled hole and casing) should be grouted and a well chamber built around the well (above ground if possible) to eliminate the possibility of potentially contaminating surface runoff getting into the well. (as per *Guidelines for drilling wells for private water supplies*, March 2007, Institute of Geologists of Ireland)

3. We recommend that any of the unsuccessful trial well which are not retained for private use should be fully decommissioned to eliminate potential pathways for surface water to contaminate groundwater.

4. We recommended that proposed sustainable yields for the successful wells, as detailed in this report, are revised if necessary following the installation of the production wells to give a more accurate estimate of their sustainable long term yield. We recommend that the Ashford production wells should be tested for a period of 28 days, and the Nuns Cross and Milltown production wells should be tested for a period of 10 days.

5. Further investigation of the groundwater resource around Milltown is recommended as currently only 400 m^3/d has been proven in this area which is approximately 2km from the higher yielding wells in Ashford.

6. Conjunctive use of the Ashford wells should be considered to cater for seasonal abstraction rates.

7. It is recommended that monitoring of the Vartry River is undertaken prior to and during any extended tests on the Production Wells to be installed in the Ashford wellfield. This monitoring programme, explained above in Section 8, will allow an assessment of the potential impacts the proposed groundwater abstractions may have on the Vartry River and its surrounding surface waters. Water level monitors will be installed in the wells and staff gauges installed along the river (upstream and downstream of the abstraction area). The data collected will be used to determine the level of interaction between the groundwater in the alluvial gravels and the river flow. A tracer test is also possible to

identify the link between the two systems. If required, further monitoring can also be undertaken up to commissioning of the water supply from these wells.

8. Following construction of the production wells at Ashford, we also recommended that regular sampling of the groundwater and surface water would provide more information on the level of interaction between the two water systems. If the unsuccessful trial well at TW4B is to be retained, this could also be instrumented to monitor the response of water levels further west from the pumping wells.

9. We recommend treatment for bacteriological parameters to protect the water supply from bacteriological contamination.

10. We recommend treatment for iron, manganese and turbidity to comply with the SI 439 of 2000 EU Drinking Water Directive.

11. We recommend that a Source Protection Plan be prepared prior to commencing negotiations with private landowners. There was no impact noted on adjacent landowner wells.

APPENDIX 1

GLOSSARY OF TERMS

GLOSSARY OF TERMS

MHC	McCarthy Hyder Consultants
WCC	Wicklow County Council
GES	Geotechnical and Environmental Services Ltd
AN	Aquifer Number
TW	Trial Well
GSI	Geological Society of Ireland
SI	Statutory Instrument
MAC	Maximum Allowable Concentration
S	Maximum draw down recorded during the 7 day period
$\Delta\Sigma$	Draw down per log cycle of time.
L	Number of log cycles of time between the end of the step and the time for which the yield estimate is to be made
Q	Flow rate.
T	Transmissivity
DAPWL	Deepest Advisable Pumping Water Level
PE	Potential Evapotranspiration
AE	Actual Evapotranspiration
ER	Effective Rainfall
R	Annual Rainfall
CFU	Colony Forming Unit
FTU	Equivalent Turbidity Unit

APPENDIX 2

BOREHOLE LOGS

APPENDIX 3

PUMP TEST DATA

APPENDIX 4

CALCULATIONS

APPENDIX 5

GROUNDWATER CHEMISTRY RESULTS

APPENDIX 6

CROSS SECTIONS ACROSS RIVER

APPENDIX 7

DRAWINGS