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Te Kaunihera ā Rohe o Waikato

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Report on Waikato Ground-Surface Water Depletion Assessment

π Prepared for

Waikato Regional Council

π June 2010, section 6 amended by WRC in October 2012

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1.0 Introduction

Waikato Regional Council (WRC) has adopted a water allocation variation to their Waikato Regional Plan. The plan identifies the potential for groundwater abstractions to adversely affect surface waterways. WRC have engaged Pattle Delamore Partners (PDP) to assess the potential effects of groundwater abstractions on surface waterways and to identify criteria through which groundwater abstractions can be classified regarding their potential effects on surface waterways.

This report has been prepared by PDP to present the results of that assessment. PDP developed an initial report during the development of the water allocation variation; WRC Technical Report 2010/28. This report is an updated version of WRC Technical Report 2010/28. Changes only relate to Section 6 to update the information to align with the adopted version of the variation. Section 6 has been written by the WRC and reviewed by PDP. It presents the following information:

- a conceptual description of the way in which groundwater abstractions affect surface waterways (Section 2);
- the parameters that influence the magnitude of surface water depletion effects (Section 3);
- methods to quantify the effect of groundwater pumping on surface waterways (Section 4);
- application of those methods using typical parameters for the Waikato region (Section 5);
- criteria to determine when the effects are significant (Section 6).

2.0 Effects of Groundwater Abstraction on Surface Waterways

2.1 Interaction Between Groundwater and Surface Water

The interaction between streams and groundwater takes place in two basic ways:

(a) streams gain water from groundwater through the streambed when the elevation of the water table adjacent to the streambed is greater than the water level in the stream (shown schematically in Figure 1);

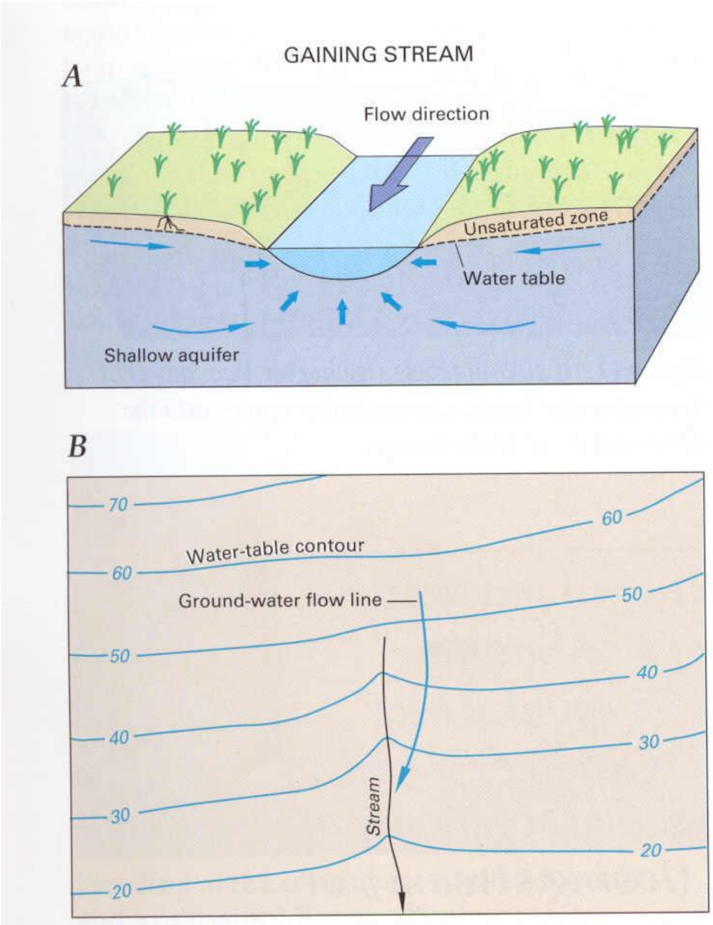


Figure 1 Gaining streams receive water from the groundwater system (A). This can be determined from water table contour maps because the contour lines point in the upstream direction where they cross the stream (B). (From USGS 1998.)

(b) streams lose water to groundwater by outflow through the streambed when the elevation of the water table is lower than the water level in the stream (shown schematically in Figure 2).

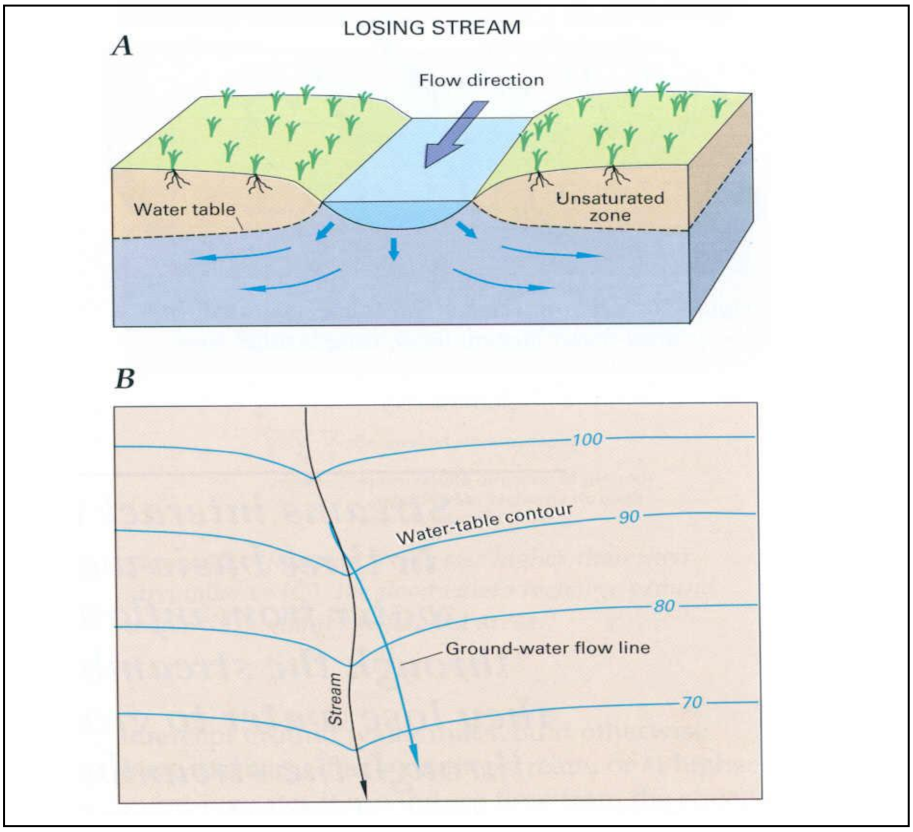


Figure 2 Losing streams lose water to the groundwater system (A). This can be determined from water table contour maps because the contour lines point in the downstream direction where they cross the stream (B). (From USGS 1998.)

