ENVIRONMENTAL MANAGEMENT GROUP

Technical report

INTERNAL

HAWKE'S BAY REGIONAL COUNCIL

SAFEGUARDING YOUR ENVIRONMENT + KAITIAKI TUKU IHO

Twyford Consent Area Technical Report - Groundwater Impact Assessment

10th October 2009

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Environmental Management Group
Technical Report

Internal

Environmental Science Section

Twyford Consent Area Technical Report – Groundwater Impact Assessment

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EXECUTIVE SUMMARY

In May 2009 resource consents to take groundwater and surface water in the Twyford Consent Area expired. To assist with issuing of consents and ensure the sustainable use, development and protection of the region's natural and physical resources, a desktop investigation was undertaken to examine the environmental effects of groundwater abstraction on the surface water and groundwater resources in the Twyford Consent Area. A total of 216 groundwater applications were reviewed and three main areas of groundwater sustainability were assessed:

1. the effects of groundwater abstraction on the long-term availability of groundwater,
2. the effects of groundwater abstraction on the flow in the Ngaruroro River and Raupare Stream, and
3. the magnitude of well interference effects on neighbouring wells.

Groundwater Levels

To assess the long-term availability of groundwater, groundwater levels monitored in the Twyford Consent Area were reviewed to observe trends and patterns over time. Results of the review showed that groundwater levels have remained relatively stable since monitoring began in 1991. The most significant trend observed was a slight increase in the seasonal variation between summer and winter months. This was attributed to an increase in groundwater abstraction over the monitoring period which caused increasing declines in groundwater levels over the summer seasons. However despite this, groundwater levels continued to recover over the winter months with no significant declines likely to affect the long-term availability of groundwater supply to existing users.

The greatest uncertainty regarding the long-term availability of groundwater is the potential effects of abstraction on surface water flows across the Heretaunga basin. Greater groundwater level declines over summer caused by groundwater abstraction results in reduced outflow of groundwater to rivers and streams. Managing these effects typically requires predictive numerical modelling to help assess the overall regional decline caused by groundwater abstraction. In 2012 a numerical model will be used to determine an allocatable volume for the Heretaunga basin. This will involve assessing the effects of abstraction on groundwater storage and associated ecosystems. Results of this investigation may find that groundwater allocation needs to be reduced if surface water flows are to be maintained above a management threshold.

Well Interference

Well interference effects were examined by calculating the cumulative theoretical drawdown at 5 main areas with the highest density of abstraction rates. The results of the drawdown assessment were compared with the available drawdown in each consented well, while taking into account seasonal variation, to determine the level of groundwater remaining. The results of this assessment showed that well interference in most wells accounted for less than 10% of the available drawdown and therefore was unlikely to significantly affect the rates and volumes allocated to existing users.

Effects on rivers, streams and springs

To determine the effects of groundwater abstraction on surface water in the Ngaruroro River and Raupare Stream a conceptual model was developed to interpret the natural interaction between surface water and groundwater. This involved creating a geological model beneath the Twyford Consent Area and interpreting areas of natural interaction based on groundwater level and surface water flow data. The results suggested natural interaction occurred along the Ngaruroro River between Fernhill and Hill Road and along the Raupare Stream between Twyford Road and Ormond Road. East of Ormond Road the aquifer was considered disconnected from surface water based on well lithology and distance to the areas where surface water and groundwater naturally interact.

The geological model indicated all wells west of Ormond Road are screened within an aquifer that naturally interacts with surface water. As such, water takes from these wells are considered a potential risk to stream flow during periods of groundwater abstraction. To determine the magnitude of effects on stream flow the theoretical stream depletion rate was quantified, where possible, and wells that caused more than 1 L/s decline in stream or river flows were considered to cause a more than minor effect. A total of 41 wells in the unconfined area were assessed of which 34 wells theoretically cause a stream depletion rate of more than 1 Ls.

Summary
The results from the assessments show that for the most part the abstraction of groundwater in the Twyford Consent Area is sustainable, but may potentially result in reduction to surface water flow in the Ngaruroro River and Raupare Stream. The report highlights many limitations and uncertainty inherent in the analysis of groundwater assessments and provides recommendations to improve the integrated management of groundwater and surface water resources. These recommendations include the use of water metering to provide realistic abstraction data for more accurate and reliable results, aquifer testing and further exploratory and monitoring well drilling to characterise and delineate aquifer properties and seasonal allocations on water take consents to better manage long-term effects.

1.0 INTRODUCTION

The Hawke's Bay Regional Council has a responsibility under the Resource Management Act to manage the sustainable use, development and protection of the region's natural and physical resources. In order to meet this responsibility, the Hawke's Bay Regional Council regulates environmental activities using rules and policy prepared in a Regional Resource Management Plan (RRMP) [1].

Under the RRMP the taking and use of groundwater in excess of 20 m^3 per day per property is classified as a discretionary activity requiring resource consent. In order to manage the groundwater resource and increase efficiency in the consent process, main water take areas in Hawke's Bay are divided into groundwater consent areas and a common expiry date issued to each consent based on a well's location. Bulk renewing of groundwater consents and reporting on resource sustainability are completed to coincide with this date.

In May 2009 groundwater consents in the Twyford Consent Area expired. To assist with issuing of groundwater consents and ensure the sustainable use, development and protection of the region's natural and physical resources, this report examines the effects of groundwater abstraction on surface water and groundwater resource in the Twyford Consent Area.

2.0 BACKGROUND

The Twyford Consent Area, shown in **Figure 1**, is located on the Heretaunga Plains about 1km north of Hastings and covers an area approximately 29 km^2. It is part of the Heretaunga basin which consists of at least 5 to 7 primary aquifers that formed during the last 250,000 years. Sediments from the Tutaekuri, Ngaruroro, and Tukituki rivers together with coastal, lagoonal, estuarine and embayment deposits form a relatively complex aquifer system composed of both confined and unconfined aquifers (Dravid & Brown, 1997 [2]).

At the western most edge of the consent area, near the base of Fernhill, the aquifer is predominantly unconfined and composed of gravels up to 60 metres thick. Toward the east, the aquifer becomes progressively confined and overlain by clays and silts. The transition between unconfined and semi-confined aquifer conditions is approximated by the presence of flowing artesian wells.

There are 216 consented groundwater takes in the Twyford Consent Area with an average consented weekly volume of 2552 m^3 (Harper, 2008 [3]). This is about 1.5 times less than the average weekly volume for resource consents in the Hawke's Bay of 3823 m^3 (Daisy database, 2006). The main groundwater use is for irrigation of orchards which accounts for 69% of the groundwater consents and 65% of the allocated weekly volume. The remaining groundwater use is for irrigation of crops, vineyards, and nurseries with some minor takes for public facilities and quarry works.

3.0 PREVIOUS REPORTS

Harper (2008, [3]) provided an initial assessment of the hydrogeology of the Twyford Consent Area including a description of the hydrogeology and hydraulic properties of the aquifer system along with a preliminary evaluation of potential stream depletion and well interference drawdown effects resulting from the proposed groundwater abstraction. This report builds on the initial assessment to provide a more detailed analysis of potential environmental effects in the Twyford Consent Area.

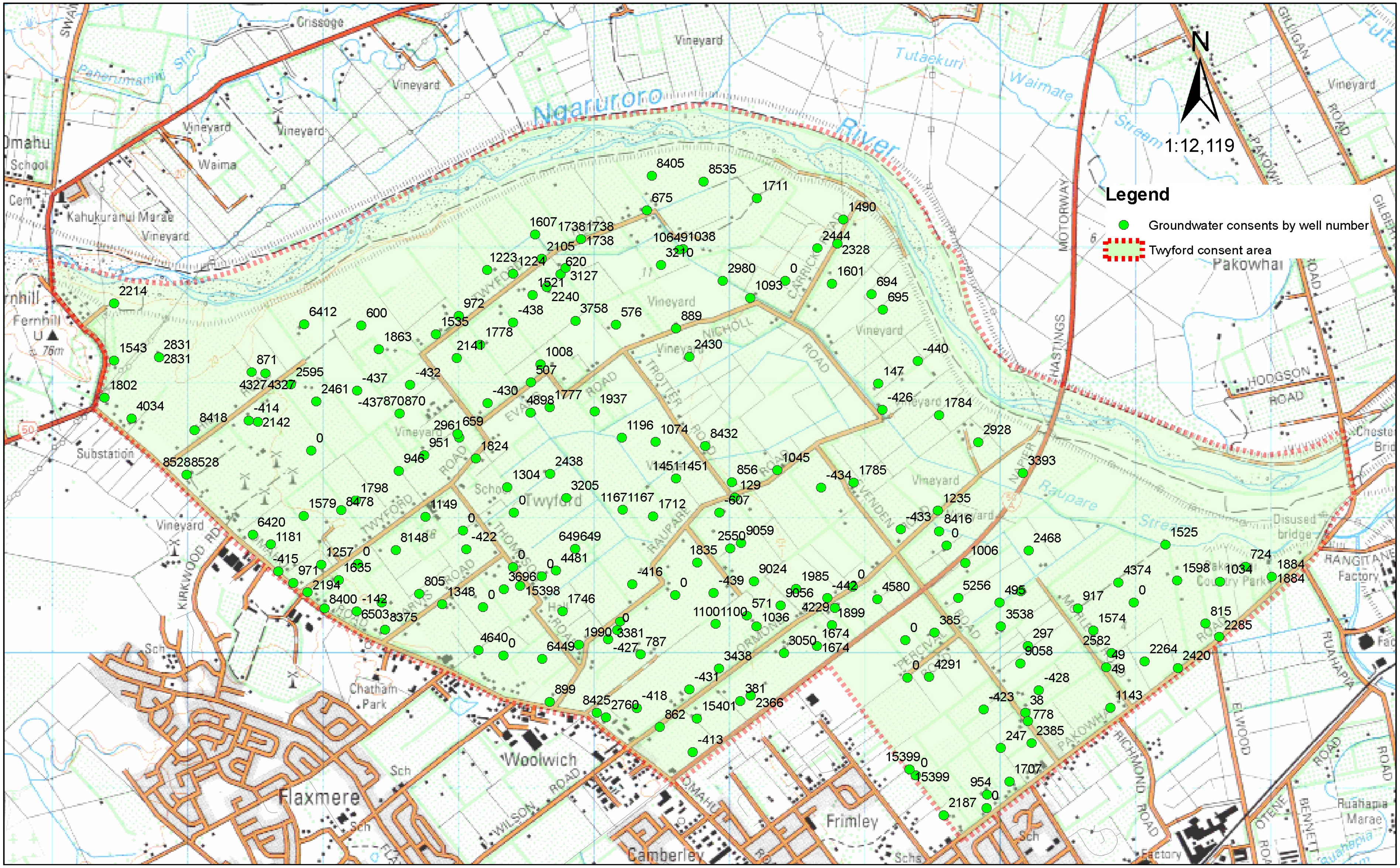


Figure 1: Twyford Consent Area and location of groundwater consent applications.

4.0 HYDROGEOLOGY BENEATH THE TWYFORD CONSENT AREA

4.1 Twyford geological model

Geological software from Rockware© was used to develop a model of the sub surface geology beneath the Twyford Consent Area. The model was developed using drillers' well log descriptions archived in the Council's database *WellStor*. This information is mainly from local drillers but data sources also include non-regional drillers and historical data from the former Geological Survey and Hawke's Bay Catchment Board. Well log information is manually entered by Council staff but historical data was transcribed using computer software and downloads. In many cases this has resulted in transcription errors.

A total of 881 well logs, shown in Figure 2, were used to develop the geological model. This number of wells is considered to provide a reasonable distribution of lithological information across the consent area. However, the interpolation of data was more reliable toward the east where well depths are greatest. In the west of the consent area where wells are typically less than 45 metres, interpretation of subsurface geology is restricted to the upper portion of the sedimentary sequence with the lithology at depth interpolated from more distant wells in the east and south.

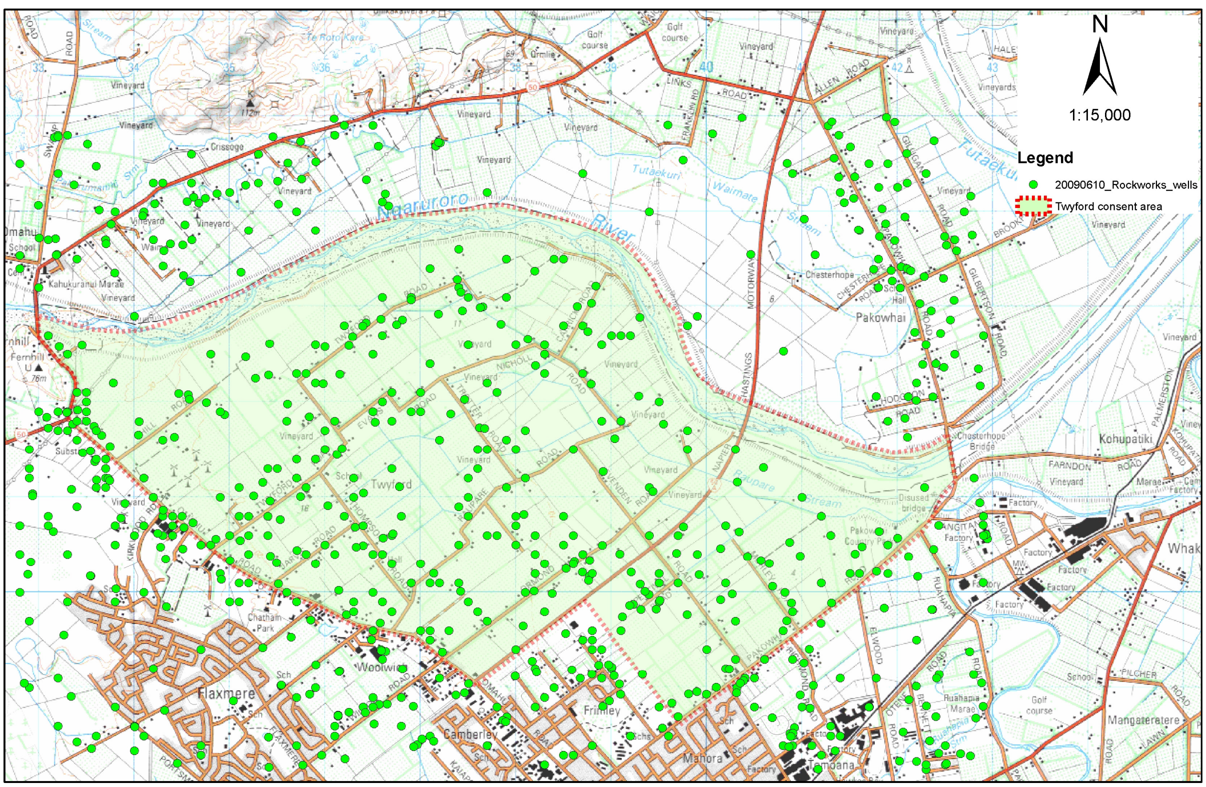


Figure 2: Wells used to develop geological model beneath the Twyford Consent Area.

The model grid area is 9.4km x 5.0km. Each grid is 100m x 100m x 0.5m. The depth of the model is 94 metres. Model dimension details are provided in Figure 3.

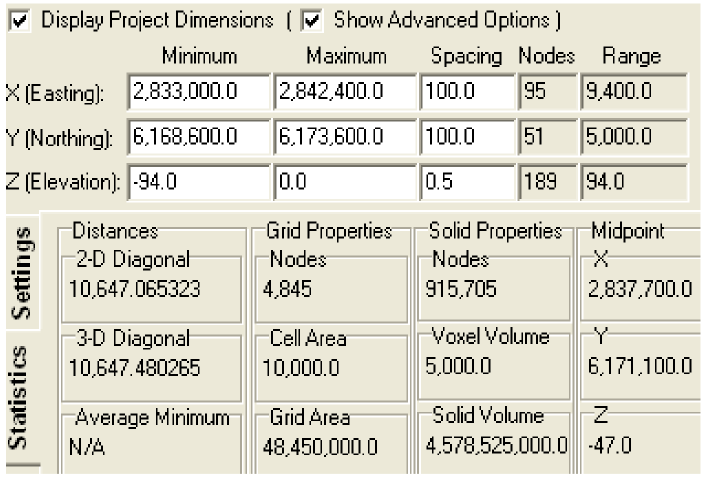


Figure 3: Model dimensions used to create the geological model.

4.2 Hydrogeological interpretation

A geological model was used to identify and delineate the hydrogeology beneath the Twyford Consent Area. The model indicates that a complex layering of sedimentary deposits form the basis of a large multi-layered aquifer system composed of a range of different sediment types. Some layers correlate between individual bore logs while others are isolated and represent individual localised lenses. Aquifers are generally composed of unconsolidated gravel but also contain layers of lower permeability materials such as silts and clays. This heterogeneity is similar across the confining layers with minor gravel and sand layers also present amongst the predominantly clay and silt based sediments. In total four main hydrogeological units were delineated; two alluvial aquifers and two confining layers.

The main aquifer, where the majority of abstraction are screened, extends eastward beneath most of the Twyford Consent Area and across the wider Heretaunga basin to the coast. A plot of well screen depths across the consent area, shown in Figure 4, indicates that the main water-bearing interval is relatively shallow near Fernhill progressively deepening to the east. This corresponds to an aquifer which is relatively unconfined from about Fernhill to Hill Road but becomes progressively overlain by clay and silt to the east. The aquifer is thickest in the unconfined area with gravels up to 60 metres thick, but thins and dips toward the east from about Hill Road where the upper gravel layers are overlain by a wedge of fine-grained silts and clay materials which form a confining layer over the underlying water-bearing gravels.

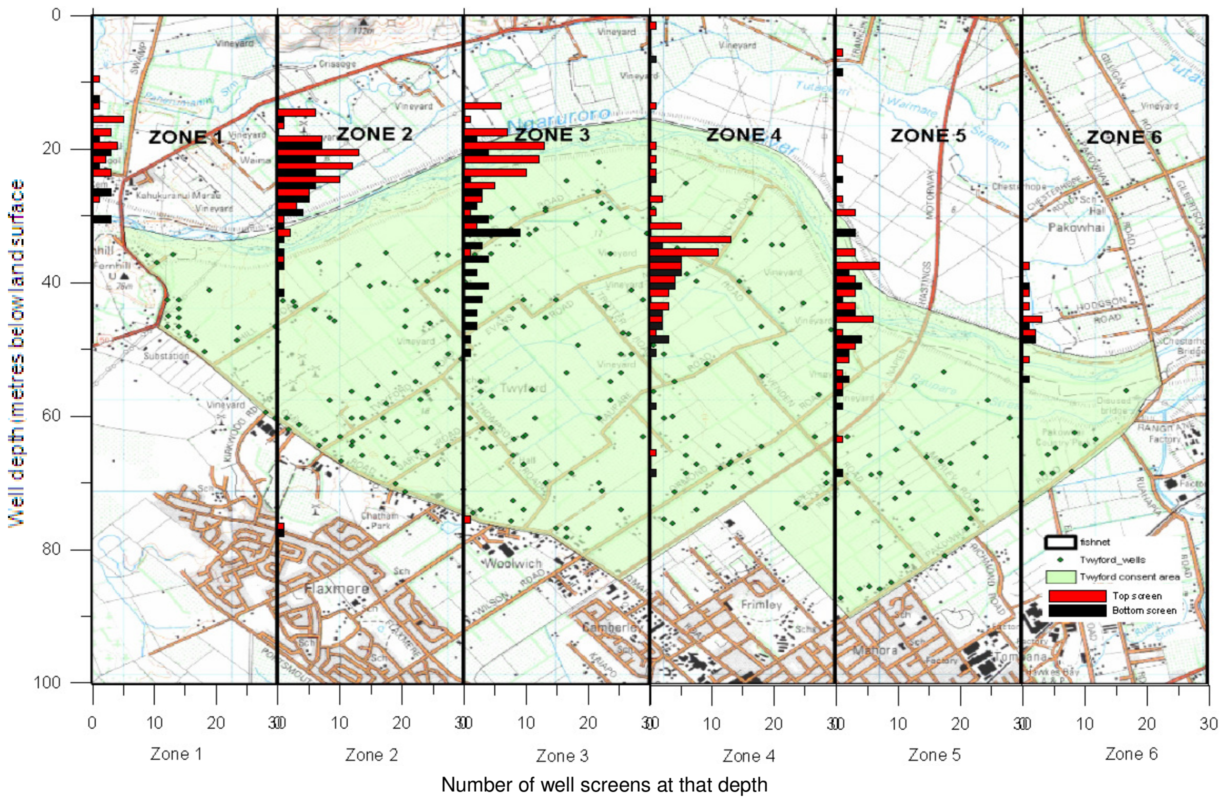


Figure 4: Well screen locations across the Twyford Consent Area.

The transition in the main aquifer between the unconfined and semi-confined areas is approximated by the presence of flowing artesian wells as shown in Figure 5. East of this transition flowing wells become more prevalent and static groundwater levels are generally recorded above land surface. This change in groundwater level is reflected by an increasing thickness of clays and silts forming the aquitard above the main aquifer. In the west, from about Hill Road to Twyford Road, the confining sediments are thin and interspersed with layers of gravels and sands that create zones of weakness from which groundwater is thought to naturally migrate upward and discharge to the surface as springs and seeps. Toward the east, from about Ormond Road, the confining sediments become gradually thicker and more clay-rich, retarding most of the groundwater movement toward the surface. The hydrogeological connection and continuity of the aquifer beneath this area is unclear and evidence from well lithology suggests the water bearing gravels may be disconnected or partially disconnected from the main aquifer located west of Ormond Road.

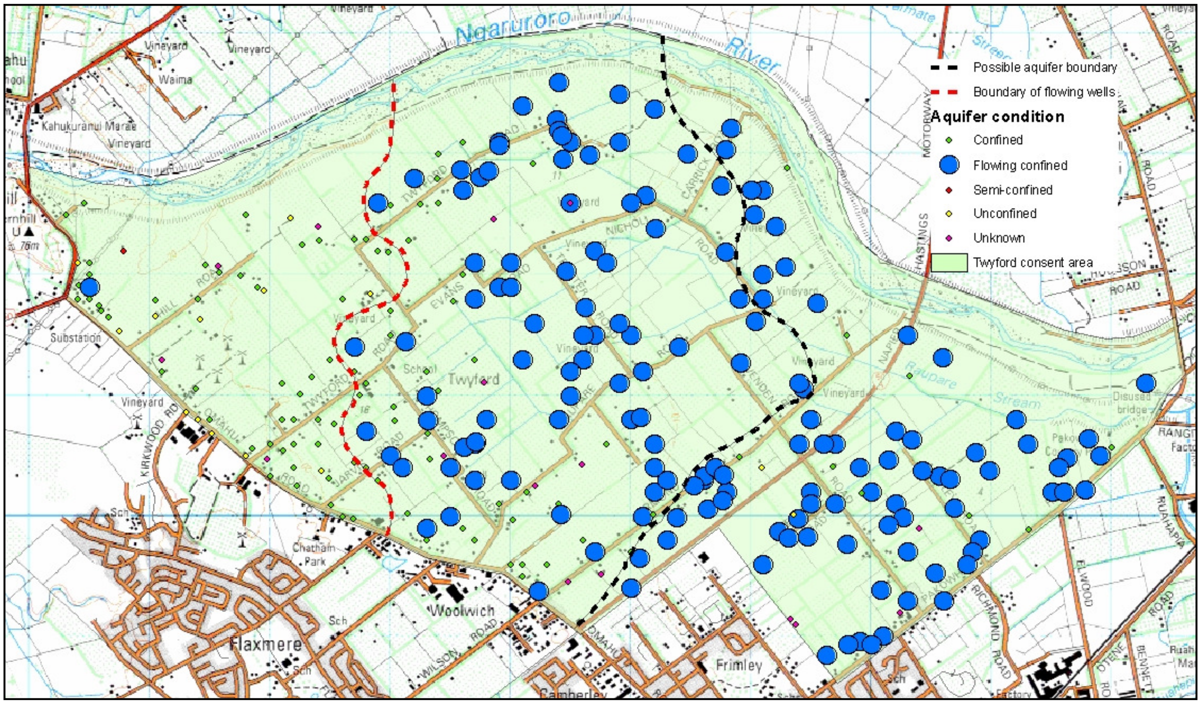


Figure 5: Location of flowing abstraction in the Twyford Consent Area.