Whilst these diagrams indicate interactions with streams, the same type of interaction between groundwater and surface water occurs through the beds of other surface waterways such as lakes and wetlands.

Within any particular waterway, it is not uncommon to have different areas that gain or lose water, or the same area losing or gaining water at different times of the year.

The most obvious indications of the variability in stream flow caused by groundwater seepage occurs in the headwaters of spring-fed streams or in stream reaches that periodically go dry because of seepage losses. Such occurrences are a clear visual indication of the type of interaction that occurs between the groundwater and surface water environments.

The rate of water movement between surface water and groundwater is determined by the parameters shown in Figure 3, namely:

- the wetted area of the surface waterway (L x W);
- the hydraulic gradient across the bed of the surface waterway:

  i = (groundwater level-surface water level)/bed thickness;
- the hydraulic conductivity of the bed material (K').

A simplified quantification of the seepage between groundwater and surface water (defined by the term "q") can be made using Darcy's equation, as shown in Figure 3.

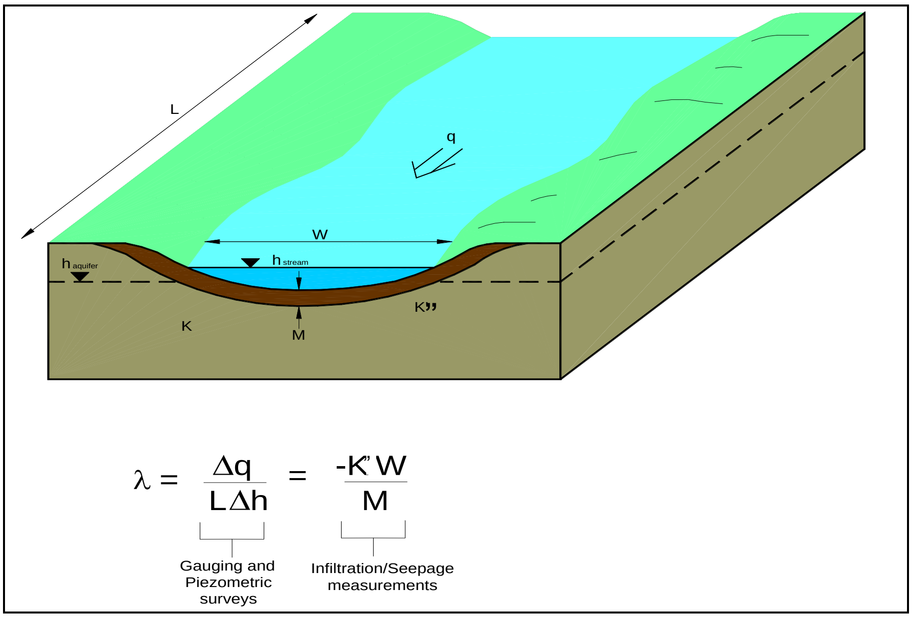


Figure 3 Schematic diagram of parameters that affect the movement of water between surface waterways and groundwater.

2.2 Groundwater Abstraction Effects

Groundwater abstractions occur by a lowering of the groundwater level in a bore, typically by a pump, which causes a hydraulic gradient that allows groundwater to flow towards the bore. This lowering of groundwater levels spreads out through the surrounding strata to create a drawdown cone around the bore. The magnitude and extent of the drawdown cone is determined by the rate of groundwater abstraction and the hydrogeologic characteristics of the surrounding strata.

When the drawdown cone extends into the area of a surface waterway, it may alter the hydraulic gradient across the bed of the surface waterway, as shown schematically in Figure 4.

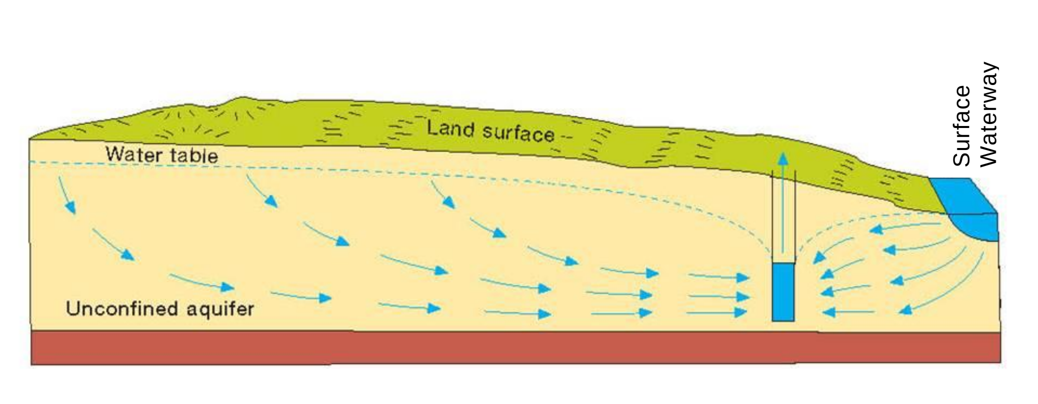


Figure 4 Surface water depletion concept.

The change in hydraulic gradient adjacent to the surface waterway will create one of the following effects:

- for a "gaining" surface waterway (e.g. Figure 1), there would be a reduction in the flow of groundwater that would otherwise have entered the surface waterway;
- for a "losing" surface waterway (e.g. Figure 2), there would be an increase in the rate of seepage from the surface waterway into the groundwater.

In both these situations, the effect is a loss from the surface waterway, i.e. a surface water depletion effect caused by the groundwater abstraction.

There may be some situations where a lowering of the groundwater level may not alter the hydraulic gradient across the bed of a surface water body, and therefore not cause a depletion effect. This occurs when the hydraulic connection between the surface water body and the groundwater may not be as direct as shown in Figure 2, but rather, it may be disconnected by an intervening unsaturated zone, as shown schematically in Figure 5.