Below the main aquifer, toward the eastern edge of the consent boundary, there is evidence of a second confining layer. Well logs in this area indicate the presence of fine-grained sediments, comprised predominantly of clay and silt layers, may extend from about 65 to 110 metres below land surface with a second deeper gravel aquifer underlying the confining sediments between 75 to 95 metres. However as shown in Figure 4, there are few abstraction at this depth from which to derive an accurate representation of the aquifer's true extent. In the unconfined zone there are no well logs available at a similar depth to confirm the continuance of this deeper water-bearing layer to the west.

4.3 Hydraulic characteristics

In order to identify representative aquifer parameters, aquifer test data for the Twyford Consent Area (Table 2 of Harper (2008) [3]) were reviewed to ascertain test quality and, if possible, verify aquifer parameters assigned to these tests in the Council's database WellStor. Table 1 presents results of this re-analysis and indicates that several of the tests recorded have a relatively low degree of reliability either due to the test methodology employed (i.e. step-rate tests) or factors affecting drawdown measurements during the test periods (e.g. interference drawdown and/or changes in river stage).

In the Twyford Consent Area 3 aquifer tests have been performed and results indicate transmissivity values range from 3000 – 22,000 m^2/day and storativity values from 0.002 – 0.00016. To help quantify the potential well interference and stream depletion effects in the Twyford Consent Area estimates of the hydraulic properties were used based on these aquifer test results and conclusions drawn from Dravid and Brown's (1997) [2] study of the Heretaunga basin. For the Twyford Consent Area the following hydraulic properties were used to characterise the main aquifer.

1. In the unconfined area of the main aquifer:
   - Transmissivity= 15,000 m^2/day, Specific yield = 0.1
2. In the semi-confined area of the main aquifer:
   - Transmissivity =15,000 m^2/day, Storativity = 0.001
3. In the confined area of the main aquifer:
   - Transmissivity = 20,000 m^2/day, Storativity = 0.0001

Aquifer test data was not available for the other layers so estimating their likely hydraulic properties was not attempted.

Note: The natural heterogeneity of the gravel materials means that there is likely to be considerable spatial variation in the aquifer hydraulic characteristics particularly with regard to aquifer storage characteristics across the unconfined/semi-confined/confined transition. The values adopted for this analysis are considered to be broadly representative of the three 'zones' of aquifer confinement identified in the consent area.

Table 1: Aquifer test results in the vicinity of the Twyford Consent Area.

Well No.	Screen Depth (m)	Test Type	Transmissivity (m^2/day)	Storativity	Notes from reassessment
1001	18.6 - 21.6	Constant rate	29,000	0.0003	Recharge boundary evident in results may over-estimate transmissivity (~17,000 m^2/day)
1109	70.0 - 76.0	Unknown	10,000		Test data not cited - reliability unknown
1348	15.2 - 22.5	Constant rate	3,000	0.002	Test results unreliable - affected by interference drawdown (significantly under-estimate T)
1695	16.6 - 22.6	Constant rate	31,000		Test results affected by river stage variation (may over-estimate T)
1703	? - 16.2	Step test	30,000		Low reliability step test - poor fit
1724	18.0 - 24.0	Unknown	12,600	0.0002	Test not cited - reliability unknown
1738	34.0 - 40.2	Constant rate	22,000	0.0002	Test reanalysed (T=29,300 m^2/day, S=0.00005)
2008	36.2 - 39.9	Step test	20,000		Test not cited
2141	36.0 - 42.0	Constant rate	20,000		Test not re-analysed, discharge rate uncertain
2237	16.6 - 22.6	Step test	13,500		Test not cited
2453	47.0 - 53.0	Step test	14,000		Test not cited
4676	37.3 - 56.7	Constant rate	22,000	0.0003	Test re-analysed (T = 34,000 m^2/day, S = 0.0003)
10372	16.7 - 19.5	Constant rate	32,000	0.0005	Test re-analysed (T=32,900 m^2/day, S=0.0005)

5.0 STREAM DEPLETION ASSESSMENT IN THE TWYFORD CONSENT AREA

5.1 Concepts of groundwater and surface water interaction

The interaction between surface water and groundwater is a common occurrence which can affect both the quantity and quality of both resources. These interactions are often difficult to observe and measure which creates uncertainty regarding their magnitude, effect and an appropriate form of management. One of the most potentially significant forms of interaction is the effect of groundwater abstraction on stream flow (PDP, 2000 [4]).

In situations where rivers or streams are hydraulically connected to an adjacent aquifer, water may flow into, or out of the stream according to the relative hydraulic gradient. Where groundwater levels are higher than the stream stage groundwater will discharge to the stream. In this case the stream is defined as a *gaining stream* and the groundwater discharge termed *baseflow*. Conversely, where surrounding groundwater levels are lower than stream stage, water may flow from the stream into the surrounding aquifer. In this case the stream is defined as a losing stream and the recharge to groundwater commonly referred to as stream leakage. Figure 6 illustrates the nature of groundwater and surface water interaction in gaining and losing streams.

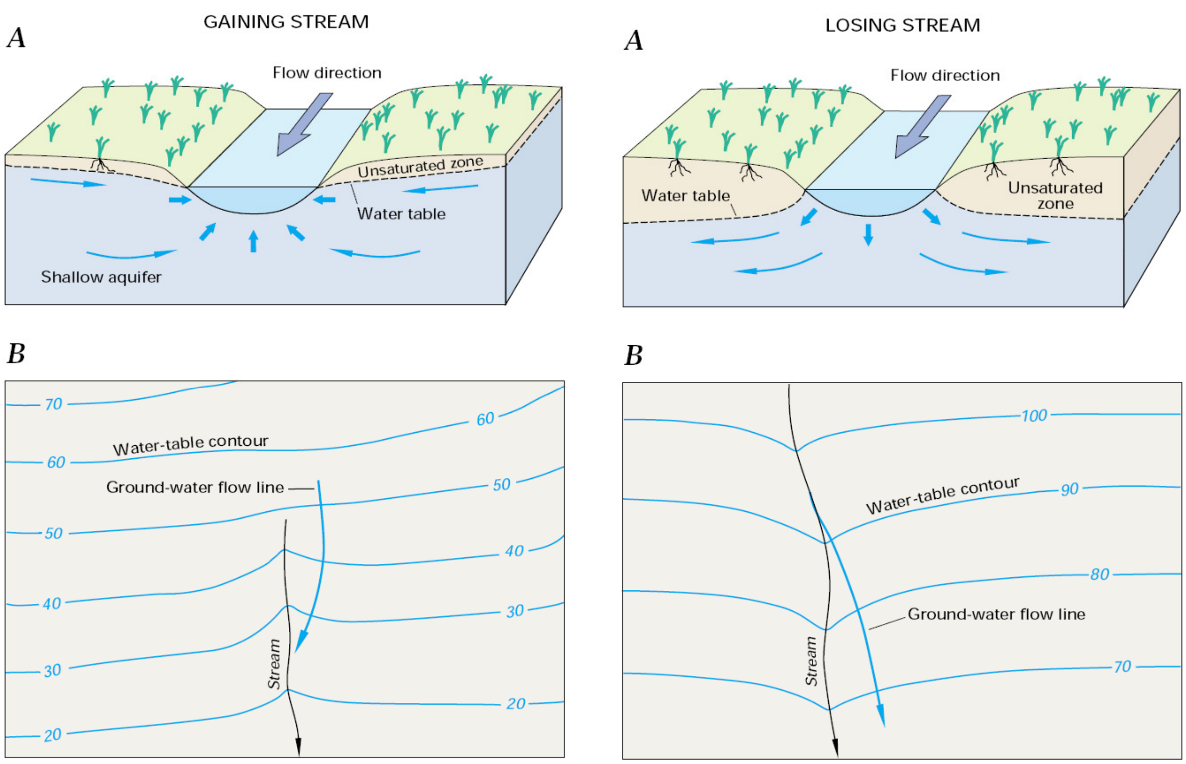


Figure 6: Gaining and losing streams.

Gaining streams receive water from the ground-water system (A). This can be determined from water-table contour maps because the contour lines point in the upstream direction where they cross the stream (B). Losing streams lose water to the ground-water system (A). This can be determined from water-table contour maps because the contour lines point in the downstream direction where they cross the stream (B) (USGS, 1998[5])).

Within any particular catchment, a stream may contain a number of reaches over which it is alternately gaining or losing. The location and extent of these gaining and losing reaches may change over time in response to changes in relative river stage and groundwater levels. These changes may result from a number of factors including climate variability, aggradation or degradation of river bed level as well as changes in groundwater levels due to seasonal variations in aquifer storage or groundwater abstraction.

A stream may also be classified as *disconnected* (Figure 7) where there is a zone of unsaturated material between the base of the stream and the underlying water table (such streams are also commonly referred to a *perched*). Although water may infiltrate vertically from a disconnected stream into the underlying water table, there is no direct hydraulic connection between the stream and aquifer. However, as with the losing and gaining streams, the degree of hydraulic connection to a perched stream can also change over time due to seasonal variations in the depth to the underlying water table.

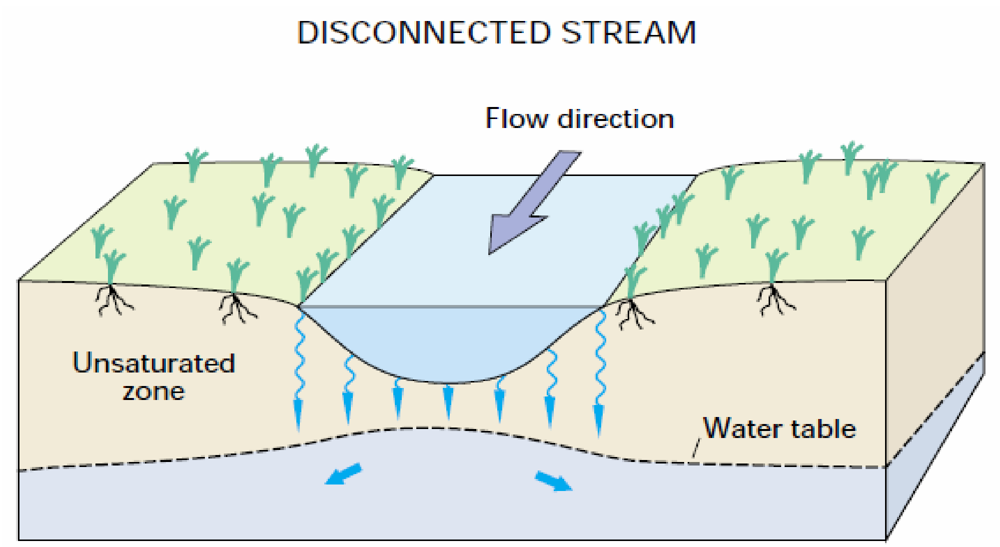
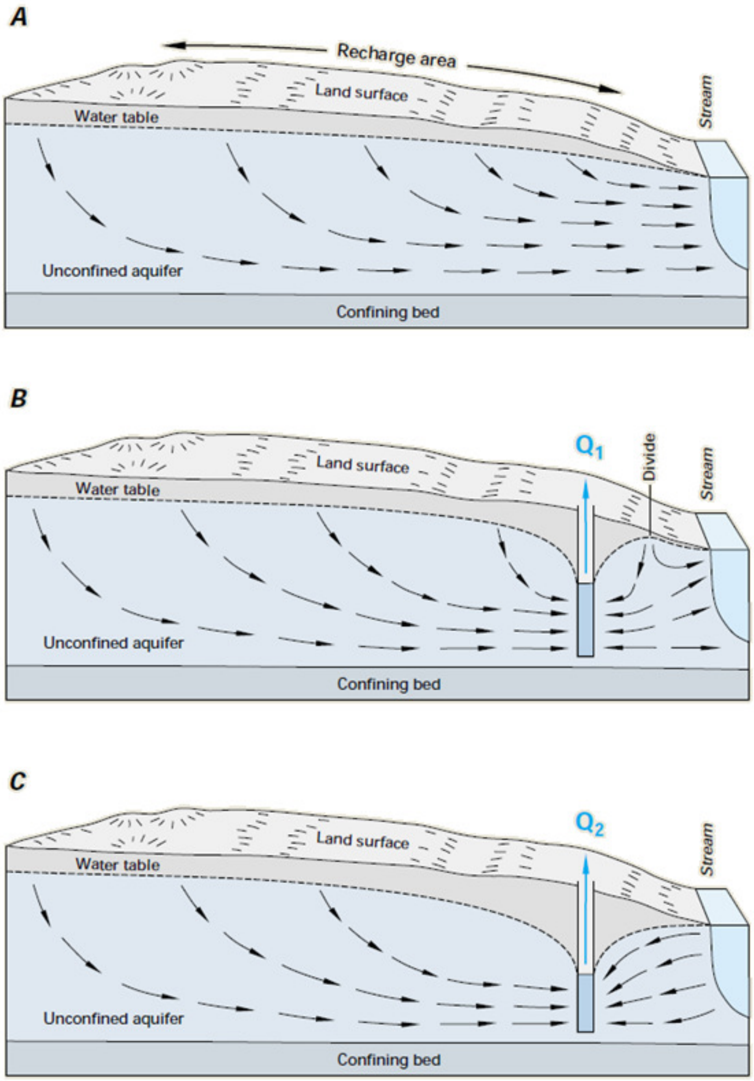


Figure 7: Disconnected stream.

Disconnected streams are separated from groundwater systems by an unsaturated zone. Where the stream is disconnected from the system by an unsaturated zone, the water table may have a discernible mound below the stream. Abstraction shallow groundwater near the stream under this condition does not affect the flow of the stream near the pumped abstraction (USGS, 1998 [5]).

Abstracting groundwater from an aquifer which is connected to a stream can have significant effects on the natural interaction that occurs between the stream and the aquifer. Abstracting groundwater can diminish the water available for stream flow by capturing some of the water that would otherwise have been discharged to the stream. In the case of a losing stream, abstraction may also increase the natural hydraulic gradient away from the stream resulting in a corresponding increase in stream leakage. Under certain conditions, where the drawdown in aquifer levels is sufficient, abstraction may also reverse the natural hydraulic gradient resulting in a naturally gaining stream losing water to the aquifer. The potential effect of groundwater abstraction on stream flow is illustrated in Figure 8 below (USGS, 1998 [5]).



Natural condition

Stream capture

Induced stream depletion

Figure 8: Effect of groundwater abstraction on stream flow.

5.2 Managing groundwater and surface water interaction in the Hawke's Bay

To manage the potential effects of groundwater abstraction on stream flows, Council regards any groundwater take from an unconfined or semi-confined aquifer in the vicinity of a surface water body in accordance with the following RRMP policies:

Policy 33 (a) Any taking of shallow groundwater within 400 metres of a river, lake or wetland as measured from the edge of the bed will be treated as if it were a direct take unless the extent to which the groundwater will deplete water in the surface water body has been assessed using an appropriate scientific procedure in which case the effects on surface water will be assessed on that basis.

Policy 33 (b) Any taking of shallow groundwater beyond 400 metres may require an assessment of effects in the river, lake or wetland if the scale of the take, the groundwater flow direction, and the transmissivity and storativity characteristics of the aquifer indicate interaction is likely to occur; in which case it may be treated as if it were a direct take.

If for any reason Council indicates a connection is likely, whether this is because a groundwater take is within 400 metres or the aquifer characteristics are conducive for stream depletion, it is the applicant's responsibility, in accordance with the RRMP to investigate this further and provide evidence to suggest otherwise.

5.3 Stream depletion assessment approach

The following sections examine the connection between the surface water and groundwater resources beneath the Twyford Consent Area. Results of this assessment are subsequently applied to help qualify the potential effects of groundwater abstraction on surface water flow. Table 2 outlines the steps taken to investigate the effects of groundwater abstraction on surface water in the Twyford Consent Area.

Table 2: Approach used to investigate effects of groundwater abstraction on surface water in the Twyford Consent Area.

STEPS	DESCRIPTION	TASKS
Step one	Interpretation of available data to determine surface water and groundwater interaction in the Twyford Consent Area.	• Review available data including stream gauging results, piezometric contour maps and groundwater levels recorded during drilling.
Step two	Examine how surface water and groundwater is connected (completed in section 4.0).	• Create a geological model using well lithology data and interpret hydrogeologic layers. • Use supporting information to help with interpretation such as static water levels and screen locations. • Examine aquifer test results to estimate hydraulic characteristics.
Step three	Develop a conceptual model of the Twyford Consent Area from the information available.	• Analyse available hydrogeological data. • Create a schematic diagram to illustrate surface water and groundwater interaction.
Step four	Identify the abstraction that is likely to affect the magnitude and extent of natural interaction between the groundwater and surface water resources.	• Assess groundwater takes using analytical methods to identify the wells within the consent area with the greatest risk of stream depletion. • Use the current understanding from the investigation to decide which wells are likely or not likely to cause stream depletion.
Step five	Conclusions and discussions	• Summarise results including reasons for the classification of individual wells or groups of wells with regard potential stream depletion effects. • Discuss the interpretation and data limitations.
Step six	Recommend future investigation work	• Identify gaps and uncertainties in the conceptual model. • Recommend future options for improving management of groundwater and surface water interaction. • Recommend management options for mitigating potential environmental effects.

5.4 Twyford groundwater and surface water interaction

5.4.1 Ngaruroro River

The concept that surface water in the Heretaunga basin interacted with groundwater was first put forward in 1887 when Hill [6] suggested groundwater was derived from river seepage flowing over the plains. In 1957 surface water flow measurements began along the Ngaruroro River and losses of flow were identified across two reaches of the river (Dravid & Brown, 1997 [2]). These river reaches were termed the minor recharge area, between Maraekakaho and Roy's Hill, and the major recharge area, between Roy's Hill and Fernhill. In 1965 Grant [7] attributed this flow loss as the major source of recharge to the main Heretaunga aquifer system.

Much of the early work concentrated on flows in the upper Ngaruroro River between Maraekakaho and Fernhill, and it was not until the late 1990's that flows in the lower Ngaruroro River were more closely investigated (Wood & Stansfield, 2001 [8]). From 1998-2001 surface water flows were measured across 6 reaches between Fernhill and Chesterhope. The results from this study suggested that although an overall loss of flow was measured, flow varied and at most reaches, both gains and losses were encountered. The loss of flow was greatest at high flows (>8000 L/s) which was attributed to a greater wetted perimeter. However, at flow rates between 5000 to 3000 L/s the rate of loss varied, except at one gauging site, where a period of gain was measured. No explanation for this variability was given by Wood & Stansfield, (2001) [8].

The largest and most consistent loss of flow measured occurred between Fernhill and Hill Road, shown in Figure 9. Along this stretch of river 6 flow measurements, shown in Figure 10, taken during average to low flow conditions in autumn 2001, recorded a loss of flow between 84 to 860 L/s. An examination of well lithology indicates the geology in this area is relatively unconfined offering little impedance to the movement of water between the stream and the aquifer. Furthermore, evidence from static water levels taken during well drilling suggests groundwater levels decline away from the river providing a hydraulic gradient conducive to natural seepage loss in this area.

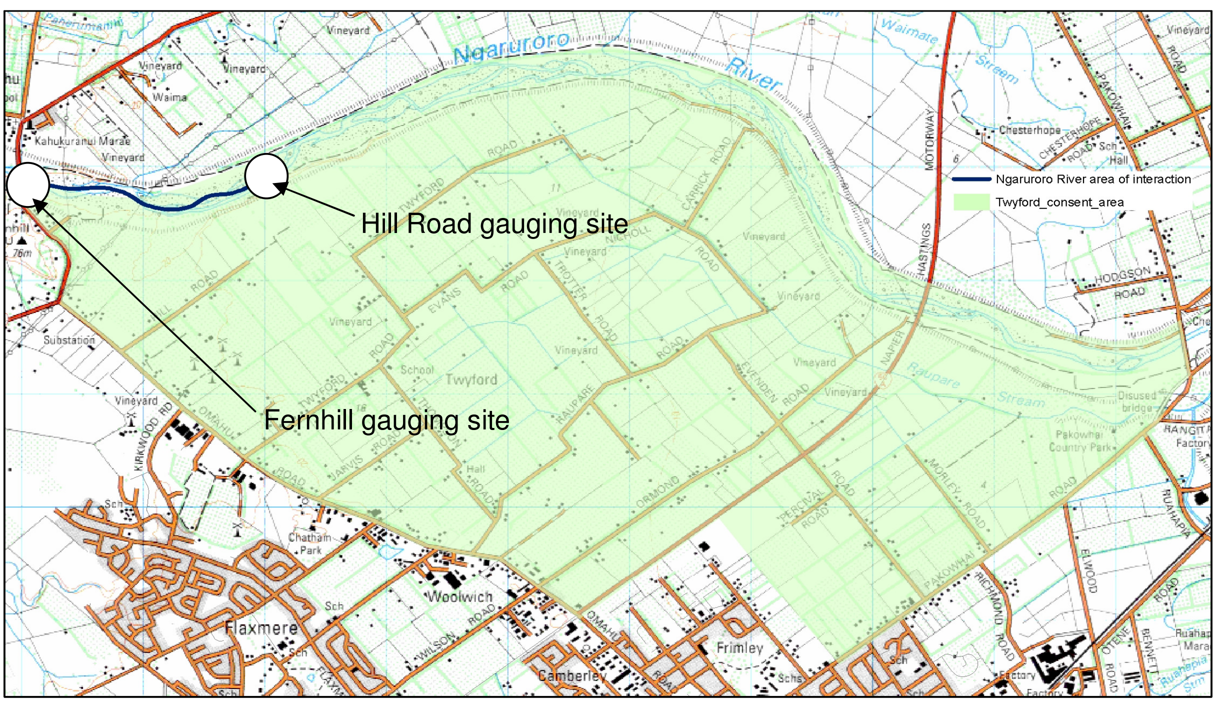


Figure 9: Location of gauging sites where loss of flow is measured along the Ngaruroro River adjacent to the Twyford Consent Area.

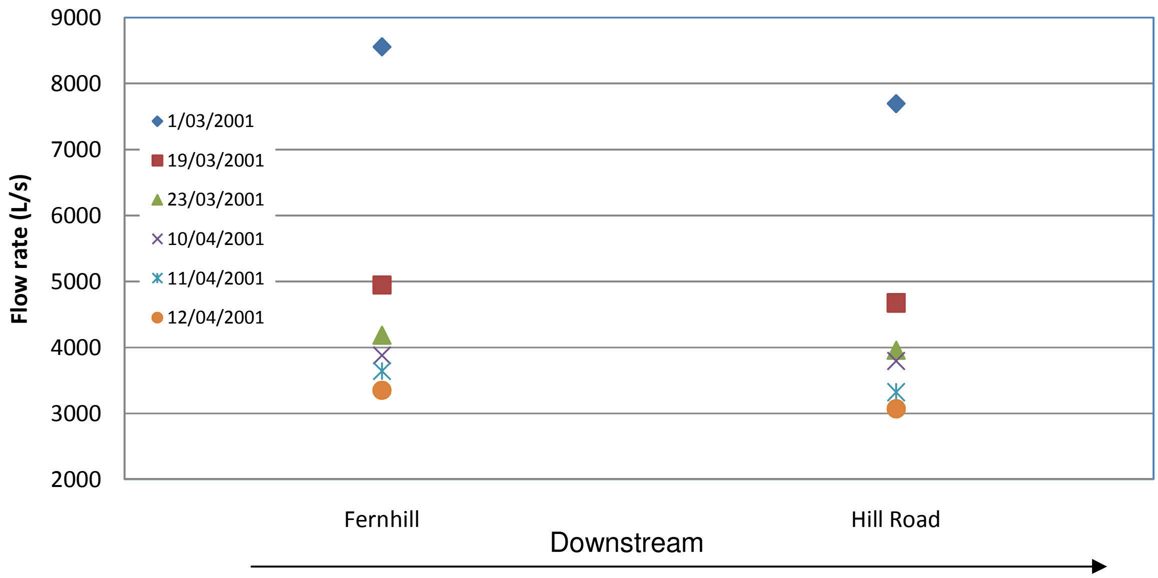


Figure 10: Ngaruroro River flow measurements taken in 2001 between Fernhill and Hill Road

5.4.2 Raupare Stream

The Raupare Stream begins at the northern extent of the Karamu catchment. Stream flow measurements, shown in Figure 11, indicate the Raupare Stream gains flow along its course until the Karamu Stream, with a significant flow contribution from an unnamed tributary between Nichol Road and Ormond Road. The Raupare Stream exhibits flow characteristics consistent with groundwater being the predominant source of flow. Stream discharge is relatively constant throughout the year with a stable and relatively slow rate of recession evident during low flow periods.

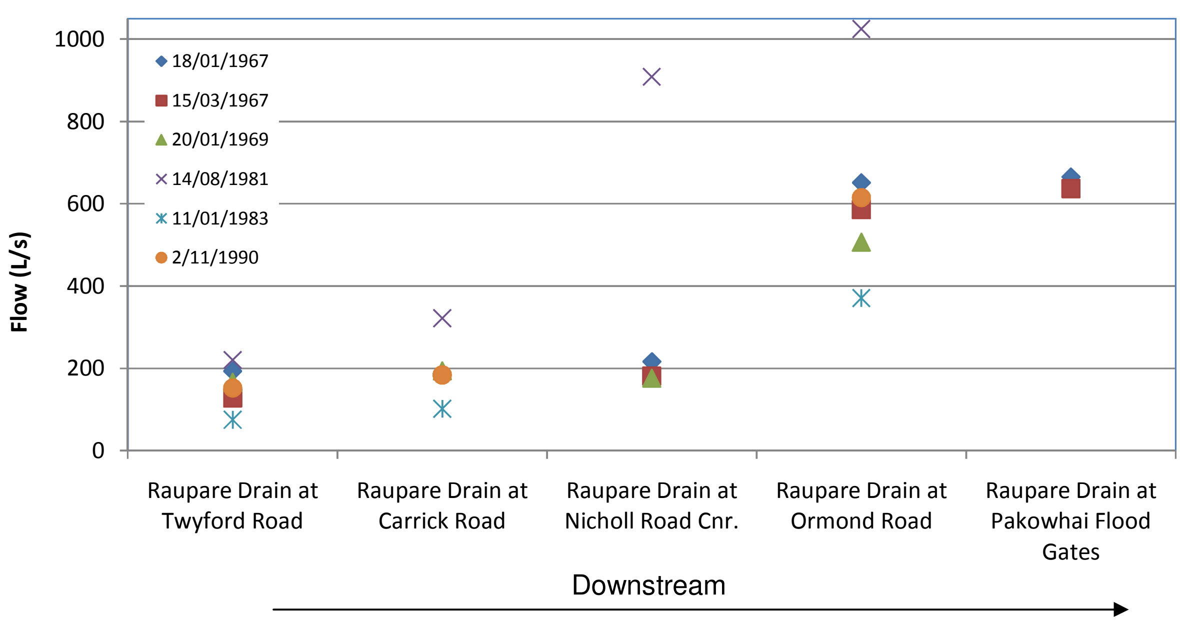


Figure 11: Flow measurements in the Raupare Stream.

Loss of flow from the Ngaruroro River to the unconfined aquifer is likely to be the main source of flow to the Raupare Stream. Results from piezometric surveys taken in 1974-77 and 1995 indicate groundwater flows eastward from the Ngaruroro River toward the coast (Dravid and Brown 1997) [2]. Upon reaching the margin of the confining layer, groundwater becomes increasingly artesian toward the east and eventually flows naturally to land surface as springs and seeps, through weaknesses within the aquitard.

To examine the relationship between flow in the Raupare Stream and groundwater from the semi-confined aquifer, discharge measured in the Raupare Stream was correlated with groundwater levels measured at well 15006 (measured within +/- 7 days). The results shown in Figure 12 indicate a strong linear relationship (R^2 = 0.77) exists between flow in the Raupare Stream and groundwater levels in the semi-confined aquifer. From these results it is expected that when groundwater levels in the aquifer rise, flow in the Raupare Stream will increase due to greater flow exiting the aquifer via springs to the stream. A similar relationship is also observed with groundwater levels recorded in well 1674 also screened to the same semi-confined aquifer as well 15006.

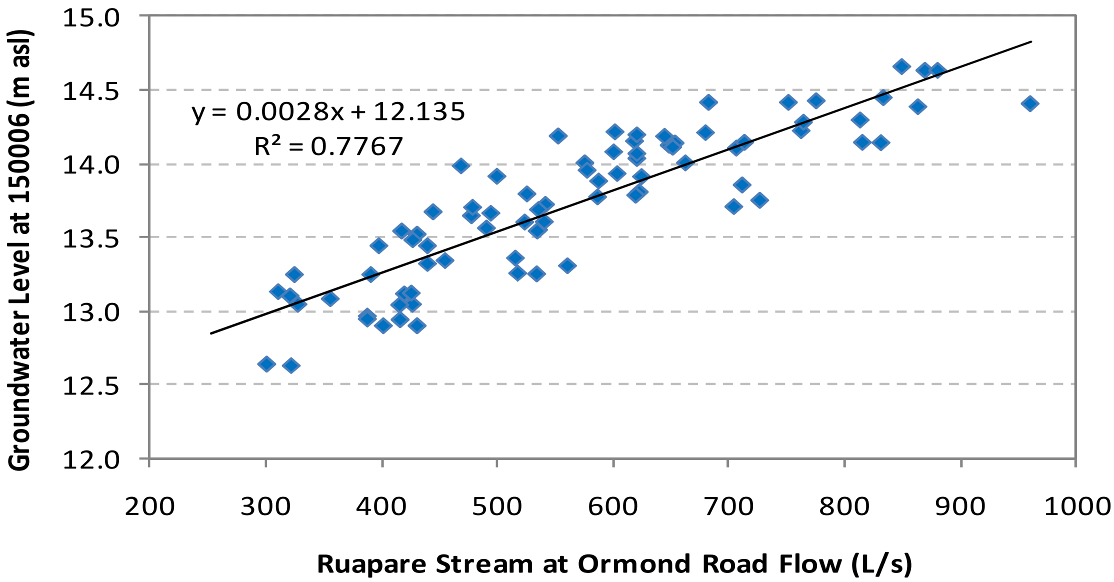


Figure 12: Correlation between groundwater level at 15006 and discharge in Raupare Stream at Ormond Road

Based on the relationship shown in Figure 12, it is clear that flow in the Raupare Stream is sensitive to relatively small changes in groundwater level in the semi-confined aquifer. For example, using the linear equation derived in Figure 12, a groundwater level decline of 0.2 metres in well 15006 would equate to a corresponding reduction of approximately 60 L/s in Raupare Stream flow at Ormond Road.

The correlation between groundwater levels in the semi-confined area and discharge in Raupare Stream indicates that flow in the Raupare Stream is likely to be strongly influenced by temporal variations in groundwater storage across the semi-confined area. Figure 13 shows a linear trend line fitted through seasonally grouped gauging data measured at Ormond Road. In order to minimise the potential for sampling bias (i.e. a greater focus on low flow periods in recent years) the data are separated into winter (May - October) and summer (November to April) periods. This analysis shows a similar, although slightly more pronounced during summer, decline in discharge over time in both data sets. This suggests there has been a gradual decline in Raupare Stream discharge over time and that this decline is sharper over summer. This pattern is similar to observations seen in groundwater levels measured in monitoring wells across the Heretaunga basin, where groundwater levels over time show an increase in seasonal variation marked by a subtle winter decline but sharper summer decline. The most likely explanation for this trend is due to increased abstraction over time.

Fitting a linear trend line to groundwater levels recorded at well 15006 from 1991 to 2009 indicates a decline of approximately 0.15 metres. Applying the equation derived from the flow correlation shown in Figure 12, this equates to a potential reduction in stream discharge of approximately 40 L/s since 1991. This is consistent with the observed decline in Raupare Stream discharge over that same period.

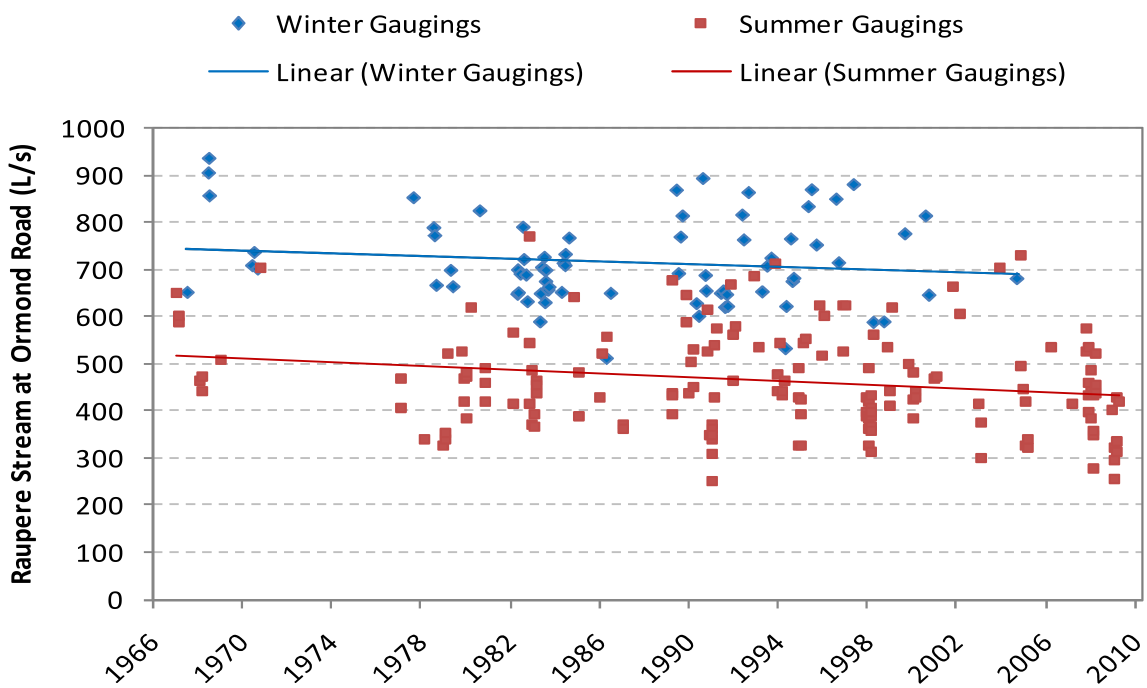


Figure 13: Temporal variation in Raupare Stream discharge at Ormond Road

Overall, the available hydrogeological evidence suggests that the Raupare Stream is effectively maintained by the through-flow of groundwater from the unconfined to confined portions of the aquifer system with stream discharge effectively representing ‘overflow’ from the aquifer system through leakage in the semi-confining clay layer. As a result, Raupare Stream discharge is sensitive to relatively small changes in groundwater levels across the semi-confined area. The available data appear to indicate a gradual reduction in stream discharge over time which is likely to reflect a corresponding reduction in groundwater levels, particularly during summer when the cumulative effects of abstraction are greatest. Due to the sensitivity of Raupare Stream to relatively small changes in groundwater level, maintenance of flow in the Raupare Stream at or above an appropriate threshold is an important consideration in the overall management of the groundwater resource in the Twyford area.

5.5 Conceptual surface water and groundwater interaction model

The natural interaction between surface water and groundwater within the Twyford Consent Area takes place in two basic ways:

1. The Ngaruroro River loses water to groundwater outflow, between Fernhill and Hill Road, and

2. The Raupare Stream gains water from groundwater inflow via seeps and springs between Twyford Road and Ormond Road.

Well lithology and the observed relationship between groundwater levels and stream discharge provide evidence of the hydrogeological connection between the surface water and groundwater in these two areas. Between Fernhill and Hill Road the Ngaruroro River is connected to the main aquifer by a relatively unconfined sequence of alluvial gravels. East of Hill Road, confining layers of silt and clay retard much of this interaction. In the Raupare Stream surface water is connected to groundwater through interspersed layers of gravel and sand which allow the natural movement of artesian groundwater to the surface.

Abstraction of groundwater in the Twyford Consent Area may affect the natural interaction of surface water and groundwater by:

1. Increasing the natural loss of flow from the Ngaruroro River, between Fernhill and Hill Road, by increasing the hydraulic gradient between water levels in the river and the aquifer.

2. Decreasing the flow to the Raupare Stream though a reduction in artesian pressure in the semi-confined area resulting in a corresponding decline in artesian spring discharge.

3. Decreasing the flow to the Raupare Stream through capture of groundwater during abstraction 'upstream' that would otherwise have been discharged as springs and seeps.

Identifying the wells that are likely to cause a potential stream depletion effect requires identifying which aquifer they pump from and whether that aquifer is connected to surface water. Well lithology provides a hydrogeological framework for investigating this physical connection.

1. A plot of well screen locations against well lithology suggests most wells pump from the main aquifer which is connected to the Ngaruroro River and Raupare Stream. This aquifer which is relatively unconfined between Fernhill and Twyford Road becomes progressively confined to the east and is thought to extend beneath much of the Twyford Consent Area to about Ormond Road.

2. East of Ormond Road the lateral continuity of the aquifer becomes difficult to delineate and well lithology indicates the aquifer may pinch out; for this reason the aquifer east of about Ormond Road is considered disconnected to surface water in the Twyford Consent Area.

Given the likely hydraulic connection of the aquifer between Fernhill and Ormond Road to surface water in the Ngaruroro River and Raupare Stream, groundwater abstraction from the main aquifer in this area has the potential effect to reduce surface water flow. Figure 14 shows the location of these potentially stream depleting wells and Figure 15 summarises the current interpretation of surface water and groundwater interaction in the area.

Although a physical connection may exist between the aquifer and an adjacent surface waterway, this does not necessarily mean the effects of groundwater pumping will result in a significant reduction in surface water flow. In particular, the magnitude and extent of stream depletion may be reduced by the presence of fine-grained sediments on the streambed (termed the clogging layer) or minor clay layers (lenses) within the aquifer materials. As a result, development of a good conceptual understanding of the hydrogeological setting, including the hydraulic properties of aquifer materials and the streambed clogging layer is crucial to allow reliable estimation of the potential magnitude of stream depletion resulting from groundwater abstraction.

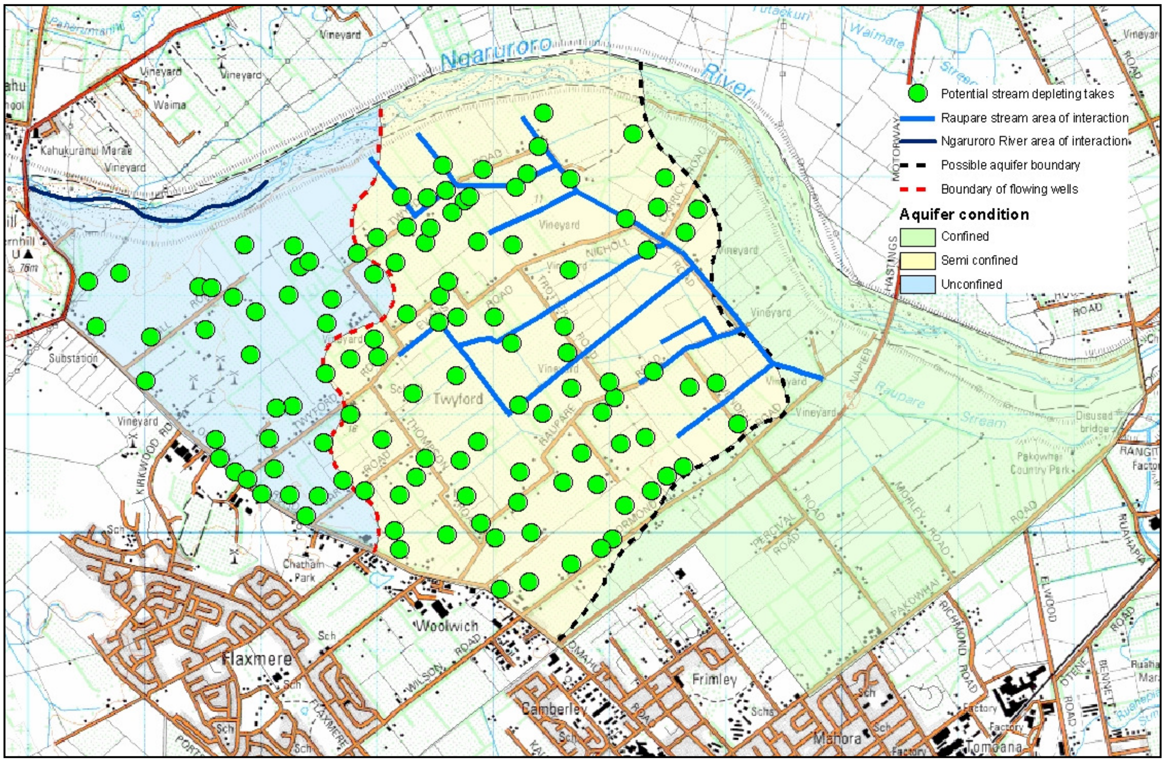


Figure 14: Location of potential stream depleting groundwater consented takes and area of surface water and groundwater interaction.

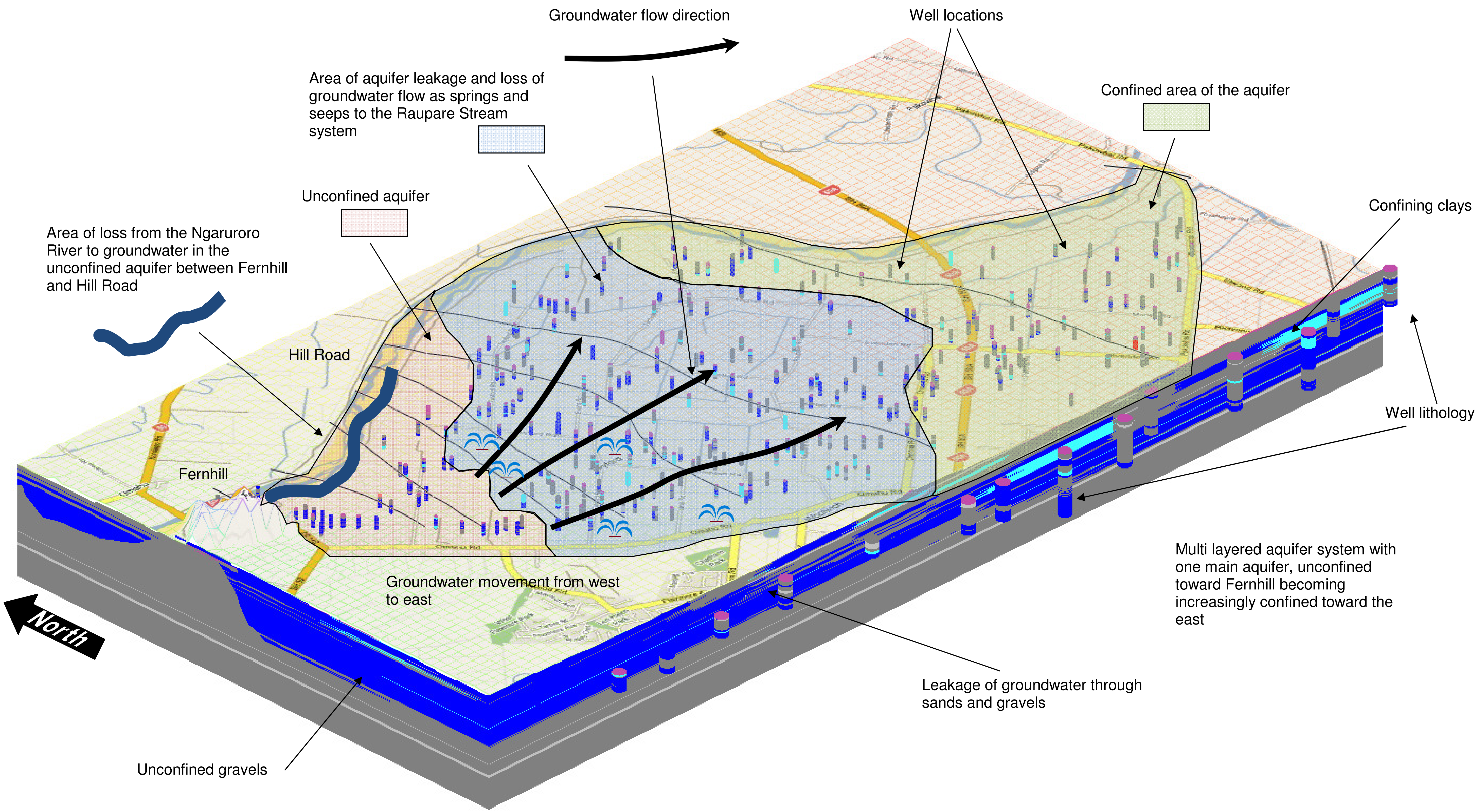


Figure 15: Conceptual model illustrating the surface water and groundwater interaction in the Twyford Consent Area.

5.6 **Quantifying the stream depletion effects**

In order to identify groundwater takes potentially resulting in a more than minor stream depletion effect on surface water a nominal rate of stream depletion was established for determining what Council regards as a more than minor effect. For the purpose of this report any groundwater abstraction resulting in more than 1 L/s stream depletion was considered a more than minor effect (Pers.comm. Darryl Lew – Environmental Regulation Manager). Any individual effect less than 1 L/s was regarded as less than minor and subsequently removed from further investigation.

Estimating the stream depletion effect typically requires the use of analytical or numerical models to predict the potential effects of groundwater pumping on stream flow. This involved choosing an appropriate model for the consent area and estimating the hydraulic properties of the aquifer. In the absence of a transient numerical groundwater model for the Heretaunga Plains aquifer system four analytical solutions were considered for estimating the stream depletion effect:

1. Glover and Balmer 1954; Jenkins 1968 – an analytical solution for a stream that fully penetrates the aquifer with no streambed resistance
2. Hantush, 1965 – an analytical solution for a stream that fully penetrates the aquifer with streambed resistance
3. Hunt, 1999 – an analytical solution for a stream that partially penetrates the aquifer with stream bed resistance
4. Hunt, 2003 – an analytical solution for a stream in an aquitard with abstraction from an underlying leaky aquifer.

The conceptual model of the Twyford Consent Area indicates that stream depletion may potentially occur along the Ngaruroro River between Fernhill and Hill Road, and along the Raupare Stream between Twyford Road and Ormond Road (Figure 14). The connection between the aquifer and surface water is illustrated below in Figure 16 which shows the Ngaruroro River partially penetrates the main aquifer over a relatively unconfined section of gravels and becomes progressively confined toward the east. The semi-confining layer is then partially penetrated by the Raupare Stream which sources its flow through upward leakage from the main aquifer via artesian springs and seeps. Accumulations of fine-grained streambed sediments (termed the streambed clogging layer) in both the Ngaruroro River and Raupare Stream are thought to impede the hydraulic connection between surface water and groundwater to varying degrees.

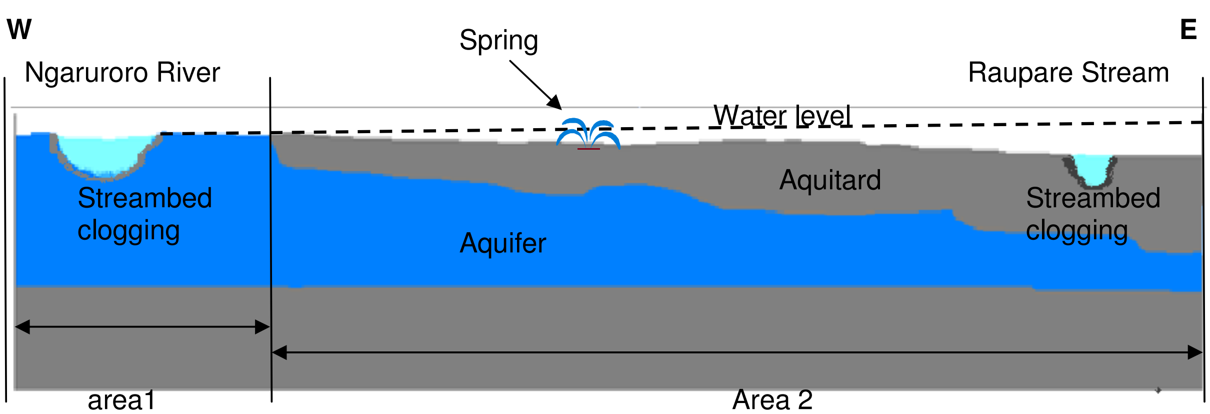


Figure 16: Conceptual hydrogeological setting between surface water and groundwater in the Twyford Consent Area.