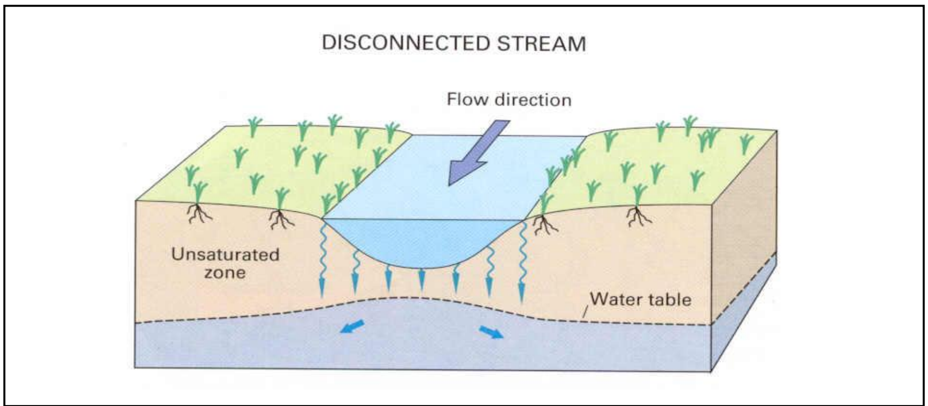


Figure 5 Disconnected streams are separated from the groundwater system by an unsaturated zone. (From USGS, 1998.)

If the water table is sufficiently deep below the bed of the surface waterway, any lowering of its level does not alter the hydraulic gradient across the bed in a meaningful way, and therefore does not alter the rate of seepage.

The purpose of this report is to describe a classification of these groundwater abstraction effects on surface waterways that can aid in the overall management of water resources in the Waikato region.

3.0 Parameters Which Influence the Magnitude of Surface Water Depletion Effects

Surface water depletion effects caused by groundwater abstractions are affected by a number of parameters related both to the surface waterway and the surrounding aquifer systems. In the first instance, consideration must be given to the conceptual hydrogeologic setting to determine whether these surface water depletion effects can actually occur. This should involve a consideration of the characteristics of the surface waterway (could it be adversely affected by depletion effects from the magnitude of groundwater abstraction that occurs in the area) and the relative elevations of the surface water level and the adjacent groundwater level (i.e. could an alteration to the groundwater levels affect the hydraulic gradient across the bed of the surface waterway, thereby inducing a depletion effect).

Two guideline values are provided to assess the depth to water at which surface water depletion effects due to altered groundwater levels will not occur in situations where there is a permeable connection between the bed of the surface waterway and the underlying groundwater. As a conservative approach it is considered that both these water depth criteria should be met before a conclusion can be reached that there is an absence of a surface water depletion effect.

(i) Hunt (1997) describes a flow net analysis which shows that when a stream is perched above the water tale, a zone of uniform vertically downwards flow occurs. This vertical flow condition is expected to be reached when the depth to the water table below the stream surface (H) is five times the maximum depth of water in the stream (D), i.e. $H \geq 5D$, as shown in Figure 6. Under these circumstances, if H is increased due to a drawdown from a pumping well, it will not induce extra seepage from the surface waterway.

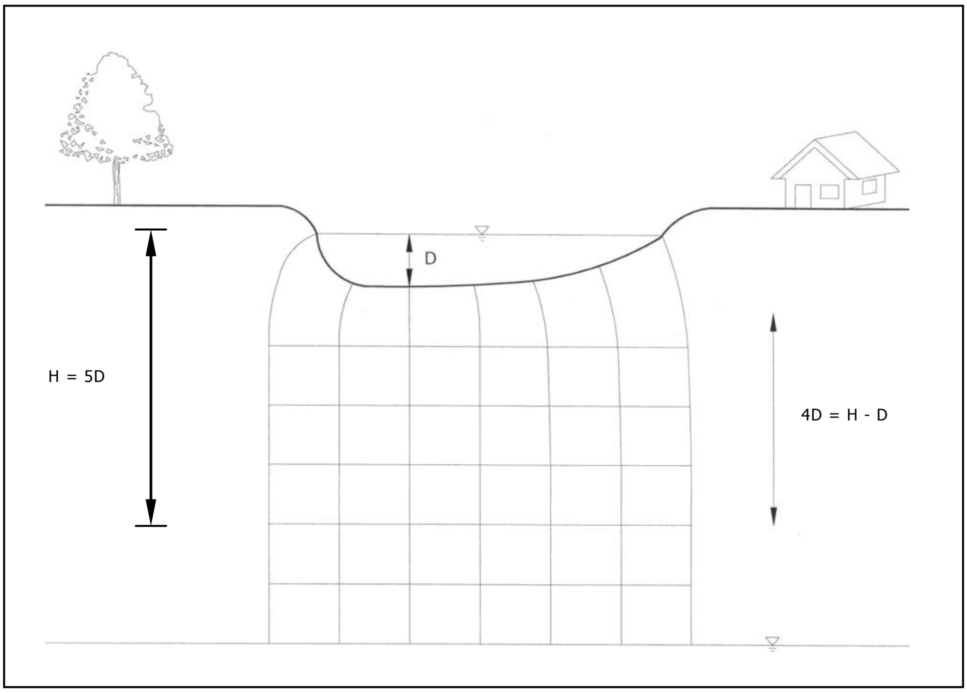
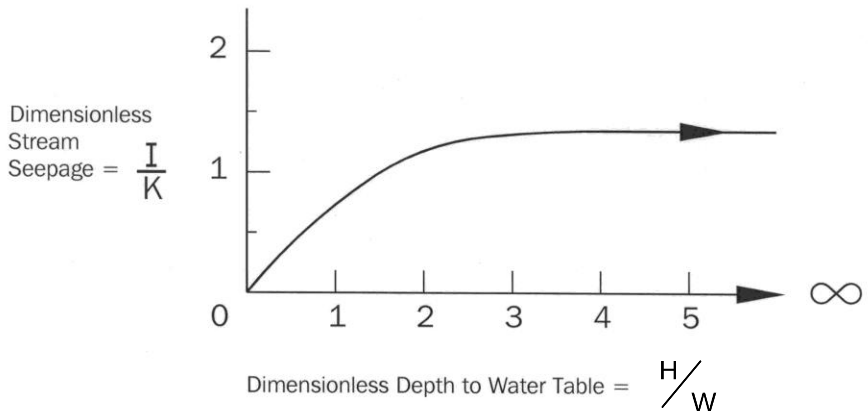


Figure 6 Flow net for seepage beneath a stream, showing that uniform vertical flow is reached by a depth of 5D below the stream surface (i.e. 4D below the streambed).