The hydrogeological setting depicted in Figure 16 indicates a transition from unconfined to semi-confined conditions within the aquifer system which cannot be reliably modelled by available analytical techniques. In order to quantify, and ultimately manage, potential stream depletion effects the consent area was divided into two main areas (area 1 - Figure 17, and area 2 - Figure 18). These areas reflect the nature of the hydrogeological setting (i.e. unconfined/semi-confined conditions) as well as the potential mechanism by which stream depletion is likely to occur (i.e. an increase in natural river recharge in the unconfined area as opposed to a reduction in artesian spring discharge in the semi-confined area).

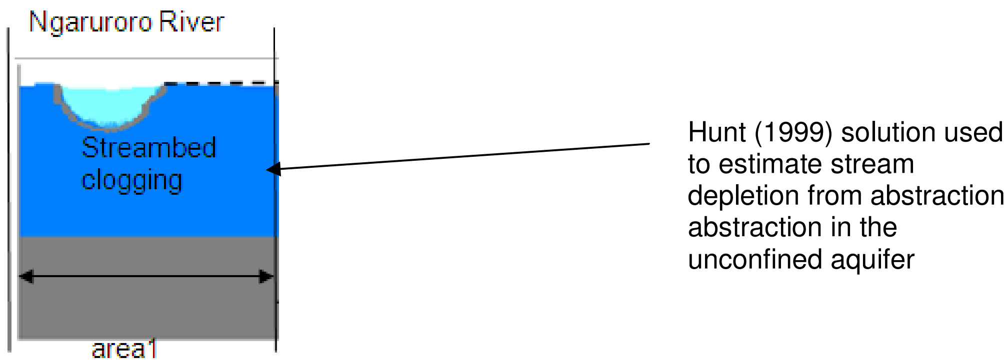


Figure 17: Area 1 – stream depletion using Hunt (1999) solution

To provide a more reasonable representation the consent area was divided into two main areas (area 1 and area 2). Area 1 represents a partially penetrating stream with streambed resistance in an unconfined aquifer. For this setting the stream depletion effects on the Ngaruroro River from abstraction in the unconfined aquifer were quantified using the Hunt (1999) solution. The stream depletion effects on the Ngaruroro River from abstraction in the semi-confined aquifer were not quantified because none of the analytical solutions are able to account for changes in aquifer confinement as abstraction effects propagate from semi-confined to unconfined conditions.

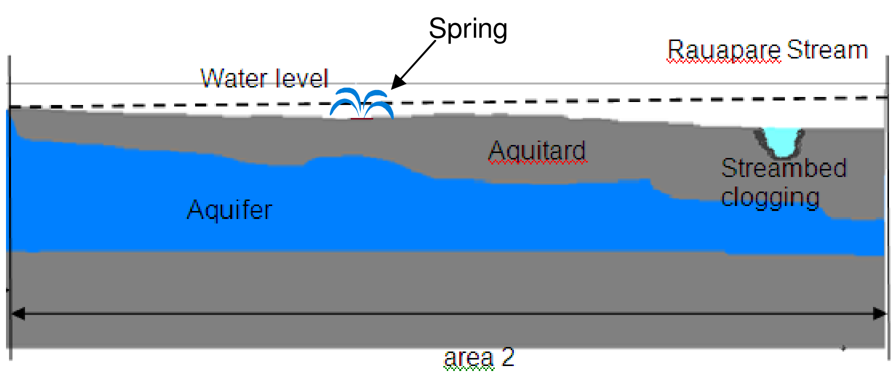


Figure 18: Area 2 – stream depletion using Hunt (2003) solution.

Area 2 represents a partially penetrating stream in an aquitard with abstraction from an underlying leaky aquifer. For this setting stream depletion effects on the Raupare Stream from abstraction in the semi-confined aquifer can be approximated using the Hunt (2003) solution. However, this requires the hydraulic properties of the aquitard which are not available. Therefore the potential stream depletion effects on the Raupare Stream from individual groundwater takes were not estimated.

5.7 Stream depletion assessment assumptions

- Stream depletion effects were calculated for worst case scenario modelling.
  - For irrigation consents this required converting the monthly allocated volume to average daily abstraction rate (l/s) and estimating the stream depletion effect over 90 days abstraction (approximately an irrigation season).
  - For frost protection consents the maximum rate of take was used to estimate stream depletion effects over a typical frost event. A duration of 4 hours was chosen based on a 1 in 5 year high (80^{th} percentile) calculated for the average frost duration during September (NIWA, 2008 [9])
- The aquifer hydraulic properties used to estimate the stream depletion effects were based on the representative estimates provided in section 4.3.
- Well distances were estimated using mapping software from Council GIS program ArcMap based on GPS bore locations recorded by Council staff.
- Estimates of streambed conductance were taken from typical values reported in Guidelines for the Assessment of Groundwater Abstraction (PDP, 1999) [4]. A maximum value of 5000 m/day was used to provide a worst case scenario. In reality, actual streambed conductance values, particularly in Raupare Stream, are likely to be significantly lower than this value.
- The calculation uses a spreadsheet created by David Scott from Environment Canterbury to calculate potential stream depletion using the Hunt (1999) method based on macros contained in the Function.xls spreadsheet developed by Bruce Hunt at the University of Canterbury (http://www.civil.canterbury.ac.nz/staff/bhunt.shtml). This requires manual entry of each pumping scenario into the spreadsheet and recording of the resulting stream depletion effect after a given duration at a nominated rate.

5.8 Stream depletion assessment results

As described in Section 5.6, a nominal rate of greater than 1 l/s stream depletion was established for determining those wells likely to cause a more than minor stream depletion effect.

The conceptual model provided in Figure 14 indicated that those abstractions most likely to cause a stream depletion effect are located west of Ormond Road within the main aquifer. East of Ormond Road the connection of the aquifer to the river is unclear and therefore the aquifer system in this area is largely considered disconnected from surface water. Based on this understanding a total of 146 groundwater consents associated with 122 abstraction were considered as potentially stream depleting.

5.8.1 Area 1 results

Area 1 represents a partially penetrating stream with streambed resistance in an unconfined aquifer as illustrated in Figure 17. For this setting the potential stream depletion effects on the Ngaruroro River from pumping in the unconfined aquifer were quantified using the Hunt (1999) solution. A total of 41 groundwater consents from 34 wells in the unconfined aquifer were assessed for stream depletion. A summary of these results are given in Appendix A.

The high aquifer transmissivity values (approximately 15,000m^2/day) assumed for the unconfined area results in the rapid propagation of pumping effects to the river and rapid stream depletion. The effects on stream flow became less significant with increasing distance from the river and for lower pumping rates. A total of 7 groundwater applications that pump from 5 wells were assessed as having a less than minor effect on river flow. All other pumping scenarios resulted in stream depletion of greater than 1 L/s. Results are shown in Figure 19.

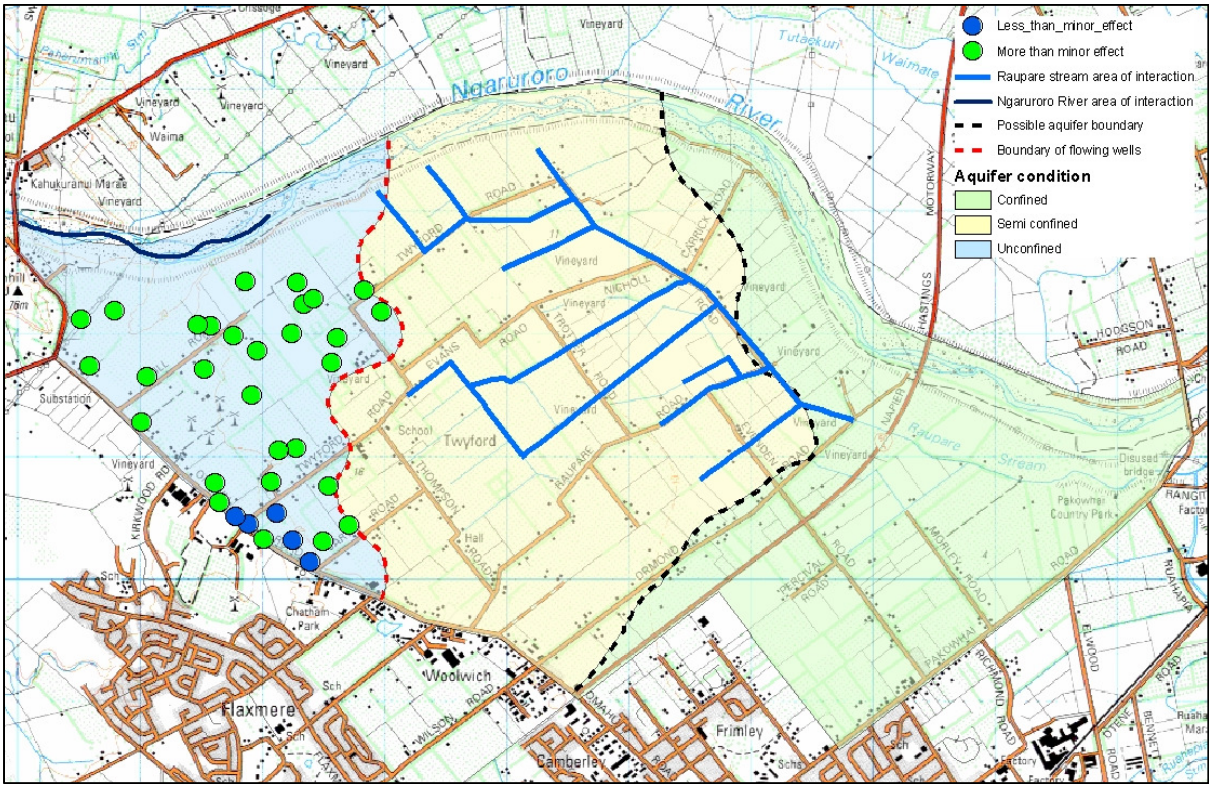


Figure 19: Ngaruroro River – Results of stream depleting assessment.

5.8.2 Area 2 results

Area 2 represents a partially penetrating stream in an aquitard with pumping from an underlying leaky aquifer as illustrated in Figure 18. The potential application of an analytical solution such as Hunt (2003), which accounts for semi-confined conditions, could not be applied because estimates of the aquitard were unavailable. As such the potential stream depletion effects in the Raupare Stream from individual bores in this area have not been estimated.

However, the analysis outlined in Section 5.4.2 clearly shows that discharge in the Raupare Stream (and hence cumulative stream depletion effects) are closely related to groundwater levels in the semi-confined area. As discharge in the Raupare Stream has been identified as one of the main criteria for groundwater management in the Twyford Consent Area, all groundwater takes in Area 2 (the semi-confined zone) are considered to contribute to the effect on surface flow which, as illustrated in Figure 13, appears to have declined steadily over the past 30 years. Therefore, as further discussed in Section 9, it is recommended that the relationship between groundwater levels and stream discharge be utilised as the basis for management of all groundwater takes in the semi-confined area to manage cumulative effects on discharge in Raupare Stream.

6.0 WELL INTERFERENCE ASSESSMENT

Abstraction of groundwater results in a local water level decline in the aquifer surrounding a well. This reduction in groundwater level occurs over a roughly cone-shaped area (termed the *cone of depression*) centred on the abstraction bore. The size and extent of the cone of depression resulting from an individual groundwater take is largely determined by the rate of groundwater abstraction and the hydraulic properties of the aquifer.

For an equivalent abstraction rate, the magnitude and extent of drawdown resulting from groundwater abstraction is dependent on the permeability and storage characteristics of the source aquifer. For example, where aquifer permeability (and/or storativity) is low, the magnitude of drawdown may be relatively large but the cone of depression will be restricted to the area immediately surrounding the pumped bore. In contrast, where aquifer permeability is high, the overall magnitude of drawdown will be less but the cone of depression may extend over a relatively wide area.

Well interference is the term used to describe the effect when the respective cones of depression formed around neighbouring wells intersect. In this case the resulting drawdown in groundwater levels will be the sum of drawdown from the individual abstraction wells. As shown in Figure 20, the drawdown resulting from adjacent abstraction wells has the potential to adversely impact on the yield available from other wells in the surrounding area if they happen to be screened near the top of the water bearing layer. In the case of the Twyford Consent Area, the cumulative interference effect is the combined drawdown resulting from the simultaneous abstraction of all proposed groundwater takes in the area.

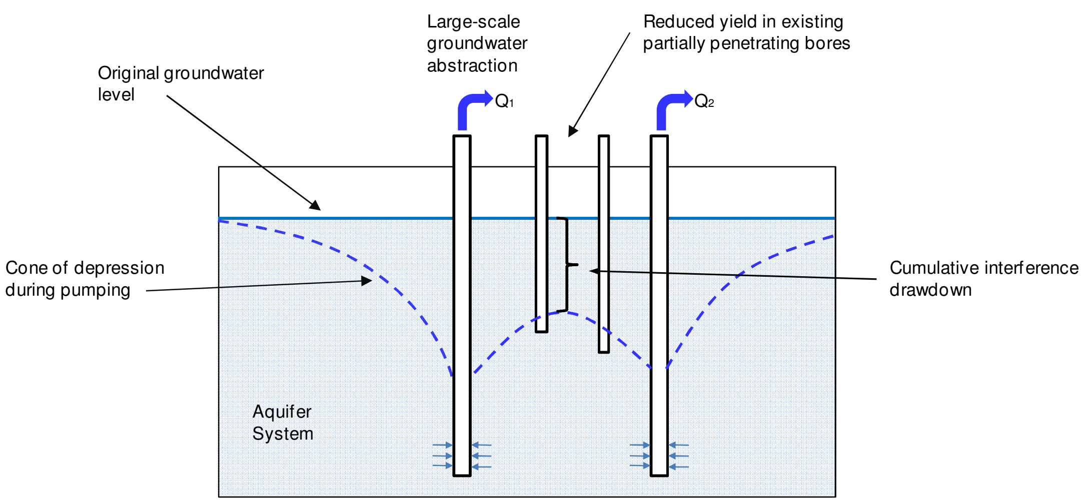


Figure 20: Schematic illustration of interference drawdown resulting in a decline in yield from neighbouring wells.

Policy 77(c) of the HBRC Regional Resource Management Plan [1] seeks to manage potential interference effects resulting from groundwater abstraction and specifies that the HBRC will:

Manage the groundwater resource in such a manner that efficient groundwater takes are not disadvantaged by new takes.

The plan provides further definition of efficient groundwater takes by way of a footnote to Policy 77(c) which states:

For the purposes of this Plan "efficient taking" of groundwater means abstraction by a bore which penetrates the aquifer from which water is being drawn at a sufficient depth to enable water to be drawn all year (i.e. the bore depth is below the range of seasonal fluctuations in groundwater level), with the bore being adequately maintained, of sufficient diameter and screened to minimise drawdown, with a pump capable of drawing water from the base of the bore to the land surface.

For this assessment the intent of Policy 77(c) is interpreted to be that groundwater abstraction will be managed to ensure that the cumulative drawdown resulting from groundwater abstraction will not result in a decline in yield in any bore which is screened below the extent of seasonal water level variation and which has a reasonable well efficiency (considered in terms of drawdown in the pumped bore per unit abstraction rate).

6.1 Background water levels

The Hawke's Bay Regional Council maintains 5 groundwater level monitoring sites in the Twyford Consent Area. Figure 21 shows a plot of water levels recorded at Well No's 7980, 15006 and 917 which are located in the unconfined, semi-confined and confined areas respectively. The data indicates the typical magnitude of seasonal water level variation increases from approximately 1.0 metres in the unconfined area, to 1.5 metres in the semi-confined area and 2.0 metres in the confined area. This variation represents seasonal fluctuations in aquifer water budget plus the cumulative drawdown resulting from existing groundwater abstraction. This seasonal variation is applied in the calculation of potential interference drawdown.

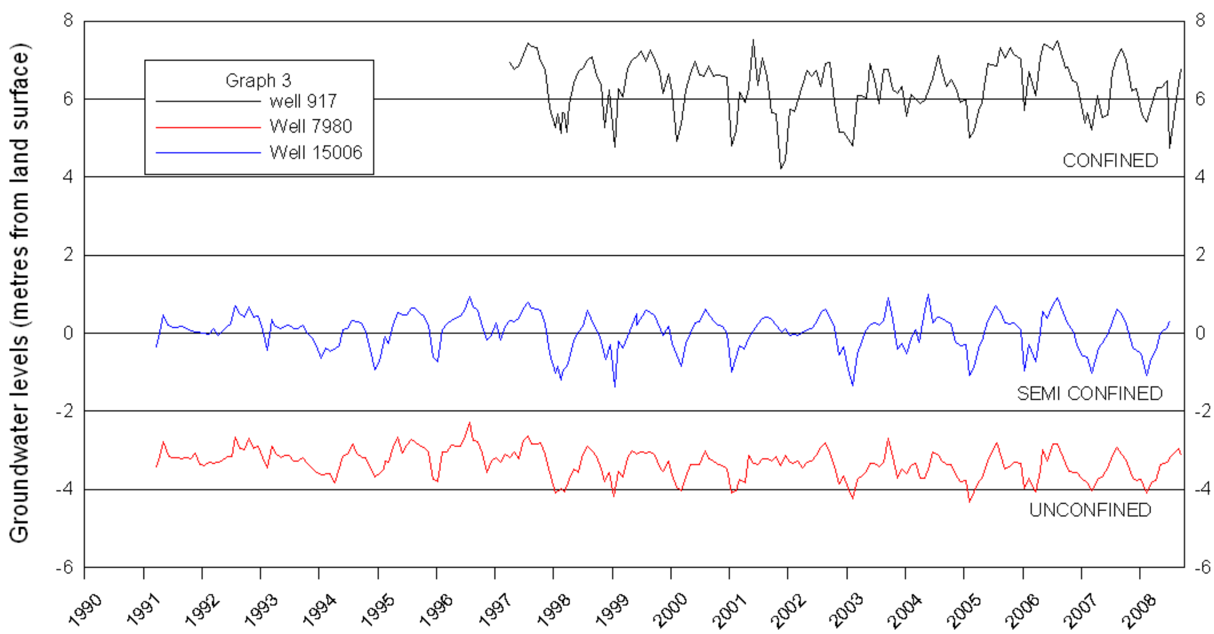


Figure 21: Representative groundwater levels in the unconfined (7980), semi-confined (15006) and confined (917) areas.

6.2 Quantifying well interference effects

In the absence of a numerical model capable of simulating the cumulative drawdown across the entire Twyford Consent Area, potential interference effects resulting from the proposed abstraction were calculated using the Multiwel programme (Scott, 2005 [10]). This programme enables calculation of the cumulative drawdown effects from multiple abstraction wells using the '*ideal* *confined*' aquifer function (Theis, 1935 [11]) or '*leaky artesian*' function with no release of water from storage in the aquitard (Hantush and Jacob, 1955 [12]).

As described in section 4.2, the hydrogeological setting in the Twyford Consent Area changes from unconfined conditions near Fernhill to more fully confined conditions to the east. One limitation of the Multiwel programme is that the required inputs include a single set of hydraulic parameters (transmissivity, storativity +/- leakage) which are applied uniformly to all abstraction wells. Given the change in aquifer hydraulic properties across the area (particularly aquifer storage characteristics) the simulation of the cumulative effects of the proposed abstraction in the Twyford Consent Area cannot be run as a single scenario.

As a result, analysis of potential interference effects was undertaken separately on individual 'clusters' of abstraction having the highest cumulative abstraction rate. These areas were taken to represent the potential 'worst-case' areas for interference drawdown. The observed seasonal water level variation (comprising seasonal variation plus current cumulative drawdown effects) was then added to the calculated interference drawdown in each 'cluster' to derive an estimate of the total cumulative drawdown resulting from the proposed abstraction.

In order to identify the areas with the highest density of groundwater abstraction, data detailing all proposed abstraction provided by the Council was modified to derive a data set for the assessment of potential interference effects by:

1. Aggregating the total instantaneous, weekly, monthly and annual abstraction rates where more than one consent was associated with a single bore; and,

2. Assigning the entire consented volume to the bore most likely to cause the largest interference drawdown (based on the distance to and abstraction rate from surrounding wells) where a single consent was split between two or more wells.

A listing of the well location and abstraction rate data used for well interference calculations is provided in Appendix B. Frost protection takes were removed from the initial calculation of interference drawdown given that these takes are typically of short duration (<8 hours), occur on an infrequent basis and generally do not occur during the period when a majority of abstraction for horticultural irrigation is occurring.

The abstraction data were then gridded using ArcGIS spatial analyst software to derive a plot of the relative density of abstraction across the Twyford Consent Area. This analysis, presented in Figure 22, shows the relative density of abstraction (volume/unit area) and allows identification of the five areas marked as having the highest density of wells and therefore the greatest potential for interference effects to occur.

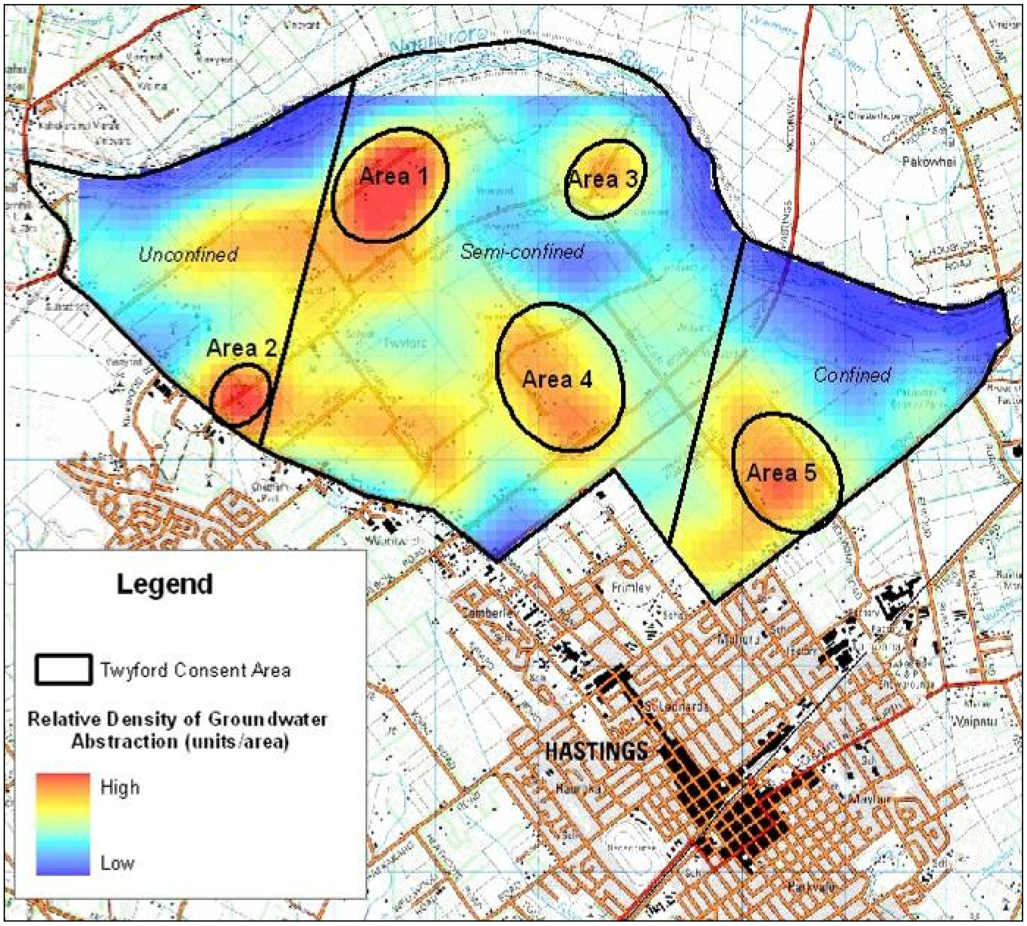


Figure 22: Areas of highest relative abstraction.

6.2.1 Abstraction scenarios

Abstraction rates for the proposed groundwater takes in the five areas of highest abstraction were entered into the Multiwel programme and interference drawdown was calculated using the Theis function using the representative aquifer parameters listed in Section 4.3. Two abstraction scenarios were run for each area representing:

1. Average seasonal abstraction - abstraction from all wells at the average seasonal rate (i.e. the weekly allocation converted to L/s) for a continuous period of 120 days; and,

2. Maximum abstraction - abstraction from all wells at the maximum rate of take. The duration of abstraction for the maximum rate scenario was assigned as the duration of maximum rate abstraction permitted by the weekly allocation (i.e. weekly allocation/maximum rate) averaged across all wells in the assessment area.

The Theis well function was utilised to calculate potential interference drawdown on the basis that it would provide a conservative estimate of drawdown resulting from abstraction. The calculated interference drawdowns are therefore likely to over-estimate the actual effects. This is because the calculation does not account for the hydraulic connection with the Ngaruroro River downstream of Fernhill. Cumulative drawdown in groundwater levels is likely to be in part balanced by additional flow loss from the river and vertical leakage in the semi-confined zone either due to hydraulic connection to overlying water-bearing strata or by way of a reduction in spring-fed stream discharge.

6.2.2 Calculation of available drawdown

In order to evaluate the magnitude of the calculated interference drawdown in terms of RRMP Policy 77 the available drawdown was estimated (where possible) for each bore in the respective assessment areas utilising data from Council's WellStor database. The available drawdown was estimated as the distance between the recorded static water level and the top of the screened interval in each bore. Where no bore construction and/or static water level information were available the bore was assumed to be screened over the lower 3 metres (i.e. total bore depth - 3 metres) and the static water level assumed to be equal to the median value recorded for other wells in the area. No estimate of available drawdown was possible for those wells which do not have depth information in the WellStor database.

6.2.3 Calculation of cumulative drawdown

For each of the abstraction areas analysed the cumulative interference drawdown was calculated to be the sum of the cumulative drawdown resulting from localised abstraction (as estimated by application of Multiwel) plus the typical seasonal groundwater level variation. As previously noted, seasonal groundwater level fluctuations are relatively uniform across the Twyford Consent Area (reflecting the high aquifer permeability) increasing in magnitude from approximately 1.0 metre in the unconfined area to 2.0 metres in the confined area. This variation is considered to represent seasonal variation in aquifer water budget plus the cumulative (i.e. regional) effect of existing abstraction with the spatial variation reflecting the difference in aquifer storage properties across the unconfined to confined aquifer transition.

The calculated cumulative drawdown was then compared to the available drawdown in each bore to derive an estimate of the relative magnitude of cumulative drawdown in each abstraction bore. Given that the interference assessment was undertaken on those areas with the highest density of groundwater abstraction, the resulting assessment of cumulative drawdown is considered to represent a 'worst case' for the Twyford Consent Area as a whole.

Estimation of potential cumulative interference effects was not extended to include potential effects on existing domestic and stock wells (i.e. permitted takes that do not require resource consent) due to the limited information available to determine location and well construction information for these wells. Again it was assumed that the magnitude of interference drawdown calculated for the highest density abstraction areas would be representative of the likely impacts in all other wells provided they were constructed in a manner consistent with Policy 77 (i.e. the bore is screened at a depth below the typical range of seasonal groundwater level variation).

6.3 Well interference assessment results

6.3.1 Area 1: Twyford Road (north)

Area 1 is located along the northern section of Twyford Road which runs roughly north-east south-west, approximately 1 kilometre south of the Ngaruroro River in the area classified as being semi-confined. Current applications for resource consent for groundwater abstraction in this area include a total of 21 separate consent applications seeking:

- A combined maximum abstraction rate of 435 L/s (with an average duration of abstraction of 2.6 days permitted by respective weekly allocations);

- A combined weekly allocation of 70,799 m^3 (equivalent to an average continuous abstraction rate of 117 L/s); and
- A total combined seasonal allocation of 1,107,905 m^3.

Table 3 provides a listing of relevant details for wells in this area held in the WellStor database including location, depth, screen depth, static water level as well as estimated available drawdown.

Table 3: Construction details for wells in Area 1

Well No.	Easting	Northing	Depth (m)	Screen Depth (m bgl)	Static Water Level (m bmp)	Estimated Available Drawdown[1] (m)
-430	2836251	6171857	40.5	39.6	-	38
507	2836534	6172002	18.5	15.6	-0.8	14
576	2837157	6172438	22.3	-	-	18
620	2836748	6172811	32.3	-	-	28
972	2835997	6172503	15.9	12.8	-0.1	11
1008	2836607	6172126	17.7	13.1	+0.8	13
1097	2836154	6172291	14.0	13.5	-1.0	11
1223	2836205	6172842	29.2	-	+0.2	25
1521	2836449	6172557	29.0	-	-0.4	25
1535	2835829	6172368	32.2	30.2	-0.9	28
1607	2836557	6173108	27.2	-	-	23
1738	2836900	6173073	40.2	34	+0.9	34
1777	2836680	6171830	33.0	27.0	+0.2	26
1937	2837002	6171823	36.0	-	-	32
2105	2836586	6172897	31.1	29.1	-	28
2141	2835967	6172193	42.0	36	-0.7	34
2240	2836641	6172715	31.8	29.8	+0.2	29
3127	2836791	6172847	40.8	38.4	+0.2	37
3758	2836858	6172467	-	-	-	-
4450	2836431	6172832	-	-	-	-
4898	2836525	6171787	28.2	25.1	0.0	24

[1] Where no data available assumes 3 metre screen and static water level of -1.0 m

Figure 23 and Figure 24 show contour plots of the localised interference drawdown calculated using Multiwel for the average and maximum rate abstraction scenarios respectively.

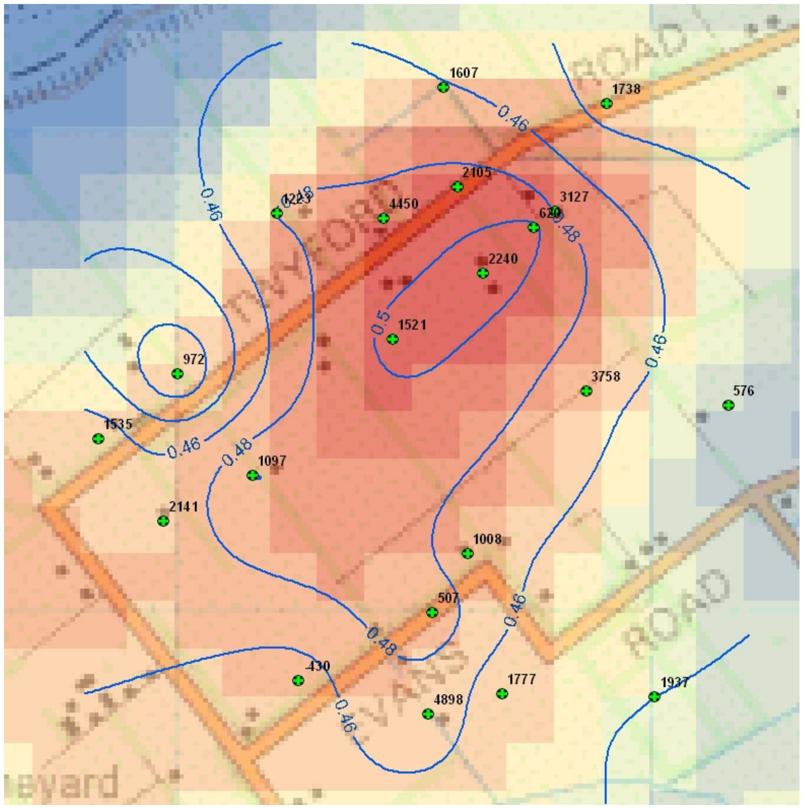


Figure 23: Calculated drawdown (m) for the Area 1 average rate abstraction scenario

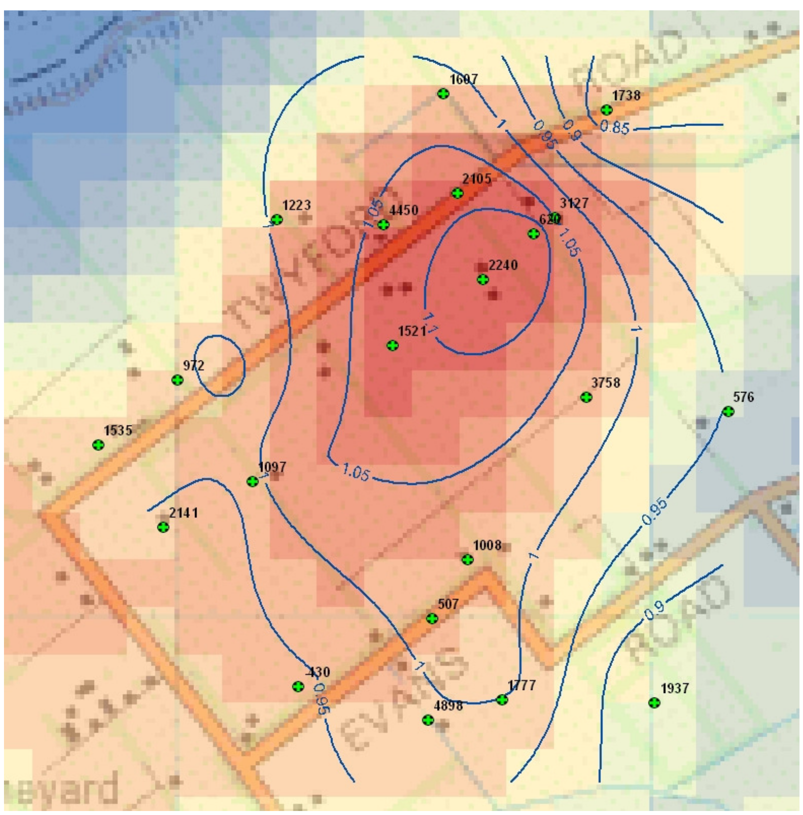


Figure 24: Calculated drawdown (m) for the Area 1 maximum rate abstraction scenario

Results of the well interference calculations indicate a maximum drawdown of approximately 0.5 metres for the average abstraction scenario and 1.1 metres for the maximum abstraction scenario. It is noted that the relatively limited magnitude of the calculated drawdown (given the significant volume of groundwater abstraction) reflects the highly permeable nature of the semi-confined aquifer in this area.

Table 4 provides a listing of the respective abstraction rates and calculated cumulative interference effect for each bore in Area 1. The calculated drawdown includes the estimated seasonal water level variation of 1.5 metres. Overall, the calculation shows that the magnitude of interference drawdown under both the average and maximum abstraction rate scenarios is generally less than 20 percent of the available drawdown in wells in Area 1.

Table 4: Calculated cumulative interference drawdown for wells in Area 1.

Well No.	Weekly Allocation (m^3)	Average abstraction Rate (L/s)	Maximum Abstraction Rate (L/s)	Duration (days)	Available Drawdown (m)	Average Abstraction Rate		Maximum Abstraction Rate[2]	
						Drawdown (m)[1]	Percentage of available drawdown	Drawdown (m)[1]	Percentage of available drawdown
-430	4,094	6.8	20	2.4	38	1.95	5.1	2.45	6.4
507	1,300	2.1	25	0.6	14	1.99	14.2	2.52	18.0
576	2,600	4.3	15	2.0	18	1.95	10.8	2.46	13.7
620	1,216	2.0	15	4.0	28	2.00	7.1	2.63	9.4
972	13,000	21.5	38	4.0	11	1.90	17.3	2.43	22.1
1008	4,496	7.4	30	1.7	13	1.97	15.2	2.52	19.4
1097	1,771	2.9	18	1.1	11	2.00	18.2	2.55	23.2
1223	2,470	4.1	7.6	3.8	25	1.98	7.9	2.52	10.1
1521	1,625	2.7	14	1.3	25	2.01	8.0	2.59	10.4
1535	2,600	4.3	5	6.0	28	1.98	7.1	2.50	8.9
1607	3,250	5.4	6.5	5.8	23	1.97	8.6	2.52	11.0
1738	5,450	9.0	65	1.0	34	1.93	5.7	2.33	6.9
1777	4,690	7.8	8.8	6.2	26	1.94	7.5	2.51	9.7
1937	2,663	4.4	33	0.9	32	1.94	6.1	2.36	7.4
2105	2,770	4.6	13	2.5	28	1.99	7.1	2.59	9.3
2141	3,439	5.7	37	1.1	34	1.97	5.8	2.42	7.1
2240	1,300	2.1	5.6	2.7	29	2.01	6.9	2.65	9.1
3127	3,250	5.4	21.15	1.2	37	1.98	5.4	2.54	6.9
3758	4,180	6.9	25	1.9	-	1.97	-	2.53	
4450	3,256	5.4	12.6	3.0	-	1.98	-	2.57	
4898	1,379	2.3	9.2	1.7	24	1.97	8.2	2.50	10.4

[1] Assumes 1.5 m seasonal water level variation plus calculated drawdown

[2] Assumes maximum rate abstraction from all wells for a continuous period of 2.5 days

6.3.2 Area 2: Twyford Road (south)

Area 2 is located at the southern end of Twyford Road immediately north of Omahu Road in the unconfined area. Current applications for resource consent for groundwater abstraction in this area include a total of 15 applications seeking:

- A combined maximum abstraction rate of 257 L/s (with an average duration of abstraction of 1.5 days permitted by respective weekly allocations);
- A combined weekly allocation of 28,907 m^3 (equivalent to an average continuous abstraction rate of 48 L/s); and
- A total combined seasonal allocation of 423,105 m^3.

Table 5 provides a listing of relevant details for wells in this area including location, depth, screen depth, static water level and estimated available drawdown.

Table 5: Construction details for wells in Area 2.

Well No.	Easting	Northing	Depth (m)	Screen Depth (m bgl)	Static Water Level (m bmp)	Estimated Available Drawdown[1] (m)
-415	2834640	6170635	-	-	-	-
-142	2835240	6170323	-	-	-	-
971	2834774	6170522	27.9	21.9	-5.7	15
1181	2834603	6170794	28.5	22.5	-6.6	15
1219	2835704	6170443	18.5	-	-4.8	10
1294	2834876	6170457	-	-	-	-
1348	2835889	6170363	23.4	15.2	-1.8	12
1579	2835060	6170802	22.6	15.5	-4.3	10
1635	2835109	6170544	26.1	20.0	-5.1	14
1798	2835266	6171076	24.1	18.1	-2.7	14
4066	2835005	6170336	21.0	16.7	-	12
6503	2835488	6170316	21.3	-	-4.6	15
8148	2835531	6170767	25.9	-	-1.2	21
8375	2835379	6170145	19.5	-	-5.5	10
8478	2835128	6171061	23.2	-	-1.8	17.4

[1] Where no data available assumes 3 metre screen and static water level of -5.0 m

Figure 25 and Figure 26 show contour plots of the localised interference drawdown calculated using Multiwel for the average and maximum rate abstraction scenarios respectively. Both plots indicate a maximum drawdown of approximately 0.1 metres in response to abstraction. The relatively limited drawdown in this area reflects the high aquifer permeability (Transmissivity = 15,000 m^2/day) and the assumed unconfined nature of the aquifer in this area (Specific yield = 0.1).

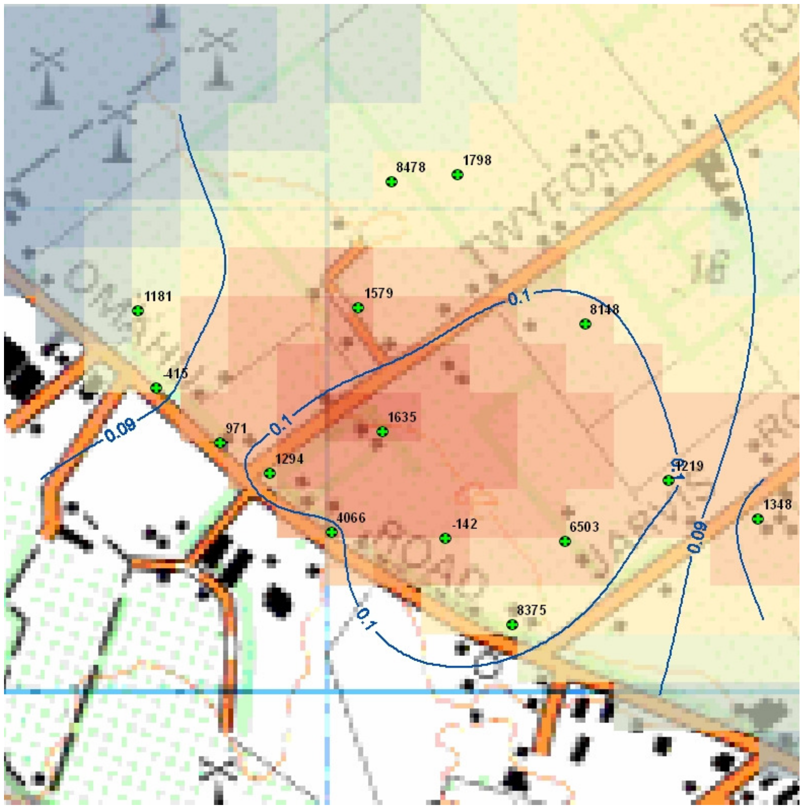


Figure 25: Calculated drawdown (m) for the Area 2 average rate abstraction scenario

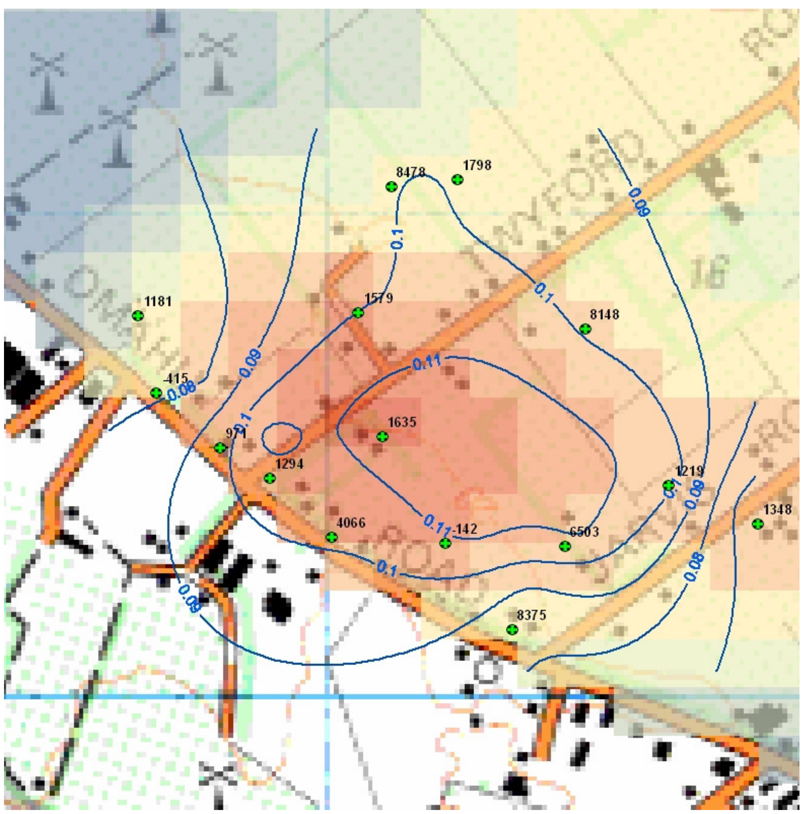


Figure 26: Calculated drawdown (m) for the Area 2 maximum rate abstraction rate scenario

Table 6 provides a listing of the respective abstraction rates and calculated cumulative interference effect for each bore in Area 2 including the calculated seasonal groundwater level variation of 1.0 metres. Overall, the calculation shows that the magnitude of interference drawdown under both the average and maximum abstraction rate scenarios is slightly over 1 metre and generally less than 10 percent of the available drawdown.

Table 6: Calculated cumulative interference drawdown for wells in Area 2

Well No.	Weekly Allocation (m^3)	Average abstraction Rate (L/s)	Maximum Abstraction Rate (L/s)	Duration (days)	Available Drawdown (m)	Average Abstraction Rate		Maximum Abstraction Rate[2]	
						Drawdown (m)[1]	Percentage of available drawdown	Drawdown (m)[1]	Percentage of available drawdown
-415	1,300	2.1	19	0.8	-	1.11	-	1.08	-
-142	919	1.5	5.5	1.9	-	1.09	-	1.11	-
971	216	0.4	2.4	1.0	15	1.10	7.3	1.11	7.4
1181	1,060	1.8	19	0.6	15	1.09	7.3	1.07	7.1
1219	3,457	5.7	25	1.6	10	1.10	11.0	1.11	11.1
1294	459	0.8	6	0.9	-	1.10	-	1.11	-
1348	7,683	12.7	40	2.2	12	1.07	8.9	1.06	8.8
1579	3,900	6.4	36.1	1.3	10	1.09	10.9	1.10	11.0
1635	734	1.2	18	0.5	14	1.11	7.9	1.12	8.0
1798	2,112.5	3.5	18	1.4	14	1.09	7.8	1.10	7.9
4066	1,071	1.8	4	3.1	12	1.10	9.2	1.10	9.2
6503	1,823	3.0	13	1.6	15	1.11	7.4	1.11	7.4
8148	1,965	3.2	18.9	3.2	21	1.10	5.2	1.10	5.2
8375	983	1.6	13	0.9	10	1.10	11.0	1.08	10.8
8478	1,224	2.0	18.9	0.8	17.4	1.10	6.3	1.10	6.3

[1] Assumes 1.0 m seasonal water level variation plus calculated drawdown

[2] Assumes maximum rate abstraction from all wells for a continuous period of 1.5 days

6.3.3 Area 3: Carrick Road

Area 3 is located along Carrick Road which runs from Nichols Road toward the Ngaruroro River in the semi-confined area. Current applications for resource consent for groundwater abstraction in this area include a total of 12 applications seeking:

- A combined maximum abstraction rate of 307 L/s (with an average duration of abstraction of 1.9 days permitted by respective weekly allocations);
- A combined weekly allocation of 45,092 m^3 (equivalent to an average continuous abstraction rate of 75 L/s); and
- A total combined seasonal allocation of 714,661 m^3.

Table 7 provides a listing of relevant details for wells in this area including location, depth, screen depth, static water level and estimated available drawdown.

Table 7: Construction details for wells in Area 3.

Well No.	Easting	Northing	Depth (m)	Screen Depth (m bgl)	Static Water Level (m bmp)	Estimated Available Drawdown[1] (m)
-999	2338650	6172542	-	-	-	-
-135	2838404	6172759	-	-	-	-
694	2839019	6172653	35.8	-	+1.2	34
1093	2838131	6172661	32.9	-	+6.0	35
1490	2838836	6173217	35.8	33.8	+2.6	36
1601	2838753	6172739	33.3	-	+3.0	33
1711	2838199	6173373	46.6	45.7	+1.5	47
2328	2838792	6173039	45.1	43.1	+1.5	45
2444	2838468	6173002	36.8	33.6	+3.6	38
2980	2838317	6172390	42.1	40.6	+3.0	44
5915	2839031	6172498	-	-	-	-

[1] Where no data available assumes 3 metre screen and static water level of +3.0 m

Figure 27 and Figure 28 show contour plots of the localised interference drawdown calculated using Multiwel for the average and maximum rate abstraction scenarios in Area 3 respectively. The data indicate a maximum drawdown of approximately 0.4 metres for the average abstraction scenario and 1.1 metres for the maximum abstraction scenario.