(ii) Bouwer (1997) describes stream seepage rates in relation to the dimensionless term H/W, where H is the depth to groundwater and W is the width of the stream (Figure 7). If the depth to groundwater is more than twice the stream width (i.e. H $\geq$ 2W), then any further lowering of the groundwater table will not significantly increase stream seepage.

It is important to acknowledge that, even if these conditions are met in the reach of a stream nearest to the well, that the abstraction may result in stream depletion further downstream or upstream if the stream is connected to groundwater in a different location that experiences the effects of the groundwater abstraction.



I = Seepage per unit area as stream seepage
K = Hydraulic conductivity of underlying strata
H = Vertical distance between the groundwater table and the water surface of the stream
W = Width of stream

Figure 7 Dimensionless plot of seepage (expressed as I/K) versus depth to groundwater (expressed as H/W) for clean stream channel (no clogging layer on bottom). (From Bouwer, 1997.)

Once it is established that surface water depletion effects induced by groundwater abstraction are feasible, then consideration must be given to the parameters that determine the nature of that effect.

Parameters used in calculations to quantify the effect include:

π the groundwater abstraction rate;

π the duration of the pumping period;

π the separation distance between the abstraction well and the surface waterway;

π the aquifer parameters that determine the shape of the drawdown cone around the pumping well, i.e. transmissivity (T), storage coefficients (S for a confined aquifer and σ for a water table aquifer) and aquitard conductance (K'/B');

π streambed conductance (λ).

A description of these parameters for the Waikato setting is presented in the following pages.

Parameter	Pumping Rate (Q)
Typical Units	m³/day or L/s
Description	The abstraction rate from a well over a fixed period of time. Note: The principle of superposition applies to surface water depletion effects, therefore the effect of intermittent pumping can be simulated by the addition of effects resulting from a sequence of pumping and recovery. Jenkins (1977) concludes that "within quite large ranges of intermittency, the effects of intermittent pumping are approximately the same as those of steady, continuous pumping of the same volume". Therefore, averaging of abstraction rates over a longer period of time (e.g. an irrigation season) provides a useful estimate of surface water depletion in many cases.
Typical Values	15-10,000 m³/day (15 m³/day is the proposed upper limit for Permitted Activity abstractions from groundwater).
Source of Data	π Direct measurement by the use of flow meters on abstraction wells π Inferred rates from pump performance curves and readings of pump electricity meters π Pumping rates specified on resource consent applications
Effect on Surface Water Depletion	Surface water depletion effects increase with larger pumping rates.

Parameter	Pumping Period (t)
Typical Units	days
Description	The duration of the pumping period of interest (see the note under "Pumping Rate" regarding intermittent pumping).
Typical Values	1-150 days (for irrigation wells). Continuous for public supply and industrial wells, although consideration of shorter periods of peak demand may be appropriate.
Source of Data	π Direct measurement linked to monitoring of flow meters and/or electricity meters π Inferred data from an irrigation design or commercial/industrial/ reticulated supply requirements π Pumping period details specified on resource consent applications
Effect on Surface Water Depletion	Surface water depletion effects increase with longer pumping periods.

Parameter	Separation Distance (L)
Typical Units	metres (m)
Description	The lateral separation distance from the abstraction well to the nearest edge of the surface waterway, measured perpendicular to the edge of the surface waterway.
Typical Values	1-2,000 m
Source of Data	π Topographic maps π Aerial photos π Direct measurement on the ground
Effect on Surface Water Depletion	Surface water depletion effects occur more rapidly with smaller separation distances. Small and distant effects may be best managed by overall catchment allocation limits rather than the direct assessment of effects from an individual well, as discussed in Section 6 of this report.

Parameter	Transmissivity of the pumped aquifer (T)
Typical Units	m²/day
Description	The transmissivity of the aquifer from which groundwater abstraction occurs (i.e. aquifer hydraulic conductivity x aquifer thickness).
Typical Values	5-3,500 m²/day
Source of Data	π Pumping tests on abstraction wells with observation wells to monitor surrounding drawdown effects π Slug tests in low transmissivity strata π Estimates from specific capacity and/or geological logs from water wells Note: The most reliable data comes from pumping tests on the well under investigation, provided that the test has used neighbouring observation wells and has been analysed in a way that takes the nearby surface waterway into account. Where multiple measurements of transmissivity are available from surrounding wells, it is most appropriate to use the geometric mean of the values.
Effect on Surface Water Depletion	Variable depending on other aquifer parameters and duration of pumping.

Parameter	Storage Coefficient: • Storativity (S) for a confined aquifer and • Specific Yield (σ) for a water table aquifer.
Typical Units	dimensionless
Description	The storage coefficient of the aquifer from which groundwater abstraction occurs (i.e. the volume of water released per unit volume of aquifer for each unit decline in the piezometric surface).
Typical Values	0.00005-0.3
Source of Data	π Pumping tests which utilise observation wells π If no data is available, S = 0.1 is a typical value taken for settings where the hydrogeologic characteristics indicate the presence of an unconfined aquifer
Effect on Surface Water Depletion	Surface water depletion effects increase with smaller values of storage coefficient. Aquifers with values of S less than 0.001 are likely to be confined by overlying lower permeability strata. However, surface water depletion effects can still occur due to leakage through the confining strata or breaches of the confining layer by the streambed or by discrete spring discharges.

Parameter	Aquitard conductance (K'/B')
Typical Units	days^{-1}
Description	For a confined or semi-confined aquifer setting, this parameter describes the vertical hydraulic conductivity (K') of lower permeability strata (i.e. aquitards) with a thickness of B' metres that overlies the pumped aquifer
Typical Values	0.000001-1 days^{-1}
Source of Data	π Pumping tests which utilise observation wells π Estimates from geological logs based on comparison with other measured values
Effect on Surface Water Depletion	Surface water depletion effects increase with higher aquitard conductance values for settings where the aquitard conductance reflects the conductance of the strata between the surface waterway and the pumped aquifer.