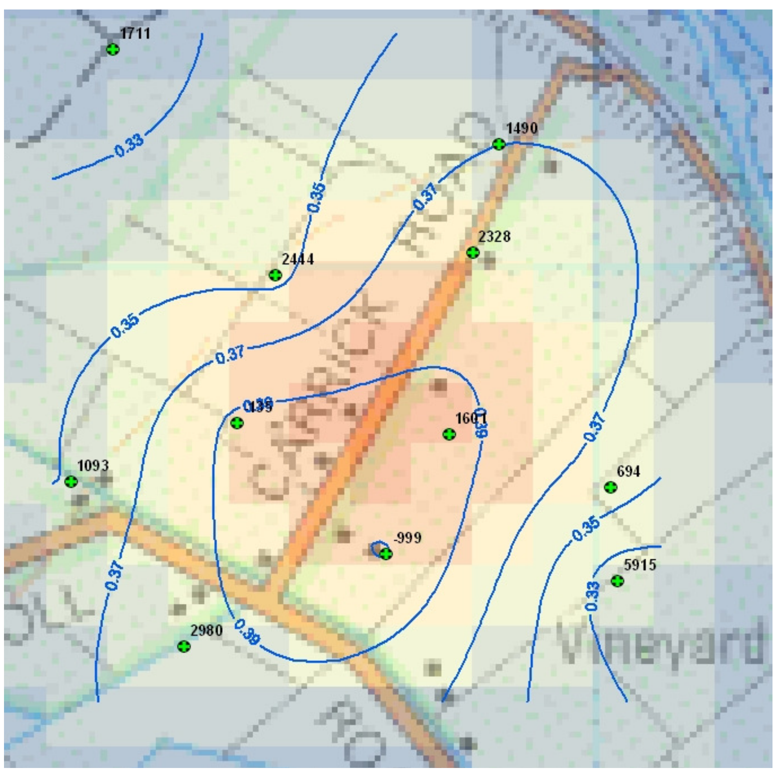


Figure 27: Calculated drawdown (m) resulting from the Area 3 average rate abstraction scenario

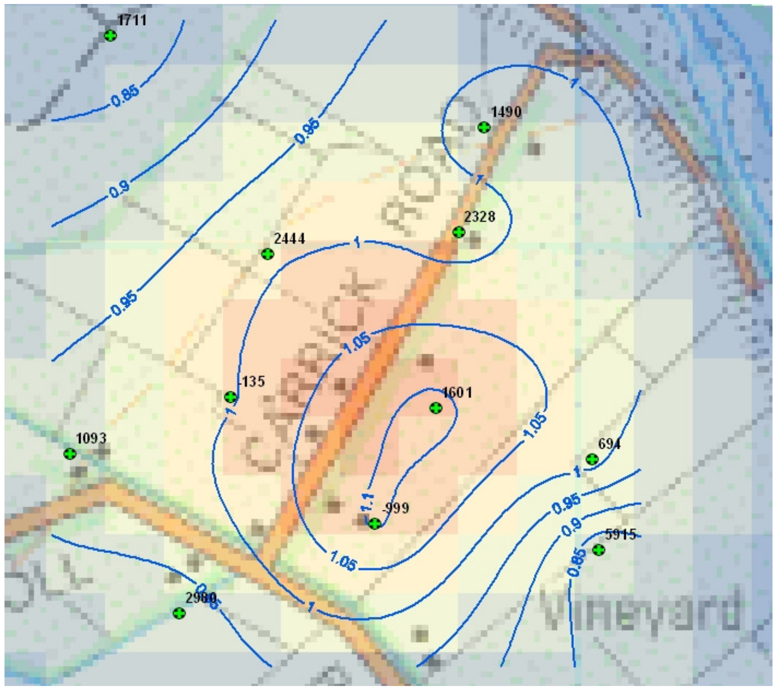


Figure 28: Calculated drawdown (m) resulting from the Area 3 maximum rate abstraction scenario

Table 8 provides a listing of the respective abstraction rates and calculated cumulative interference effect for each bore in Area 3 including the calculated seasonal groundwater level variation of 1.5 metres. Overall, the calculation shows that the magnitude of interference drawdown under both the average and maximum abstraction rate scenarios between 1.9 and 2.6 metres which is less than 10 percent of the available drawdown.

Table 8: Calculated cumulative interference drawdown for wells in Area 3.

Well No.	Weekly Allocation (m^3)	Average abstraction Rate (L/s)	Maximum Abstraction Rate (L/s)	Duration (days)	Available Drawdown (m)	Average Abstraction Rate		Maximum Abstraction Rate[2]	
						Drawdown (m)[1]	Percentage of available drawdown	Drawdown (m)[1]	Percentage of available drawdown
-999	130	0.2	3.6	0.4	-	1.91	-	2.61	-
-135	2,000	3.3	32	0.7	-	1.90	-	2.50	-
694	5,794	9.6	25	2.7	34	1.86	5.5	2.52	7.4
1093	4,225	7.0	19	2.6	35	1.85	5.3	2.48	7.1
1490	3,525	5.8	11	3.7	36	1.87	5.2	2.52	7.0
1601	2,600	4.3	7.5	4.0	33	1.90	5.8	2.61	7.9
1711	6,720	11.1	50	1.6	47	1.82	3.9	2.31	4.9
2328	3,250	5.4	32	1.2	45	1.89	4.2	2.48	5.5
2444	7,001	11.6	32	2.5	38	1.85	4.9	2.49	6.6
2980	699	1.2	30	0.3	44	1.88	4.3	2.42	5.5
5915	9,148	15.1	65	1.6	-	1.82	-	2.31	-

[1] Assumes 1.5 m seasonal water level variation plus calculated drawdown

[2] Assumes maximum rate abstraction from all wells for a continuous period of 1.9 days

6.3.4 Area 4: McNab Road

Area 4 is located adjacent to McNab Road between Raupare Road and Ormond Road in the semi-confined area. Current applications for resource consent for groundwater abstraction in this area include a total of 15 applications seeking:

- A combined maximum abstraction rate of 355 L/s (with an average duration of abstraction of 1.3 days permitted by respective weekly allocations);
- A combined weekly allocation of 36,829 m^3 (equivalent to an average continuous abstraction rate of 61 L/s); and
- A total combined seasonal allocation of 563,370 m^3.

Table 9 provides a listing of relevant details for wells in this area including location, depth, screen depth, static water level and estimated available drawdown.

Table 9: Construction details for wells in Area 4.

Well No.	Easting	Northing	Depth (m)	Screen Depth (m bgl)	Static Water Level (m bmp)	Estimated Available Drawdown[1] (m)
-652	2838305	6170812	-	-	-	-
-441	2838631	6170566	-	-	-	-
-439	2837889	6170413	-	-	-	-
-163	2838486	6170481	-	-	-	-
129	2838100	6171200	37.8	37.8	+4.6	42
571	2838200	6170400	32.8	-	+1.8	32
856	2838000	6171500	32.5	-	+4.4	34
1451	2837600	6171300	34.1	-	+3.0	34
1674	2838641	6170055	38.0	32.0	+2.0	34
1712	2837500	6171000	36.3	35.1	+2.4	37
1835	2837800	6170600	18.3	12.2	-1.5	11
2946	2837934	6171018	36.0	33.5	+3.0	34
3050	2838380	6169988	39.7	33.7	+3.5	37
4229	2838773	6170337	39.3	34.8	+0.6	35
9056	2838300	6170300	27.4	27.4	-	-
9059	2838082	6170818	36.0	36.0	+3.7	40
15335	2837595	6170433	-	-	-	-

[1] Where no data available assumes 3 metre screen and static water level of +3.0 m

Figure 29 and Figure 30 show contour plots of the localised interference drawdown calculated using Multiwel for the average and maximum rate abstraction scenarios in Area 4 respectively. The data indicate a maximum drawdown of approximately 0.25 metres for the average abstraction scenario and 0.8 metres for the maximum abstraction scenario.

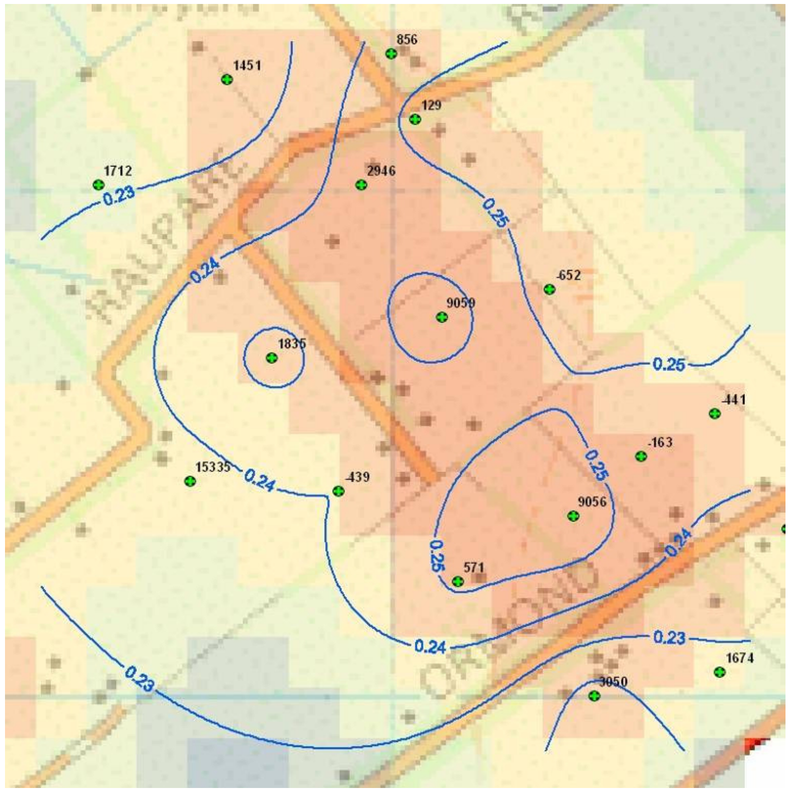


Figure 29: Calculated drawdown (m) resulting from the Area 4 average rate abstraction scenario

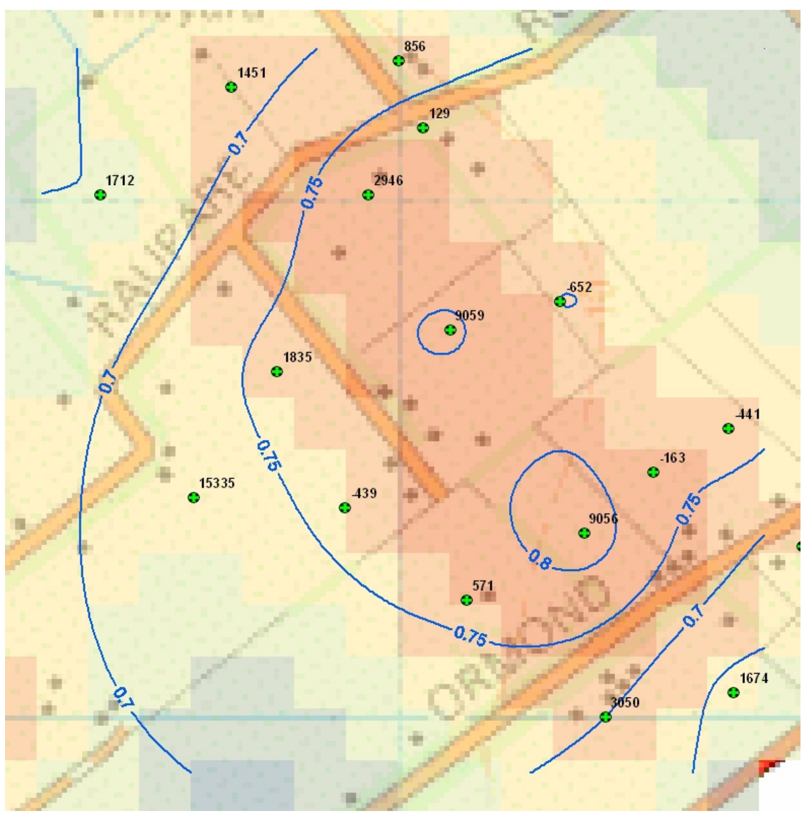


Figure 30: Calculated drawdown (m) resulting from the Area 4 maximum rate abstraction scenario

Table 10 provides a listing of the respective abstraction rates and calculated cumulative interference effect for each bore in Area 4 including the calculated seasonal groundwater level variation of 1.5 metres. Overall, the calculation shows that the magnitude of interference drawdown under the average and maximum abstraction rate scenarios is likely to be between 1.8 and 2.3 metres. With a single exception (Well No. 1835) the calculated interference effect is less than 10 percent of the available drawdown in wells in Area 4.

Table 10: Calculated cumulative interference drawdown for wells in Area 4.

Well No.	Weekly Allocation (m^3)	Average abstraction Rate (L/s)	Maximum Abstraction Rate (L/s)	Duration (days)	Available Drawdown (m)	Average Abstraction Rate		Maximum Abstraction Rate[2]	
						Drawdown (m)[1]	Percentage of available drawdown	Drawdown (m)[1]	Percentage of available drawdown
-652	1,421	2.3	13	1.3	-	1.75	-	2.30	-
-441	655	1.1	4	1.9	-	1.75	-	2.30	-
-439	2,860	4.7	25	1.3	-	1.74	-	2.26	-
-163	2,377	3.9	20	1.4	-	1.74	-	2.26	-
129	1,243	2.1	13	1.1	42	1.75	4.2	2.28	5.4
571	1,168	1.9	19	0.7	32	1.75	5.5	2.26	7.1
856	1,474	2.4	20	0.9	34	1.74	5.1	2.21	6.5
1451	4,000	6.6	25	1.9	34	1.72	5.1	2.18	6.4
1674	2,293	3.8	38	0.7	34	1.73	5.1	2.13	6.3
1712	2,260	3.7	25	1.0	37	1.79	4.8	2.15	5.8
1835	1,400	2.3	25	0.6	11	1.75	15.9	2.26	20.5
2946	2,925	4.8	20	1.7	34	1.74	5.1	2.28	6.7
3050	4,193	6.9	22	2.2	37	1.72	4.6	2.20	5.9
4229	1,383	2.3	25	0.6	35	1.74	5.0	2.17	6.2
9056	689	1.1	3.6	2.2	-	1.76	-	2.33	-
9059	4,380	7.2	42	1.2	40	1.73	4.3	2.24	5.6
15335	2,108	3.5	16	1.5	-	1.74	-	2.22	-

[1] Assumes 1.5 m seasonal water level variation plus calculated drawdown

[2] Assumes maximum rate abstraction from all wells for a continuous period of 1.5 days

6.3.5 Area 5: Morley Road

Area 5 is located between Morley and Evenden Roads immediately west of Pakowhai Road in the confined aquifer area. Current applications for resource consent for groundwater abstraction in this area include a total of 19 applications seeking:

- A combined maximum abstraction rate of 322 L/s (with an average duration of abstraction of 1.3 days permitted by respective weekly allocations);
- A combined weekly allocation of 34,302 m^3 (equivalent to an average continuous abstraction rate of 57 L/s); and
- A total combined seasonal allocation of 663,067 m^3.

Table 11 provides a listing of relevant details for wells in this area including location, depth, screen depth, static water level and estimated available drawdown.

Table 11: Construction details for wells in Area 5

Well No.	Easting	Northing	Depth (m)	Screen Depth (m bgl)	Static Water Level (m bmp)	Estimated Available Drawdown[1] (m)
-428	2840290	6169720	-	-	-	-
-423	2839852	6169579	-	-	-	-
-420	2840829	6169602	-	-	-	-
-419	2840664	6169855	-	-	-	-
38	2840400	6169900	-	-	-	-
49	2840900	6169800	39.9	-	+4.0	41
152	2840000	6170200	36.6	-	+4.4	38
247	2840082	6169386	48.7	46.6	+4.0	48
297	2840200	6170100	38.7	-	+4.0	39
385	2839500	6170200	39.6	-	+5.5	42
495	2839900	6170400	39.0	-	+0.8	37
917	2840476	6170592	31.2	29.2	+6.0	35
1143	2840534	6169527	55.7	48.6	+5.0	53
1988	2840146	6170463	32.0	29.6	+1.3	31
2385	2840278	6169268	48.4	-	+3.3	48
2468	2840200	6170700	36.0	34.1	+4.0	38
2582	2840818	6170002	42.1	-	-	-
4291	2839470	6169826	40.6	-	+6.0	44
9058	2840144	6169925	44.5	-	+4.5	46

[1] Where no data available assumes 3 metre screen and static water level of +4.0 m

Figure 31 and Figure 32 show contour plots of the localised interference drawdown calculated using Multiwel for the average and maximum rate abstraction scenarios in Area 5 respectively. The data indicate a maximum drawdown of approximately 0.25 metres for the average abstraction scenario and 0.75 metres for the maximum abstraction rate scenario.

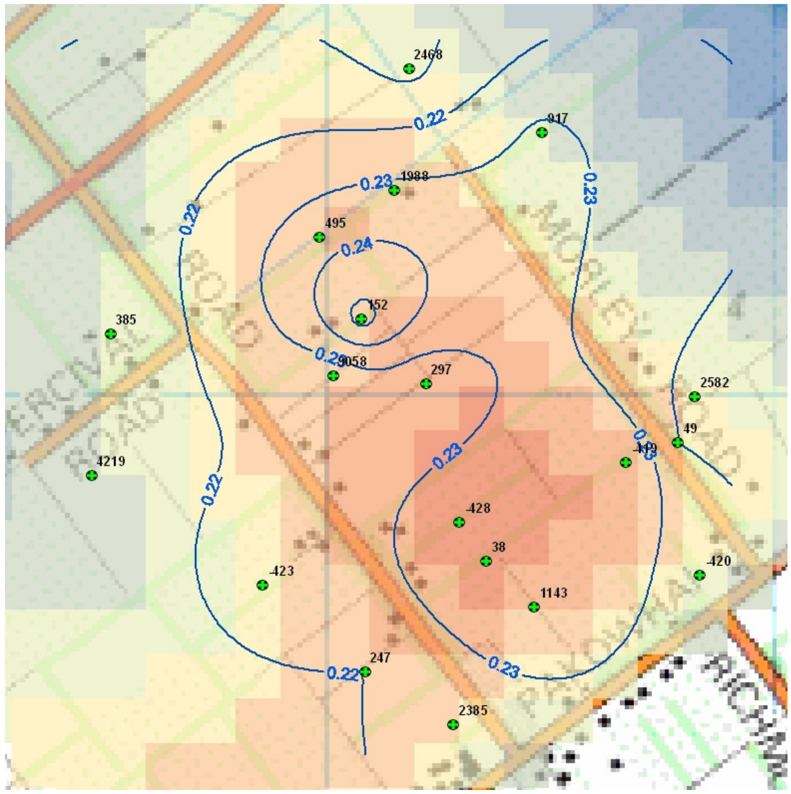


Figure 31: Calculated drawdown (m) resulting from the Area 5 average rate abstraction scenario

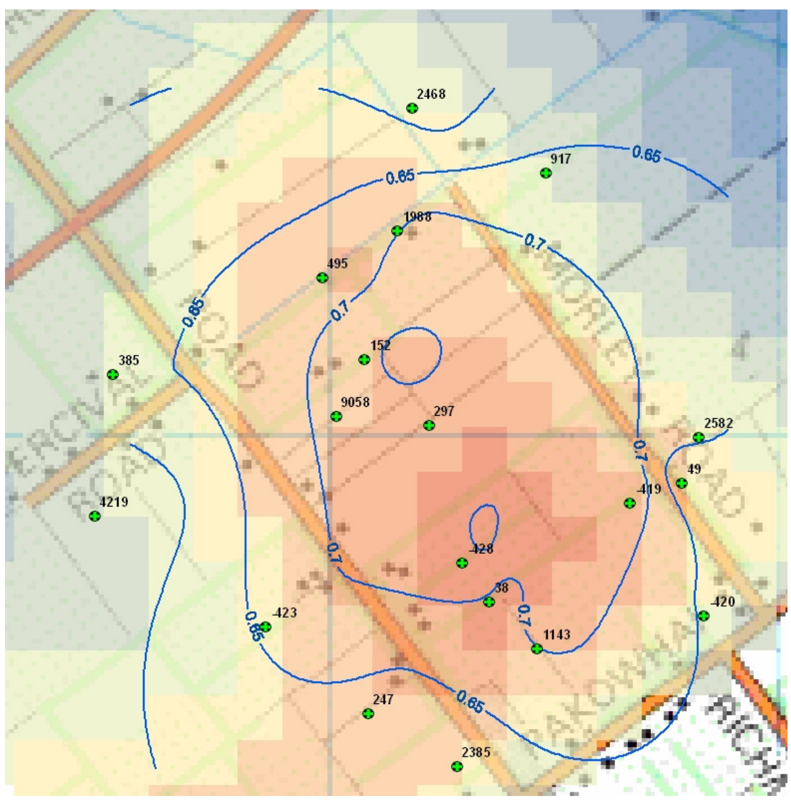


Figure 32: Calculated drawdown (m) resulting from the Area 5 maximum rate abstraction scenario

Table 12 provides a listing of the respective abstraction rates and calculated cumulative interference effect for each bore in Area 5 including the calculated seasonal groundwater level variation of 2.0 metres. Overall, the calculation shows that the magnitude of interference drawdown under the average and maximum abstraction rate scenarios is between 2.3 and 2.8 metres which is less than 10 percent of the available drawdown.

Table 12: Calculated cumulative interference drawdown for wells in Area 5.

Well No.	Weekly Allocation (m^3)	Average abstraction Rate (L/s)	Maximum Abstraction Rate (L/s)	Duration (days)	Available Drawdown (m)	Average Abstraction Rate		Maximum Abstraction Rate[2]	
						Drawdown (m)[1]	Percentage of available drawdown	Drawdown (m)[1]	Percentage of available drawdown
-428	1,418	2.3	13.9	1.2	-	2.24	-	2.74	-
-423	2,293	3.8	6.3	4.2	-	2.22	-	2.65	-
-420	36	0.1	2.5	0.2	-	2.23	-	2.69	-
-419	346	0.6	4	1.0	-	2.24	-	2.76	-
38	1,028	1.7	25	0.5	-	2.24	-	2.69	-
49	2,057	3.4	29.2	0.8	41	2.22	5.4	2.61	6.4
152	1,185	2.0	22.7	0.6	38	2.25	5.9	2.77	7.3
247	1,801	3.0	20	1.0	48	2.22	4.6	2.63	5.5
297	4,610	7.6	30	0.8	39	2.22	5.7	2.73	7.0
385	2,881	4.8	8	4.2	42	2.21	5.3	2.65	6.3
495	1,994	3.3	30	0.8	37	2.24	6.1	2.69	7.3
917	100	0.2	3	0.4	35	2.23	6.4	2.67	7.6
1143	218	0.4	5	0.5	53	2.24	4.2	2.82	5.3
1988	1,950	3.2	13.9	1.6	31	2.23	7.2	2.72	8.8
2385	520	0.9	10	0.6	48	2.22	4.6	2.64	5.5
2468	3,113	5.2	30	1.2	38	2.21	5.8	2.58	6.8
2582	2,275	3.8	11	2.4	-	2.22	-	2.67	-
4291	1,867	3.1	27	0.8	44	2.22	5.0	2.58	5.9
9058	4,610	7.6	30	1.8	46	2.22	4.8	2.73	5.9

[1] Assumes 2.0 m seasonal water level variation plus calculated drawdown

[2] Assumes maximum rate abstraction from all wells for a continuous period of 1.3 days

6.4 Frost Protection Takes

The Twyford groundwater consent renewal process includes applications for 31 frost protection takes located at the sites shown on Figure 33. These takes are assigned a maximum abstraction rate (ranging from 3 L/s to 111 L/s) but do not have weekly, monthly or annual volumetric limits set as they are typically exercised on an intermittent basis (typically in spring and/or autumn) over a relatively short duration (< 8 hours). Despite the relatively high instantaneous abstraction rate, the potential for frost protection takes to result in significant interference drawdown is considered to be relatively minor due to the high aquifer permeability across the Twyford Consent Area and the relatively short duration (and intermittent nature) of abstraction.

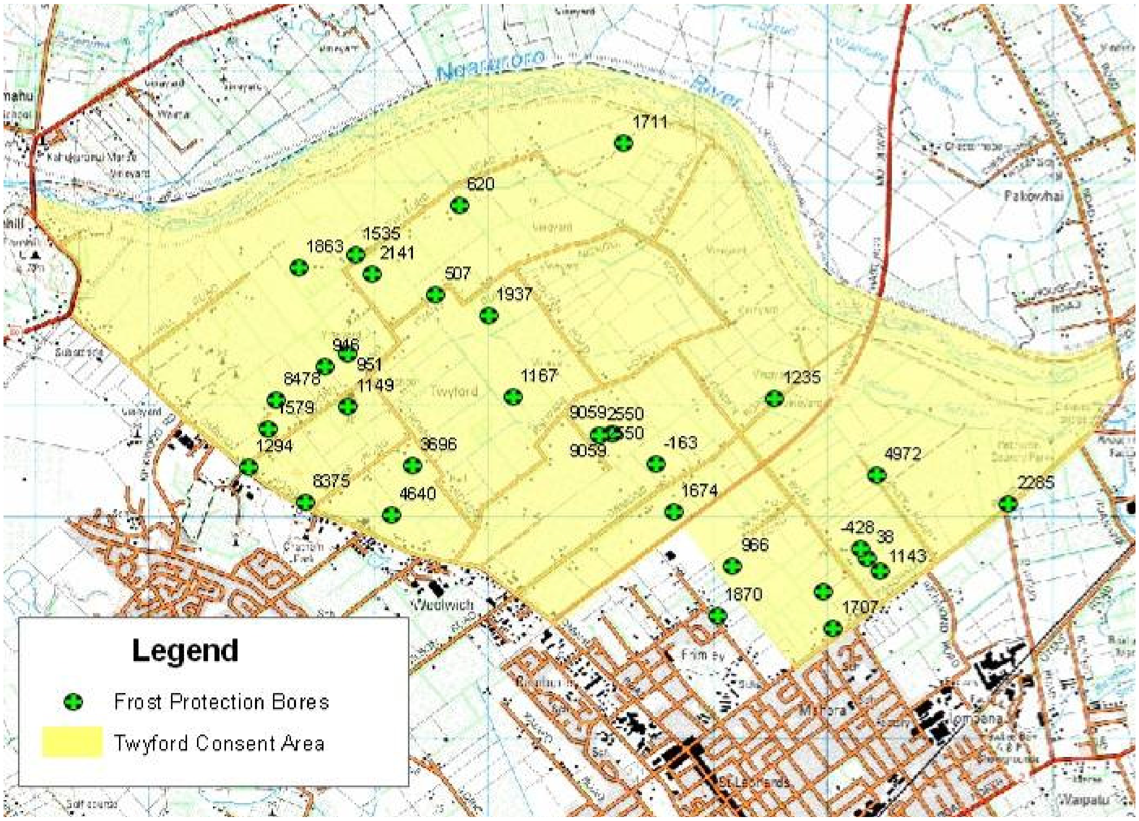


Figure 33: Location of proposed frost protection takes.