Parameter	Streambed Conductance (λ)
Typical Units	m/day
Description	A measure of the vertical hydraulic conductance through the streambed to the underlying aquifer. For a simple water table aquifer, streambed conductance can be defined as: $$\lambda = \frac{K''W}{B''}$$ where K" is the vertical hydraulic conductivity of the strata between the stream and the pumped aquifer, including the streambed material (m/day) W is the width of the streambed (m) B" is the thickness of the strata between the stream and the pumped aquifer (m)
Typical Values	0.001-5,000 m/day
Source of Data	π Pumping tests with multiple observation bores π Gauging surveys (to determine gains or losses in flow along stream reaches), coupled with elevation surveys of stage height and groundwater levels π Seepage meters π Infiltration tests π Excavation of test pits in dry streambeds for direct inspection of streambed strata (although this method is not accurate for a quantitative assessment)
Effect on Surface Water Depletion	Surface water depletion effects increase with larger values of streambed conductance.

The relationship between all of the parameters listed in the preceding panels is shown schematically in Figure 8.

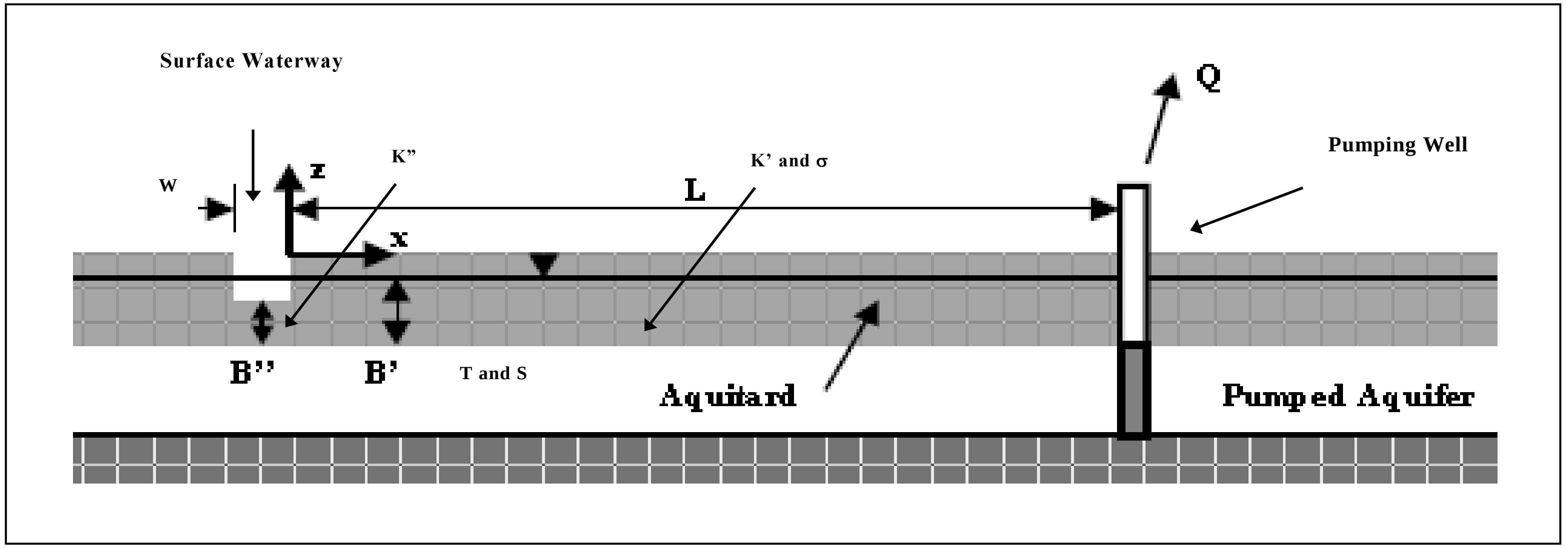


Figure 8 Geology for the surface water depletion analytical solution developed by Dr Bruce Hunt.

4.0 Methods to Quantify the Effect of Groundwater Pumping on Surface Waterways

There are a range of methods that can be used to quantify the effects of groundwater pumping on surface waterways. Due to this variability that occurs within natural strata, it is not possible to precisely characterise the movement of groundwater through the use of a system of numerical equations. Therefore, the tools that are available to quantify groundwater effects represent a broad brush simplification of the natural situation. However, despite their approximation of the real effect, they provide an essential tool to classify and manage the effects that arise from groundwater abstractions.

Most groundwater settings can be approximated by simplified hydrogeological settings, which can be described by analytical solutions. One of the most versatile analytical solutions for the quantification of surface water depletion effects has been developed by Dr Bruce Hunt at the University of Canterbury, and is described in his paper entitled "Unsteady Stream Depletion when Pumping from Semiconfined Aquifer" (Journal of Hydrologic Engineering; pp 12-19; January/February 2003). From here on referred to as the Hunt 2003 solution. The analytical solution relates to the hydrogeolgic setting that is shown schematically in Figure 8, where groundwater is abstracted from a well screened across a permeable aquifer that is overlain by strata through which the vertical leakage of water can occur. A stream is located within the overlying strata and leakage of water can also occur between the surface waterway and the pumped aquifer, by the movement of water through the streambed and the strata that overlies the pumped aquifer due to the change in hydraulic gradient induced by the pumping well.

Figure 8 shows the schematic representation of the parameters that were described in Section 3 of this report. These can be grouped into the following components:

- the pumped aquifer has a drawdown (s), a transmissivity (T) and an elastic storage coefficient or storativity (S);
- the overlying strata has a drawdown at the water table (s'), a vertical hydraulic conductivity (K'), a thickness (B') and a storage coefficient or specific yield (σ);
- the stream has a width (W) and the strata making up the streambed and extending from the streambed down to the contact with the pumped aquifer has a vertical hydraulic conductivity (K") and a thickness (B");
- the well is located at a distance (L) from the edge of the stream and abstracts water at a pumping rate (Q).

The analytical equation calculates the reduction in surface flow (q) caused by pumping from the well (Q). It also calculates the drawdown (drop in water level) caused by pumping at any point in both the pumped aquifer (s) and the overlying strata (s').

The pattern of drawdown and surface flow depletion provided by this solution is based on the Boulton solution for a delayed yield aquifer, and consequently graphs of drawdown versus time and surface water depletion versus time (plotted with time on a logarithmic scale) show two inflection points, as shown in Figures 9a and 9b. The drawdown pattern in these figures has been calculated with the following parameters:

- pumped aquifer transmissivity = T = 1,000 m^2/day;
- pumped aquifer storativity = S = 5 x 10^{-4};
- aquitard leakage = K'/B = 0.05 $days^{-1}$;
- water table storage coefficient = σ = 0.1;
- stream bed leakage = λ = 10 m/day;
- well stream separation distance = L = 200 m (the drawdown effect is calculated at a point midway between the stream and the pumping well).