In order to validate the limited potential for interference drawdown from frost protection takes the Multiwel programme was utilised to estimate potential interference drawdown resulting from applications in the semi-confined area in the vicinity of Raupare Road. Frost protection wells in this area were selected for assessment rather than those in the unconfined area due to the greater potential for interference drawdown due to the lower assumed aquifer storativity (0.001 compared to 0.1 in the unconfined area).

Table 13 provides a summary of the abstraction rates for proposed frost protection takes in this area (abstraction rates are combined where multiple consents relate to the same bore) along with the calculated interference drawdown for each bore after an assumed abstraction period of 8 hours. These data indicate the cumulative interference drawdown in this area is likely to be no more than 0.3 metres.

Table 13: Calculated interference drawdown from frost protection takes in the semi-confined area

Well No.	Easting	Northing	Abstraction Rate (L/s)	Calculated Interference Drawdown (m)
-163	2838486	6170481	20	0.32
1167	2837214	6171086	40	0.18
1235	2839533	6171068	63	0.14
1674	2838641	6170055	38	0.23
2550	2837980	6170748	50	0.31
9059	2838092	6170756	42	0.34

6.5 Summary

The analysis presented in this section demonstrates that, due to the highly permeable nature of the aquifer system, well interference effects resulting from groundwater abstraction in the Twyford Consent Area is unlikely to result in more than minor well interference effects on bores constructed and maintained in accordance with Policy 77 of the HBRC Regional Resource Management Plan. This conclusion applies to both longer-term abstraction for horticultural irrigation as well as short-term, high rate abstraction for frost protection.

7.0 GROUNDWATER AVAILABILITY

The sustainability of groundwater involves the management of many factors such as loss of wetland, land subsidence, saltwater intrusion, and changes in groundwater quality (USGS, 1999 [13]). Stream depletion and well interference was addressed in sections 5.0 and 6.0 respectively, in this part of the report we look at the sustainability of groundwater storage due to groundwater abstraction.

Groundwater abstraction results in changes to groundwater storage shown by decreases in groundwater levels. The effects can have both a local and regional impact. At a local scale groundwater abstraction causes a phenomenon known as a cone of depression. This effect is usually short-term and once ceased groundwater levels typically return back to normal. The cumulative effects of groundwater abstraction result in regional groundwater level changes such as increased seasonal variation or long-term groundwater level declines. These effects can take years to decades to appear depending on the characteristics of the aquifer.

The groundwater level in an aquifer system represents a dynamic equilibrium between recharge and discharge processes. In general, aquifer recharge processes tend to be episodic (e.g. rainfall infiltration) or influenced by seasonal variability (e.g. periods of higher river flows) while discharge processes (baseflow and aquifer leakage) tend to be more constant over time. As a result the amount of water stored in an aquifer system tends to vary on a seasonal basis in response to the magnitude and timing of recharge events. Groundwater levels rise when recharge is in excess of discharge and decline when discharge exceeds inflow. Over the long-term the volume of aquifer storage (and hence groundwater levels) tend to fluctuate around a long-term mean with variations between successive years reflecting inter-annual climate variability.

In the predevelopment stages of an aquifer system, prior to groundwater abstraction, groundwater levels do not tend to shift greatly from the long-term mean. This is because changes in recharge and discharge do not vary greatly over the long-term. However, during development for uses such as irrigation or municipal supply, groundwater abstraction can significantly alter the natural balance and cause changes to groundwater level patterns and long-term trends. The magnitude of change depends on the characteristics of the aquifer and volume of groundwater abstracted.

The effects of groundwater abstraction and natural changes in recharge and discharge are monitored in the Hawke's Bay using SoE monitoring wells. In the Heretaunga basin 32 monitoring wells, shown in Figure 34, are used to observe how aquifers are responding to change; four of these are located in the Twyford Consent Area. Most of the monitor wells in the Heretaunga basin have been monitored for about twenty years or less, this means that little is known about the predevelopment state of the aquifer system prior to groundwater abstraction.

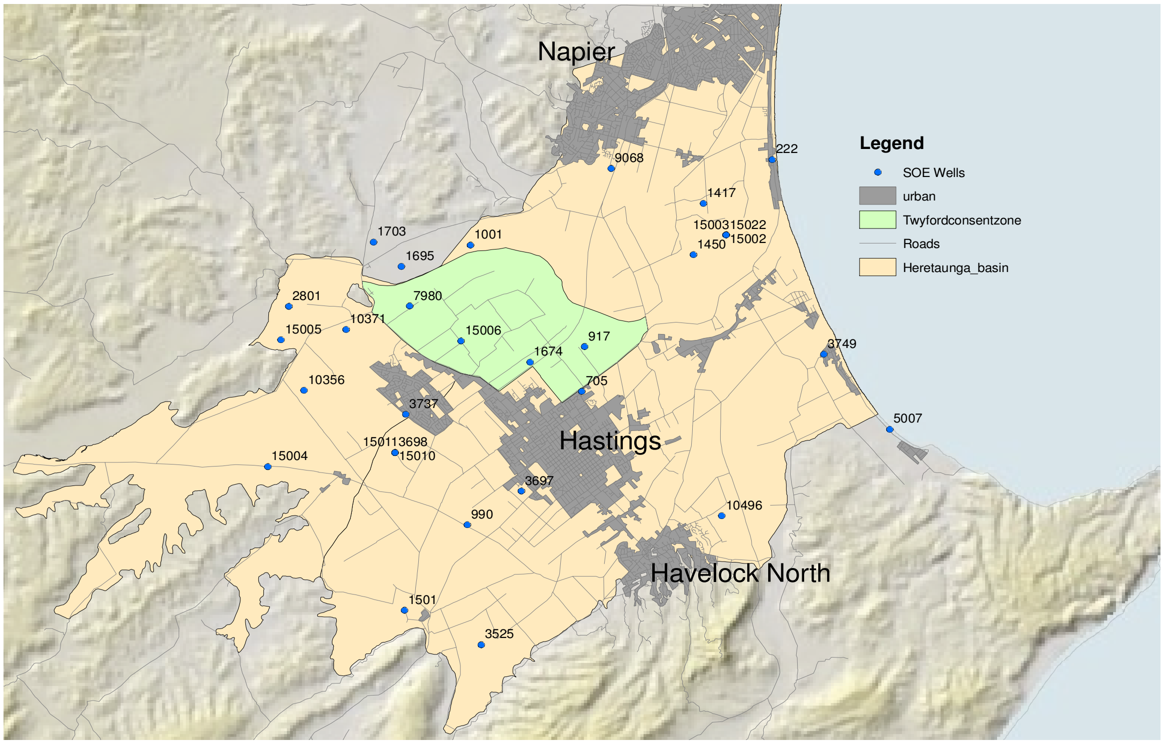


Figure 34: Location of SoE monitor wells in the Heretaunga basin.

Over the last 20 years, groundwater levels have remained relatively stable across the majority of the Heretaunga basin with only a slight increase in the seasonal variation between summer highs and winter lows. In the Twyford Consent Area groundwater levels show a similar pattern with water levels declining over summer then recovering during winter. The most noticeable pattern observed is an increasing seasonal variation particularly in the confined aquifer resulting from lower groundwater levels over summer. This is most likely due to increased abstraction. Results from groundwater level monitoring in the Twyford area are shown in Figure 35.

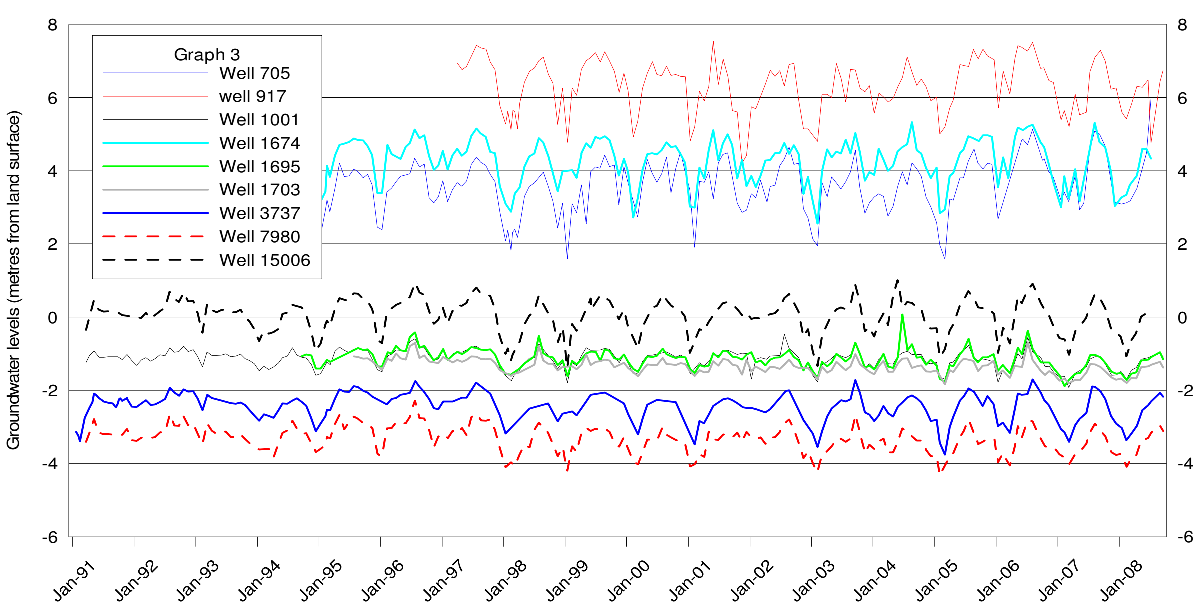


Figure 35: Groundwater levels in the Twyford area

In the Twyford Consent Area groundwater levels range from 7 metres above land surface to about 4 metres below land surface depending on the location within the consent area. Most wells are on average approximately 30 metres deep and have an available drawdown of more than 25 metres. Given this level of availability and the current response to groundwater abstraction it is unlikely that groundwater abstraction at the current consented rates and volumes will significantly affect the long-term availability of groundwater supply to existing users. It is also unlikely that increased abstraction, at the current rate of change, will cause a significant effect. However, further lowering of groundwater levels over summer may result in a significant reduction to groundwater outflow which will affect surface water and may require restrictions on the volume and rates of groundwater abstracted in the basin and the Twyford Consent Area to help manage the potential effects on surface water flows.

Lower groundwater levels over summer means less groundwater outflow. In the Twyford Consent Area this is of particular concern due to the dependence of flow in the Raupare Stream on groundwater outflow from the confined aquifer. A correlation of stream flow with groundwater levels, shown in Figure 12, indicates lowering of summer groundwater levels over time may result in significant flow reductions in the Raupare Stream. The cause of the flow reduction is a combination of natural and pumping-induced effects on the aquifer system. At this stage the magnitude of each effect cannot be quantified and it is unknown whether the pumping-induced effects are primarily the result of regional declines or localised effects.

To help manage the effects of groundwater abstraction on regional groundwater levels a numerical model will be used in 2012 to predict the effects of different pumping scenarios on groundwater storage and connected ecosystems. This will then be used to determine an allocatable volume for the basin that gives an acceptable level of decline.

7.1 Summary

Groundwater level monitoring in the Twyford Consent Area and Heretaunga basin indicate groundwater level declines are small and there is plenty of available drawdown for groundwater abstraction. The greatest concern is the potential effects on connected surface water. Based on the relationship between stream discharge and groundwater levels observed in the Twyford Consent Area small declines in groundwater storage may have significant impacts on surface water flows such as the Raupare Stream. So although, plenty of groundwater is available and only small changes to groundwater levels are likely with increased abstraction, the effects on flow in the Raupare Stream could be significant.

8.0 CONCLUSIONS

This report provides an assessment of potential environmental effects associated with the proposed groundwater abstraction from the Twyford Consent Area and concludes:

1. The Twyford Consent Area overlies a complex layering of sedimentary deposits that form the basis of a large multi-layered aquifer system. The majority of wells are screened to an aquifer that is unconfined between Fernhill and Twyford Road becoming progressively confined toward the east. The confining layers between Twyford Road and Ormond Road produce a weak seal from which artesian groundwater flows naturally to land surface and is the main source of flow to the Raupare Stream. East of Ormond Road the confining layers form a better seal which retards this movement of groundwater.

2. Surface water interacts with groundwater along the Ngaruroro River between Fernhill and Hill Road and along the Raupare Stream between Twyford Road and Ormond Road. Groundwater is connected to surface water in the Ngaruroro River through an unconfined section of gravels which allows the natural movement of water between the river and the aquifer. The connection of groundwater to surface water in the Raupare Stream is thought to occur through preferential flow paths in the aquitard from interspersed layers of sands and gravels.

3. Abstraction from the main aquifer which is connected to the Ngaruroro River and Raupare Stream can potentially reduce surface water flows in the Twyford Consent Area. The magnitude of depletion is dependent on the abstraction rate, distance of the well to river/stream and the hydrogeological characteristics in the area. A nominal rate of greater than 1 l/s was established to determine which abstraction were considered to pose a more than minor stream depletion effect.

4. A total of 217 groundwater consents are located within the Twyford Consent Area, 72 of those consents are located east of about Ormond Road and considered disconnected to the main aquifer due to aquifer confinement indicated by well lithology. The remaining 145 groundwater consents are located west of Ormond Road within the main aquifer which is connected to the Ngaruroro River and Raupare Stream. These consents are considered to be located in a hydrogeological setting conducive for stream depletion to occur and were assessed to examine the magnitude of their effect.

5. Groundwater takes identified as potentially stream depleting were further divided into two groups to reflect the transition in aquifer confinement across the Twyford Consent Area and the potential mechanism by which stream depletion is likely to occur. Area 1 included those bores located in the unconfined area where direct stream depletion effects on the Ngaruroro River are most likely to occur. Area 2 included the remaining bores located in the semi-confined section of the aquifer where groundwater abstraction has the potential to impact on artesian spring discharge to Raupare Stream.

6. Consent applications in Area 1 were assessed using standard analytical methods. This assessment identified that 34 of the 41 applications in this area were likely to result in a more than minor stream depletion effect (i.e. >1 L/s).

7. Due to the limited data available to describe the hydraulic properties of the confining layer materials individual stream depletion assessments were not undertaken for consent applications in Area 2. However, analysis of available data indicates that discharge in the Raupare Stream is sensitive to relatively small declines in groundwater levels resulting from groundwater abstraction. As a result, all proposed groundwater takes in this area were identified as potentially contributing to the cumulative depletion of flow in the Raupare Stream.

8. Assessment of the cumulative well interference effects suggest that even in areas with the highest density of groundwater abstraction cumulative drawdown of groundwater levels resulting from the proposed abstraction is less than 10% of available drawdown and therefore unlikely to result in a more than minor effect on yields from adequately constructed wells across the Twyford Consent Area

9. Groundwater levels recorded in the Twyford Consent Area have remained relatively stable over the past 15 to 20 years. The most obvious effect of increased abstraction over this period is an increase in the seasonal variability reflecting increased abstraction during the summer months although data suggest aquifer levels recover fully during winter. It is therefore concluded that the proposed levels of groundwater abstraction are unlikely to result in a more than minor impact on long-term aquifer storage volumes but this may have a significant effect on outflow to springs which fed the Raupare Stream

9.0 RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

Based on the assessment outlined in this report a number of recommendations have been developed to assist management of the groundwater resource in the Twyford Consent Area. These recommendations relate to the collection of information to facilitate future management of the resource as well as controls intended to maintain environmental values associated with the groundwater system and include:

- Ongoing development and refinement of the groundwater level and stream flow monitoring network in the Twyford Consent Area.
- Placing conditions specifying seasonal volumes based on calculated crop water requirements on individual resource consents to enable improved management of the cumulative volume of groundwater abstraction.
- Requiring groundwater users holding resource consent to record the actual volume of abstraction and regularly forward this information to the HBRC.
- Applying pumping controls to manage individual and cumulative stream depletion effects in the Ngaruroro River and Raupare Stream.
- Requiring applications for new resource consents to be supported by aquifer testing information to improve definition of aquifer hydraulic characteristics.

9.1 Environmental Monitoring

Data collected from the existing groundwater level and stream flow gauging network in the Twyford Consent Area has proved invaluable in developing a conceptual understanding of aquifer hydrogeology and identifying the hydraulic connection between surface and groundwater resources. At a minimum it is recommended that environmental monitoring network is maintained at current levels to enable assessment of relative changes in key environmental indicators (groundwater levels and stream discharge). However, it is also recommended that consideration be given to:

- Automated monitoring of groundwater levels in selected SoE bores. This level of data collection is likely to be a requirement to support active management of environmental effects through application of pumping restrictions.
- Additional monitoring of discharge in Raupare Stream and the Ngaruroro River. Given issues with weed growth it may not be possible to install a rated flow site on the Raupare Stream; however quantification of the impacts of groundwater abstraction on stream discharge could be improved by an increased frequency of monitoring at multiple gauging sites in the Raupare catchment. Similarly, more regular concurrent flow gauging in the

Ngaruroro River between Fernhill and Hill Road would improve understanding of the potential magnitude of stream depletion effects.

9.2 Seasonal allocation

Allocation is an important tool used in the management of groundwater resources and allows Council to avoid adverse environmental effects associated with groundwater abstraction. For example, instantaneous rates provide a mechanism for controlling short-term effects such as well interference or stream depletion while weekly volumes help ensure the efficient use of water and prevent wastage of groundwater through excess abstraction.

Until recently, not much consideration had been given to seasonal or annual allocation which made predicting long-term effects difficult. As a worst case scenario weekly volumes were often used to calculate the overall annual effect of groundwater abstraction. This tended to exaggerate the long-term effects because the allocated groundwater use did not reflect actual groundwater use. However, because historical resource consents did not previously stipulate a seasonal or annual volume, consideration of the long-term effects had to be given using worst-case assumptions which involved using weekly allocatable volumes and assuming resource consents were exercised all year; as they were legally entitled to do. To help more accurately manage the long-term effects of groundwater abstraction it is recommended that annual/seasonal volumes in addition to instantaneous, daily or weekly volumes, be placed on individual resource consents in the Twyford Consent Area.

9.3 Water metering

In 2007 the Ministry for the Environment published a Proposed National Environmental Standard (NES) for the Measurement of Water Takes (MfE, 2007). This document proposed that all water takes requiring resource consent (i.e. excluding permitted takes) should be metered with information on the volume of water used supplied to the appropriate Regional Council. The overall objectives of the NES were identified as being:

- To ensure consistency at a national, regional and catchment level in the measurement and reporting of water use
- To enable water users and regulators to easily determine compliance with water take consents
- Providing accurate information about actual water taken in any catchment.

Although the NES is still at a draft stage it is recommended that the Council adopt proposed requirements for water metering in the Twyford Consent Area. This information will assist management of the resource by enabling quantification of the magnitude of effect on groundwater levels and stream discharge for a given volume of abstraction.

Recording of actual water usage may also provide additional benefits by allowing identifying consent holders who do not fully utilise their consented allocation providing an opportunity for re-allocation of the unused water to additional groundwater users (thereby increasing allocation efficiency). Metering of water takes may also facilitate the transfer of allocation between individual resource users in accordance with RMA Section 136.

9.4 Application of restrictions on abstraction to manage individual and cumulative stream depletion effects

As a result of the hydraulic connection between groundwater and surface water resources in the Twyford Consent Area, management of groundwater abstraction has to take account of environmental flow criteria established for relevant surface water bodies.

9.4.1 Ngaruroro River

Recent hearings for resource consent applications in the Karamu and Ngaruroro catchments have established a mechanism whereby groundwater takes identified as having a high degree of hydraulic connection to surface water are subject to minimum flow criteria established for the relevant surface water bodies. The rationale for this management approach is to ensure that stream depletion effects resulting from groundwater abstraction do not exacerbate the duration, magnitude and frequency of low flow events. In this regard, groundwater takes classified as having a high degree of hydraulic connection are essentially treated as being analogous to equivalent surface water and subject to similar minimum flow conditions established under Policy 73 of the Regional Resource Management Plan.

Due to the high aquifer permeability in the Twyford Consent Area the effects of groundwater abstraction propagate rapidly across the aquifer system. Analytical modelling of groundwater takes in the unconfined area (Area 1) indicates that the rate of stream depletion increases rapidly to a level close to the instantaneous rate of abstraction. Correspondingly these calculations also show stream depletion effects dissipate rapidly once pumping is stopped. As a result, application of pumping controls offers a mechanism to mitigate adverse effects on river flows during low flow periods. It is therefore recommended that the HBRC consider application of pumping controls based on minimum flows established for the Ngaruroro River on groundwater takes from the unconfined area (Area 1) identified as potentially stream depleting in Section 5.9.1 of this report.

9.4.2 Raupare Stream

Policy 74 of the RRMP specifies a minimum flow of 300 L/s in Raupare Stream at Ormond Road. Given the dependence of Raupare Stream on artesian discharge across the semi-confined area this minimum flow establishes potential criteria for the management of groundwater abstraction and consequent cumulative stream depletion effects in the semi-confined area.

Figure 36 shows a plot of the Ormond Road gauging data as a percentage of the minimum flow. These data indicate that flows have generally been recorded above the minimum flow except during low flow events observed during 1990-91 and 2009. However, the data also appear to indicate an ongoing trend of lower summer minimum flows (indicated by the dashed line) consistent with the observed trend of greater seasonal decline in groundwater levels due to increased abstraction over this period.

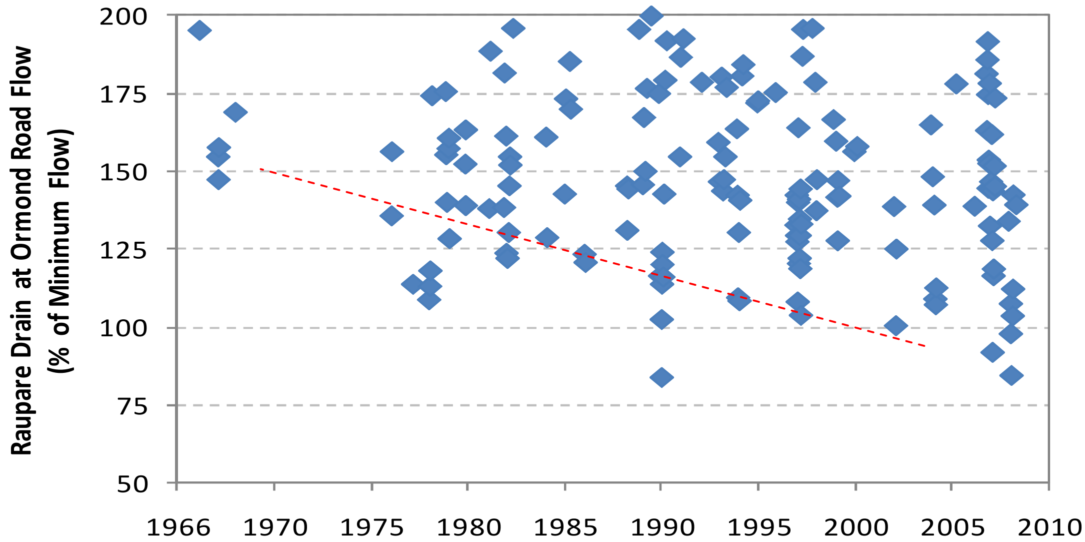


Figure 36: Gauged discharge in Raupare Stream at Ormond Road as a percentage of minimum flow (300 L/s)

However, due to the irregular nature of flow gauging measurements, the measured flows do not necessarily represent the actual low flows occurring in any given season. Based on the observed correlation between groundwater levels and Raupare Stream discharge (refer to Section 5.4.2), Figure 37 shows a plot of water levels recorded in bore 15006 over the period 1991 to 2009 against levels corresponding to flows of 100, 75, 50 percent of the minimum flow (essentially equivalent to a synthetic hydrograph for discharge in the Raupare Stream). These data indicate that since 1998 flows have regularly dropped to levels close to or below the minimum flow (9 out of 11 seasons) and may have fallen below 75 % of the minimum flow during 1999, 2003 and 2009.