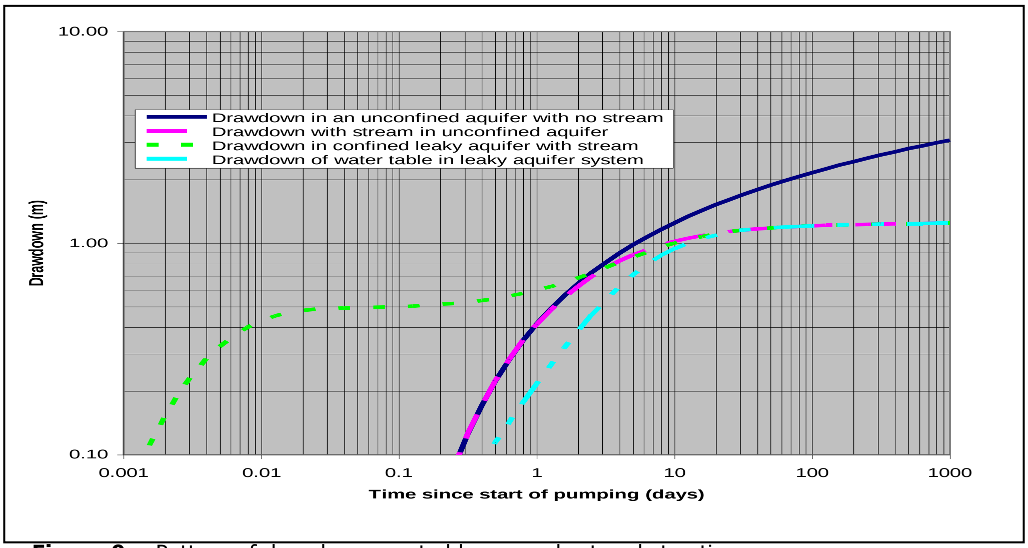


Figure 9a: Pattern of drawdown created by groundwater abstraction.

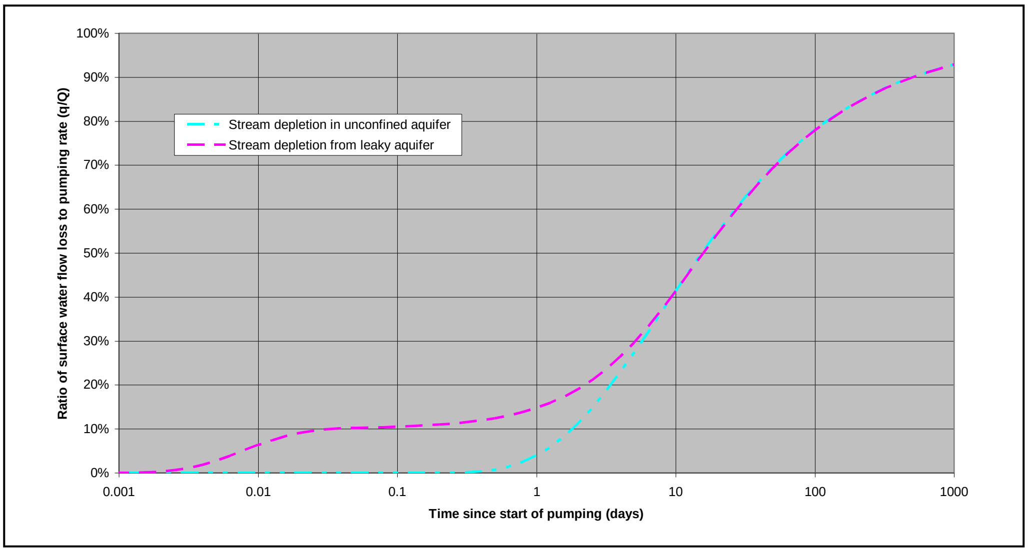


Figure 9b: Pattern of surface water depletion created by groundwater abstraction.

The first part of the curve is dominated by the release of water from elastic storage effects (confined aquifer behaviour) and the second part of the curve is related to a situation where drainage from the stream and from the overlying strata containing the water table become more dominant. However, unlike the Boulton pumping test solution, the drawdown approaches a maximum drawdown limit (horizontal asymptote) due to the seepage effects from the surface waterway and ultimately the surface water depletion rate reaches the full abstraction rate from the well (i.e. q/Q = 100%).

Figure 9b shows the stream depletion effect that is estimated to result from the same simulation used to create Figure 9a. As with the drawdown pattern, the lower storage coefficient in the leaky aquifer induces a more widespread drawdown effect and a fast surface flow loss of small magnitude, but as the pumping time continues, the effects of leakage merge with the result from an unconfined aquifer.

Some of the key approximations for this analytical solution are:

- the aquifer and aquitard layers are laterally extensive and have uniform parameters;
- the surface waterway is represented as a narrow straight line that extends over a long distance;
- depletion of the stream flow is the only source of external recharge to the aquifer.

These are significant simplifications compared to a real groundwater system, and they must be recognised when interpreting the results of the analytical solution. If a more detailed analysis is required to evaluate more variable hydrogeological settings, then a numerical modelling approach may be required, although to carry out such assessments in a realistic manner involves a significantly more sophisticated level of analysis compared to the more straightforward approach presented in this report. Therefore, despite its simplifying limitations, the analytical solution provides a simple and consistent approach for comparing and ranking the effects of groundwater abstractions on surface waterways. Furthermore, the Hunt 2003 solution can be adapted to simpler groundwater environments than the one shown in Figure 8, with the appropriate choice of parameters, as noted below:

- by setting K′ (the hydraulic conductivity of the aquitard) to zero and $S = \sigma$, the solution describes an unconfined aquifer with a stream recharge source. For this situation, λ and K″/B″ simply represent the hydraulic conductance of the stream bed;
- by setting λ (the conductance of the strata beneath the streambed) to zero, the solution describes the response of a semi-confined aquifer to pumping with no surface water effects (i.e. the Boulton Solution). This provides a useful comparison for the analysis of pumping test data to indicate the difference created by the effect of the surface waterway.