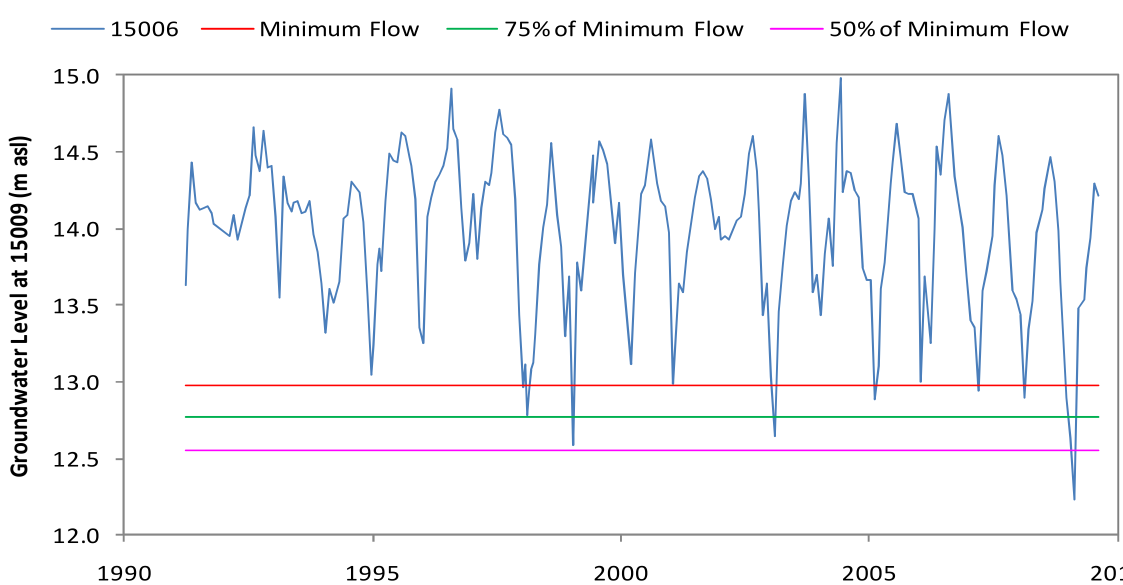


Figure 37: Groundwater levels measured in Well No. 15006 over the period 1991-2009 compared to equivalent percentages of MALF in Raupare Stream at Ormond Road.

The data presented in Figure 36 and Figure 37 indicate that discharge in Raupare Stream regularly falls to levels close to the minimum flow and may decline significantly below the minimum flow during drought events. Given the correlation between groundwater levels and stream discharge it is highly likely that the occurrence and magnitude of these low flow events is highly influenced by declines in groundwater levels due to the existing groundwater abstraction regime, particularly in the semi-confined area (Area 2). As shown in Section 6.0, localised drawdown from groundwater abstraction in this area (calculated to range between 0.3 and 1.1 metres depending on the rate of abstraction) is likely to be of a sufficient magnitude to result in a significant decline in artesian spring discharge to Raupare Stream.

It is therefore recommended that if the Council wish to mitigate the frequency, magnitude and duration of low flow events occurring in the Raupare Stream as a result of groundwater abstraction, then application of abstraction restrictions be considered for groundwater takes in the semi-confined area (Area 2). Such pumping restrictions would attempt to arrest the decline in stream discharge due to groundwater level drawdown resulting from abstraction to maintain Raupare Stream discharge close to the nominated minimum flow.

Any trigger level set for the implementation of restrictions on abstraction to maintain Raupare Stream discharge above the minimum flow would have to take account of the natural decline in groundwater levels during summer. This would likely require a trigger for the implementation of abstraction controls to be set at a groundwater level equivalent to the minimum flow (12.98 m asl in monitoring well 15006) plus an appropriate buffer (~0.15 metres) to allow for natural groundwater level recession. This would result in pumping restrictions commencing at a level of 13.13 m asl which is virtually equivalent to MALF in the Raupare Stream at Ormond Road (13.12 m asl in monitoring well 15006). Such a trigger would obviously require a change in the existing pumping regime for groundwater takes in the semi-confined area which would adversely impact on the reliability of supply for groundwater users.

However, the Council could consider alternative means for the use of minimum groundwater level triggers to mitigate impacts of groundwater abstraction on Raupare Stream discharge during low flow periods. For example, implementation of pumping controls at a level equivalent to the minimum flow (12.98 m asl in monitoring well 15006), although not necessarily preventing Raupare Stream dropping below the nominated minimum flow, would likely avoid the significant decline in stream discharge occurring during past drought events. A further option could be for a partial restriction on groundwater abstraction to be implemented prior to groundwater levels reaching the minimum flow with a full restriction only applying once levels fall below the minimum flow. This latter option would appear to provide a trade-off between a reduction in supply reliability and strict maintenance of stream flows above the nominated minimum.

Application of controls on groundwater abstraction in the semi-confined area appears to offer a means of mitigating adverse effects of groundwater abstraction on Raupare Stream discharge during low flow periods. However, any such restrictions will impact on the reliability of supply for existing groundwater users. It is therefore suggested that development of any such management interventions be undertaken in consultation with resource users, taking into consideration relevant ecological and cultural values associated with Raupare Stream.

9.5 Requirements for aquifer test data

One of the major constraints in developing a hydrogeological model of the Twyford area to enable estimation of the potential effects of groundwater abstraction was the lack of data available to characterise the hydraulic properties of the aquifer materials. Given that allocation pressure on the resource is likely to increase into the future, the availability of information describing aquifer hydraulic properties is likely to be become increasingly important to support resource management decision-making. It is therefore recommended that future applications for resource consent to abstract groundwater from the Twyford Consent Area be supported by aquifer tests data of sufficient quality to determine appropriate aquifer hydraulic characteristics such as aquifer transmissivity, storativity and leakage parameters.

10.0 RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

In order to enable integrated management of groundwater and surface water resources in the Twyford Consent Area further investigation are recommended to characterise the hydrogeology of the aquifer system including the scale and magnitude of surface water and groundwater interaction in the Ngaruroro River catchment. These investigations may include:

- Drilling of additional monitoring wells or geophysical investigations to characterise the hydrogeology in areas where there is uncertainty. Particularly toward the river where there is less lithological information from wells to interpret aquifer configuration and connections with surface water.

- Develop an aquifer testing programme to calculate the hydraulic characteristics of the aquifer, aquitard and streambed materials and to determine the extent and presence of boundaries such as recharge zones (i.e. rivers) or no flow boundaries (i.e. hills). This would require testing across the consent area in various layers in order to characterise large areas of the aquifer yet to be tested. More reliable estimates will provide greater certainty regarding stream depletion and well interference calculations.

- Develop a program of stream gauging to better quantify and delineate the groundwater and surface water interaction. The focus of this investigation would be to identify areas where surface water and groundwater appear to be interacting and quantify the temporal variability in flux over a range of climatic conditions. Such investigations may be complimented by seepage meters, heat tracer methods, and environmental tracers.

- Investigations to develop appropriate methods or guidelines to characterise and manage the direct and cumulative stream depletion effects resulting from groundwater abstraction.

- Improved estimates used to calculate water budgets for an aquifer or basin such as more accurate estimates of rainfall recharge in the unconfined area using lysimeters, piezometric surveys to measure groundwater through flow, velocity and direction, and water metering data to determine actual groundwater use.

11.0 APPENDIX A

Appendix A: Stream depletion results from the unconfined aquifer

Consent	Well No.	Easting	Northing	Abstraction rate (L/s)	Distance to river (m)	Stream depletion rate (L/s)	Use
WP090240T	1294	2834876	6170457	6.00	2,217	0.25	frost
WP090134T	1535	2835829	6172368	5.00	1,320	1.13	frost
WP080620T	1579	2835060	6170802	36.10	1,918	2.84	frost
WP080580T	1863	2835327	6172250	43.00	883	17.90	frost
WP090196T	2141	2835967	6172193	89.00	1,499	15.04	frost
WP090224T	8375	2835379	6170145	5.00	2,640	0.08	frost
WP090310T	8478	2835128	6171061	18.90	1,693	2.28	frost
WP080370T	-437	2835234	6172015	7.62	940	6.52	irrigation
WP090313T	-415	2834640	6170635	2.15	2,016	1.50	irrigation
WP080628T	-142	2835240	6170323	1.52	2,428	0.97	irrigation
WP090119T	-131	2834908	6171506	2.70	1,200	2.20	irrigation
WP080453T	600	2835276	6172433	3.22	768	2.84	irrigation
WP080371T	870	2835560	6171778	8.26	1,341	6.57	irrigation
WP090306T	871	2834467	6172088	3.68	565	3.36	irrigation
WP090341T	971	2834774	6170522	0.36	2,139	0.24	irrigation
WP090182T	1181	2834603	6170794	1.75	1,855	1.26	irrigation
WP080536T	1219	2835704	6170443	5.72	2,494	3.60	irrigation
WP090239T	1294	2834876	6170457	0.76	2,217	0.51	irrigation
WP090133T	1535	2835829	6172368	4.30	1,320	3.43	irrigation
WP090062T	1543	2833509	6172131	4.53	1,152	3.73	irrigation
WP080619T	1579	2835060	6170802	6.45	1,918	4.58	irrigation
WP090309T	1635	2835109	6170544	1.21	2,180	0.82	irrigation
WP090083T	1798	2835266	6171076	3.49	1,732	2.58	irrigation
WP080579T	1863	2835327	6172250	4.23	883	3.66	irrigation
WP090195T	2141	2835967	6172193	5.69	1,499	4.39	irrigation
WP090260T	2142	2834512	6171717	2.15	931	1.84	irrigation
WP090118T	2461	2834945	6171869	8.60	878	7.43	irrigation
WP090140T	2595	2834757	6171994	4.96	689	4.43	irrigation
WP080364T	2831	2833782	6172199	11.81	880	10.20	irrigation
WP090124T	2967	2835607	6171979	3.08	1,260	2.49	irrigation
WP090261T	4034	2833579	6171744	2.11	1,319	1.69	irrigation
WP090308T	4066	2835005	6170336	1.77	2,358	1.15	irrigation
WP080372T	4327	2834567	6172078	10.48	571	9.55	irrigation
WP090122T	5387	2835406	6172292	2.67	937	2.28	irrigation
WP080498T	6412	2834855	6172441	6.61	378	6.22	irrigation
WP090414T	6503	2835488	6170316	3.01	2,518	1.89	irrigation
WP090149T	8148	2835531	6170767	3.25	2,127	2.21	irrigation
WP090223T	8375	2835379	6170145	1.63	2,640	0.99	irrigation
WP090307T	8418	2834045	6171656	8.60	1,108	7.14	irrigation
WP090305T	8478	2835128	6171061	2.02	1,693	1.50	irrigation
WP090183T	8528	2834006	6171291	6.35	1,458	4.94	irrigation

12.0 APPENDIX B

Appendix B: Consent data and bore location used for well interference assessments

Consent Number	Well Number	Easting	Northing	Maximum Rate (L/s)	Weekly Volume (m^3)	Monthly Volume (m^3)	Annual Allocation (m^3)
WP080364T	2831	2833782	6172199	23	7140	28560	168675
WP080370T	-437	2835234	6172015	24	4610	18440	70740
WP080371T	870	2835560	6171778	29	4994	19976	76635
WP080372T	4327	2834567	6172078	32	6338	25352	97268
WP080376T	983	2838971	6169241	5	585	2340	8640
WP080377T	1674	2838641	6170055	38	2293	9172	33600
WP080380T	1636	2839246	6168523	18	1202	4808	17760
WP080381T	4637	2839324	6169142	3	2275	9100	33600
WP080409T	1100	2838017	6169951	18	2925	11700	43200
WP080432T	15329	2843281	6169991	20	4180	16720	64845
WP080433T	3758	2836858	6172467	25	4180	16720	64845
WP080434T	2430	2837651	6172224	30	8360	33440	138120
WP080441T	1884	2842002	6170570	40	2541	10164	41376
WP080447T	385	2839511	6170141	8	2881	11524	44213
WP080453T	600	2835276	6172433	16	1950	7800	28800
WP080477T	659	2835971	6171640	12.6	1625	6500	26880
WP080483T	15400	2839033	6168343	6.7	998	3992	14400
WP080497T	5915	2839031	6172498	65	9148	36592	121700
WP080498T	6412	2834855	6172441	25	4000	16000	70740
WP080501T	1348	2835889	6170363	40	7683	30732	117900
WP080524T	571	2838124	6170233	18.75	1168	4672	16463
WP080525T	3393	2840353	6171152	20	2967	11868	43488
WP080526T	1006	2839755	6170691	16.7	1801	7204	26400
WP080528T	-430	2836251	6171857	20	4094	16376	6000
WP080529T	1008	2836607	6172126	30	4496	17984	68550
WP080530T	9059	2838092	6170756	42	4380	17520	67160
WP080535T	-163	2838486	6170481	20	2377	9508	32925
WP080536T	1219	2835704	6170443	25	3457	13828	28950
WP080537T	2328	2838792	6173039	32	3250	13000	55235
WP080539T	1835	2837757	6170675	25	1400	5600	26775
WP080540T	-999	2838650	6172542	3.6	130	520	19200
WP080541T	1988	2840146	6170463	13.9	1950	7800	28800
WP080542T	495	2839978	6170357	30	1994	7976	76635
WP080543T	2468	2840178	6170735	30	3113	12452	47160
WP080575T	1521	2836449	6172577	14	1625	6500	26190
WP080576T	2582	2840818	6170002	11	2275	9100	33600
WP080577T	1785	2838913	6171268	25	2800	11200	48000
WP080578T	1784	2839545	6171767	60	2800	11200	48000
WP080579T	1863	2835327	6172250	43	2561	10244	36035
WP080582T	1304	2836303	6171184	25	2100	8400	30720

Consent Number	Well Number	Easting	Northing	Maximum Rate (L/s)	Weekly Volume (m^3)	Monthly Volume (m^3)	Annual Allocation (m^3)
WP080583T	8405	2837424	6173548	18	3200	12800	76800
WP080585T	8425	2837055	6169530	12.6	280	1120	3570
WP080586T	2760	2837055	6169528	3	780	3120	40560
WP080592T	2385	2840278	6169268	10	520	2080	7680
WP080602T	649	2836856	6170776	26.5	4127	16508	60480
WP080619T	1579	2835060	6170802	36.1	3900	15600	62400
WP080626T	-438	2836405	6172453	13	980	3920	14400
WP080628T	-142	2835240	6170323	5.5	919	3676	13710
WP090041T	2143	2839181	6171681	30	2800	11200	48000
WP090047T	-423	2839852	6169579	6.3	2293	9172	33600
WP090049T	1973	2839116	6171804	8	2600	10400	46230
WP090053T	576	2837157	6172438	15	2600	10400	38400
WP090054T	-439	2837889	6170413	25	2860	11440	42240
WP090057T	49	2840779	6169898	29.2	2057	8228	35520
WP090058T	1451	2837669	6171225	25	4000	16000	63503
WP090059T	1167	2837214	6171086	28.6	7984	31936	114720
WP090060T	1712	2837414	6171017	25	2260	9040	33120
WP090061T	1196	2837156	6171608	18	2129	8516	31200
WP090062T	1543	2833509	6172131	32	2739	10956	41475
WP090080t	5932	2836034	6170791	30	3275	13100	48000
WP090081T	-151	2836406	6170633	30	1921	7684	29475
WP090082T	4640	2836143	6170024	50	6000	24000	95499
WP090083T	1798	2835266	6171076	18	2112.5	8450	31200
WP090087T	724	2841806	6170642	25	2305	9220	35370
WP090088T	1490	2838836	6173217	11	3525	14100	64845
WP090103T	954	2839791	6169090	35	2800	11200	47160
WP090104T	2187	2839633	6168861	20	2600	10400	38400
WP090105T	1990	2836891	6170089	10	3900	15600	63623
WP090106T	15335	2837595	6170433	16	2108	8432	76800
WP090107T	787	2837317	6170003	6.3	3811	15244	81600
WP090108T	15153	2839369	6169101	33	4500	18000	69030
WP090109T	4481	2836713	6170617	20	3100	12400	48480
WP090110T	-292	2839631	6170828	3.2	907	3628	43200
WP090111T	3381	2837208	6170263	8	484	1936	9600
WP090112T	6449	2836591	6169984	25	2800	11200	44640
WP090118T	2461	2834945	6171869	16	3748	14992	52863
WP090119T	-131	2834908	6171506	16	1630	6520	60698
WP090122T	5387	2835406	6172292	15	1613	6452	23668
WP090123T	1045	2838369	6171368	27.5	1875	7500	26590
WP090124T	2967	2835607	6171979	15	1865	7460	23800
WP090125T	3696	2836328	6170476	15	1121	4484	15550
WP090127T	620	2836748	6172811	15	1216	4864	17375

Consent Number	Well Number	Easting	Northing	Maximum Rate (L/s)	Weekly Volume (m^3)	Monthly Volume (m^3)	Annual Allocation (m^3)
WP090130T	1738	2836900	6173073	65	5450	21800	85440
WP090133T	1535	2835829	6172368	5	2600	10400	38922
WP090139T	-417	2836189	6169860	20	1801	7204	26400
WP090140T	2595	2834757	6171994	15	3000	12000	56615
WP090142T	38	2840350	6169634	25	1028	4112	14519
WP090143T	2420	2841300	6169869	11.2	2851	11404	43200
WP090144T	1034	2841614	6170518	25	2656	10624	40676
WP090146T	1707	2840054	6169005	9.6	3250	13000	23800
WP090148T	-428	2840290	6169720	13.9	1418	5672	21120
WP090149T	8148	2835531	6170767	20	1965	7860	28800
WP090151T	1074	2837632	6171523	25	2112	8448	38675
WP090154T	3210	2837282	6173036	20.8	1310	5240	19200
WP090155T	-441	2838631	6170566	3.98	655	2620	9600
WP090156T	3127	2836791	6172847	31.15	3250	13000	48000
WP090157T	2105	2836586	6172897	13	2770	11080	41601
WP090158T	129	2838040	6171147	13	1243	4972	17605
WP090159T	-652	2838305	6170812	13	1421	5684	20120
WP090160T	-433	2839102	6170927	9.5	3830	15320	57600
WP090161T	247	2840080	6169385	20	1801	7204	26400
WP090167T	-434	2838678	6171236	19	7677	30708	115200
WP090168T	675	2837386	6173270	13	3900	15600	57600
WP090170T	1711	2838199	6173373	50	6720	26880	118200
WP090172T	2008	2838560	6169600	25	2275	9100	32350
WP090177T	1038	2837653	6172998	16	4480	17920	76800
WP090178T	2961	2836002	6171489	2.5	583	2332	7438
WP090179T	1223	2836205	6172842	7.6	2470	9880	42528
WP090180T	972	2835997	6172503	38	13000	52000	220470
WP090181T	4550	2836431	6172832	12.6	3256	13024	48000
WP090182T	1181	2834603	6170794	19	1060	4240	18864
WP090183T	8528	2834006	6171291	15.6	3843	15372	66864
WP090184T	-435	2836184	6170327	25	1638	6552	24000
WP090185T	2780	2837599	6171750	10	4032	16128	129600
WP090189T	4898	2836525	6171787	9.2	1379	5516	24000
WP090192T	507	2836534	6172002	25	1300	5200	19200
WP090193T	1607	2836557	6173108	6.5	3250	13000	48000
WP090195T	2141	2835967	6172193	37	3439	13756	50400
WP090197T	1937	2837002	6171823	33	2663	10652	39024
WP090199T	951	2835761	6171476	50	5850	23400	86400
WP090209T	2438	2836672	6171333	25	3073	12292	47160
WP090213T	1097	2836154	6172291	18	1771	7084	26160
WP090214T	381	2838075	6169650	25	2900	11600	50304
WP090215T	2240	2836641	6172715	5.6	1300	5200	19200

Consent Number	Well Number	Easting	Northing	Maximum Rate (L/s)	Weekly Volume (m^3)	Monthly Volume (m^3)	Annual Allocation (m^3)
WP090217T	694	2839019	6172653	25	5794	23176	85980
WP090219T	9058	2840009	6170049	30	4610	18440	70740
WP090220T	2946	2837934	6171018	20	2925	11700	44637
WP090221T	1235	2839533	6171068	25	2372	9488	35040
WP090223T	8375	2835379	6170145	13	983	3932	14400
WP090225T	297	2840216	6170029	30	4610	18440	70740
WP090226T	5927	2837013	6169964	7.6	983	3932	14400
WP090227T	4374	2840868	6170526	30	3073	12292	47160
WP090228T	4229	2838773	6170337	25	1383	5532	21222
WP090238T	1777	2836680	6171830	8.8	4690	18760	81600
WP090239T	1294	2834876	6170457	6	459	1836	6720
WP090248T	152	2840072	6170174	22.7	1184.5	4738	17496
WP090249T	2285	2841599	6170126	18	2210	8840	20230
WP090250T	9056	2838351	6170363	3.6	689	2756	28800
WP090251T	1149	2835763	6171004	44	2293	9172	33600
WP090254T	4964	2839311	6169822	20	3890	15560	57600
WP090255T	1093	2838131	6172661	19	4225	16900	62400
WP090256T	4291	2839470	6169826	27	1867	7468	28650
WP090260T	2142	2834512	6171717	19	1300	5200	19200
WP090261T	4034	2833579	6171744	46	1279	5116	24000
WP090262T	856	2837993	6171276	20	1474	5896	21600
WP090267T	2980	2838317	6172390	30	699	2796	8925
WP090268T	4580	2839088	6170404	27	4100	16400	64800
WP090269T	1746	2836762	6170313	13.6	2808	11232	50300
WP090270T	-416	2837226	6170521	7	3458	13832	48475
WP090273T	-119	2839893	6168856	0.6	290	1160	4800
WP090274T	-420	2840829	6169602	2.5	36.09	144.36	4560
WP090274T	-419	2840664	6169855	4	346	1384	43851
WP090274T	1143	2840457	6169530	5	217.91	871.64	27587
WP090276T	917	2840476	6170592	3	100	400	30196
WP090295T	8216	2837300	6169592	22.7	4550	18200	68985
WP090305T	8478	2835128	6171061	18.9	1224	4896	31200
WP090306T	871	2834467	6172088	25	2227	8908	58320
WP090307T	8418	2834045	6171656	18.9	5201	20804	78124
WP090308T	4066	2835005	6170336	4	1071	4284	17903
WP090309T	1635	2835109	6170544	18	734	2936	12935
WP090311T	946	2835554	6171353	25	2503	10012	62495
WP090313T	-415	2834640	6170635	19	1300	5200	23580
WP090341T	971	2834774	6170522	2.4	216	864	14400
WP090348T	3050	2838392	6170008	22	4193	16772	7200
WP090354T	2444	2838468	6173002	32	7001	28004	104406
WP090376T	-135	2838404	6172759	32	2000	8000	35370

Consent Number	Well Number	Easting	Northing	Maximum Rate (L/s)	Weekly Volume (m^3)	Monthly Volume (m^3)	Annual Allocation (m^3)
WP090377T	1601	2838753	6172739	7.5	2600	10400	38400
WP090414T	6503	2835488	6170316	13	1823	7292	26063
WP090418T	1870	2839030	6169128	11.7	1958	7832	24990
WP090424T	2928	2839797	6171512	38	4322	17288	63840

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