The application of this solution for surface water depletion situations in the Waikato is discussed in Section 5 of this report.

5.0 Application of Surface Water Depletion Calculations to the Waikato

The Hunt 2003 solution provides a consistent basis for evaluating groundwater abstractions and classifying them in terms of their relative effect on surface waterways. An indicative simulation has been carried out for three situations that might commonly occur based on a well located 500 m from a stream. The schematic layout of the aquifers and the aquifer parameters used in the simulations are shown schematically in Figure 10. The Hunt 2003 equation provides a realistic representation of Scenario 1 and 2, however for Scenario 3 it only allows for vertical flow downwards into the pumped aquifer, including vertically downwards seepage from the stream. Therefore, horizontal flow in the overlying aquifer (and lateral seepage from the stream into the overlying aquifer) is ignored. This creates a degree of uncertainty for the Scenario 3 simulation, although the uncertainty does not necessarily cause an underestimate of the stream depletion effect. The effect of horizontal flow in the shallow aquifer may be:

- to allow more stream depletion via lateral flow in the shallow aquifer;
- to allow more loss of upper aquifer storage, which would result in a corresponding reduction in the water lost from the stream.

The resulting stream depletion effect for the three scenarios described in Figure 10 is shown in Figure 11. They demonstrate how low permeability strata between the pumped aquifer and the surface waterway can significantly affect the rate at which stream depletion effects will develop.

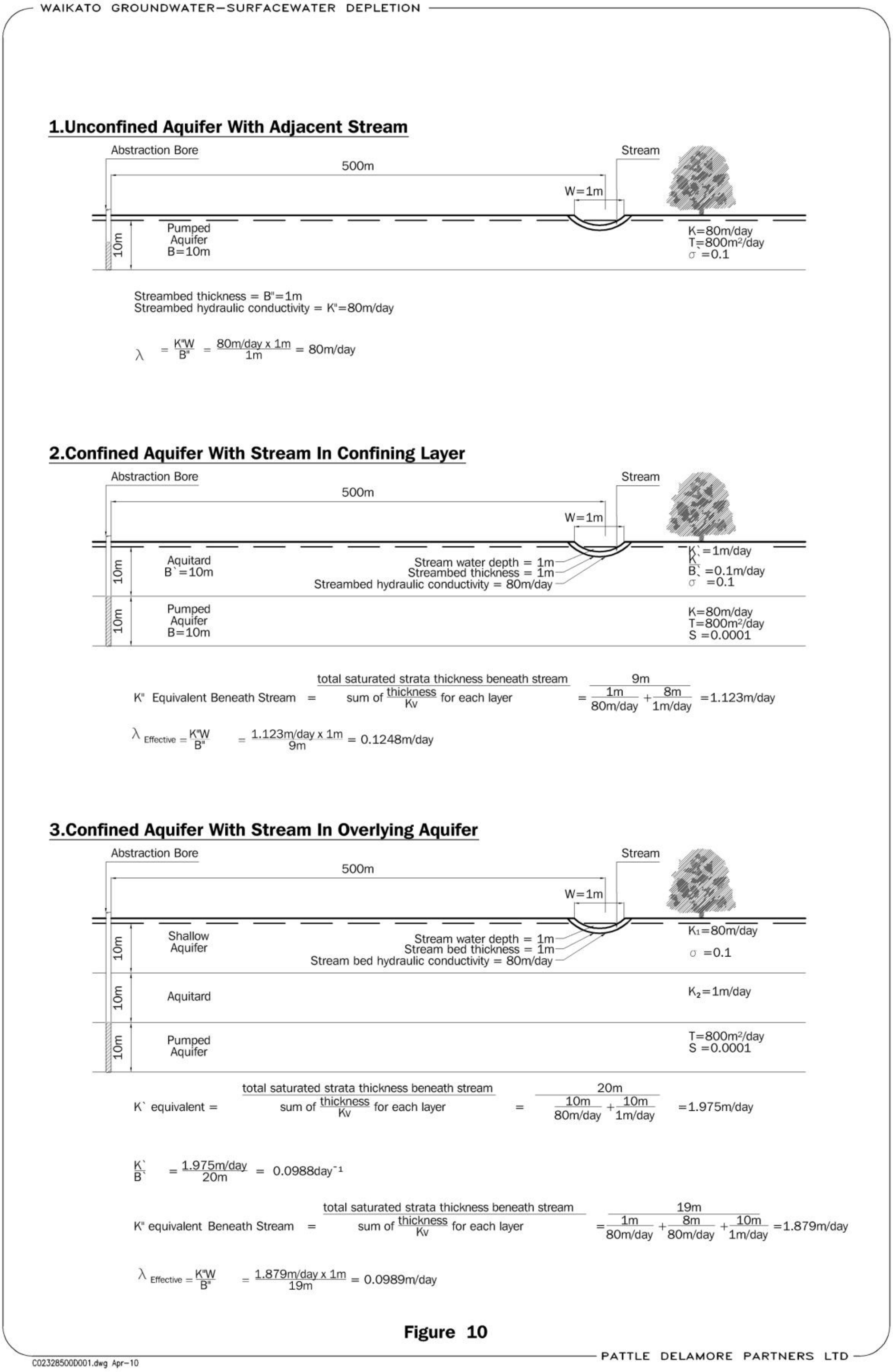

WAIKATO GROUNDWATER—SURFACEWATER DEPLETION
1.Unconfined Aquifer With Adjacent Stream
Abstraction Bore
Stream
500m
W=1m
10m
Pumped Aquifer B=10m
K=80m/day
T=800m²/day
σ =0.1
Streambed thickness = B"=1m
Streambed hydraulic conductivity = K"=80m/day
λ = K"W / B" = 80m/day x 1m / 1m = 80m/day
2.Confined Aquifer With Stream In Confining Layer
Abstraction Bore
Stream
500m
W=1m
10m
Aquitard B`=10m
Stream water depth = 1m
Streambed thickness = 1m
Streambed hydraulic conductivity = 80m/day
K`=1m/day
K`/B` =0.1m/day
σ =0.1
10m
Pumped Aquifer B=10m
K=80m/day
T=800m²/day
S =0.0001
K" Equivalent Beneath Stream = total saturated strata thickness beneath stream / sum of thickness/Kv for each layer = 9m / (1m/80m/day + 8m/1m/day) =1.123m/day
λ Effective = K"W / B" = 1.123m/day x 1m / 9m = 0.1248m/day
3.Confined Aquifer With Stream In Overlying Aquifer
Abstraction Bore
Stream
500m
W=1m
10m
Shallow Aquifer
Stream water depth = 1m
Stream bed thickness = 1m
Stream bed hydraulic conductivity = 80m/day
K1=80m/day
σ =0.1
10m
Aquitard
K2=1m/day
10m
Pumped Aquifer
T=800m²/day
S =0.0001
K` equivalent = total saturated strata thickness beneath stream / sum of thickness/Kv for each layer = 20m / (10m/80m/day + 10m/1m/day) =1.975m/day
K`/B` = 1.975m/day / 20m = 0.0988day⁻¹
K" equivalent Beneath Stream = total saturated strata thickness beneath stream / sum of thickness/Kv for each layer = 19m / (1m/80m/day + 8m/80m/day + 10m/1m/day) =1.879m/day
λ Effective = K"W / B" = 1.879m/day x 1m / 19m = 0.0989m/day
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Figure 10

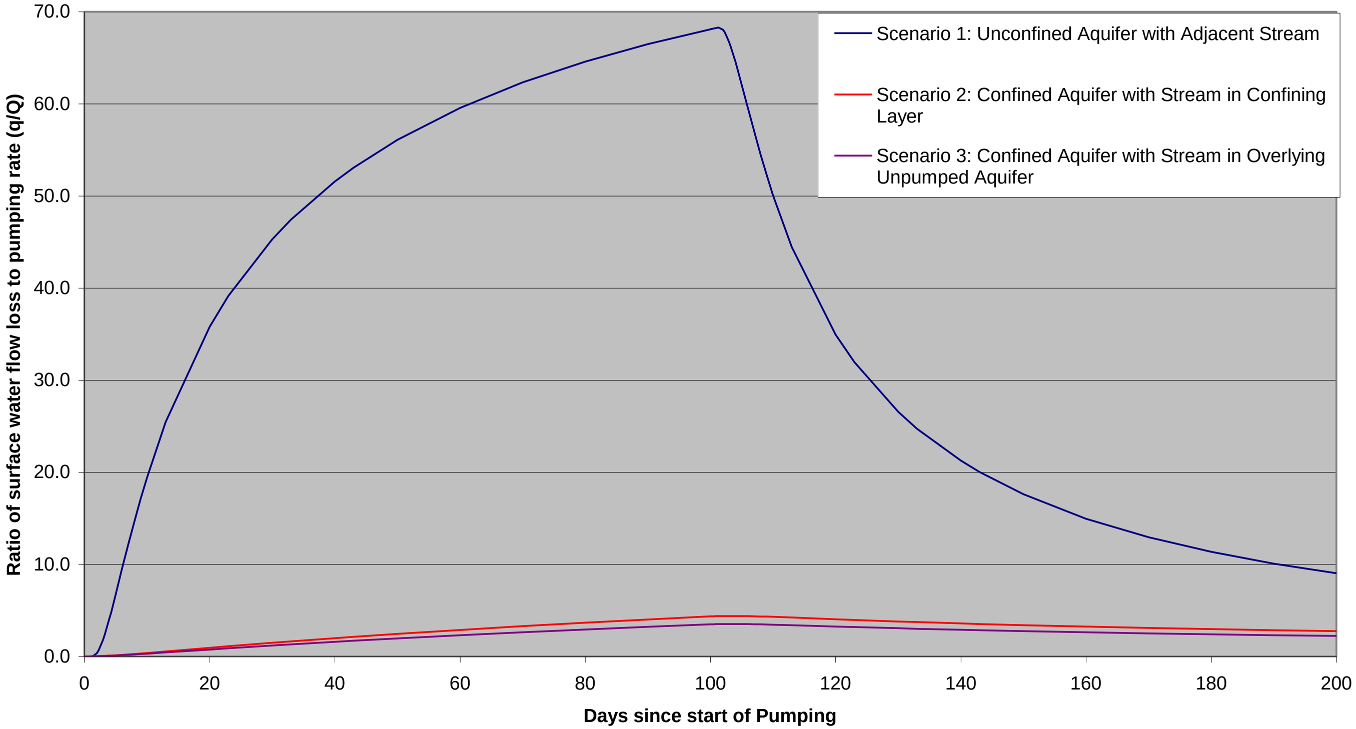


Figure 11 Simulation of Three Typical Scenarios.

For the purposes of this report, the equation is used in the form of a simple unconfined aquifer adjacent to the stream to provide an indication of the range of potential effects that may occur and the relative impacts that arise from changes in separation distance and aquifer transmissivity and storage. In the interests of reducing the number of variables in the assessment, we have adopted the following approach:

- the surface water depletion effect is reported as a ratio of the groundwater abstraction rate (i.e. q/Q). This provides a consistent measure of the relative degree of hydraulic connection between the well and the surface waterway. It is a measure of the proportion of the groundwater pumping rate that is affecting a nearby surface waterway;
- a consistent time has been used for the assessment. Such an approach is desirable to compare the relative effect of a range of abstractions. The choice of the appropriate time period could be related to the typical continuous period of time during which a well might operate at its maximum consented rate prior to a period of low flow or low level conditions in a surface waterway, which might be around 7 days. Alternatively, a time period could be chosen to reflect a pumping duration at which the effects of the abstraction become steady. Figure 12 provides an assessment of these time related effects for a range of scenarios with different aquifer parameters, as defined in Table 1. The results indicate that for high transmissivity aquifers (Scenario 3a-3c), most of the surface water depletion effects occur over a summer irrigation season (e.g. 100 days pumping), however for lower transmissivity strata (Scenarios 1 and 2) surface water depletion effects build up more gradually. Therefore, for the purposes of this assessment, we have considered the effects over a summer irrigation season (100 days). It is expected that longer term more gradual effects are best managed by seasonal allocations from the groundwater resource rather than by direct determination of surface water depletion effects;
- the stream bed conductance has nominally been based on a 1 m wide (W = 1m) and 1 m thick stream bed (i.e. B″ = 1 m), with a vertical hydraulic conductivity that is one tenth of the hydraulic conductivity of the pumped aquifer, i.e.

  $$K'' = 0.1K = 0.1T/b.$$

  For the purposes of this assessment, a 10 m thick pumped aquifer has been assumed (i.e. b = 10 m).

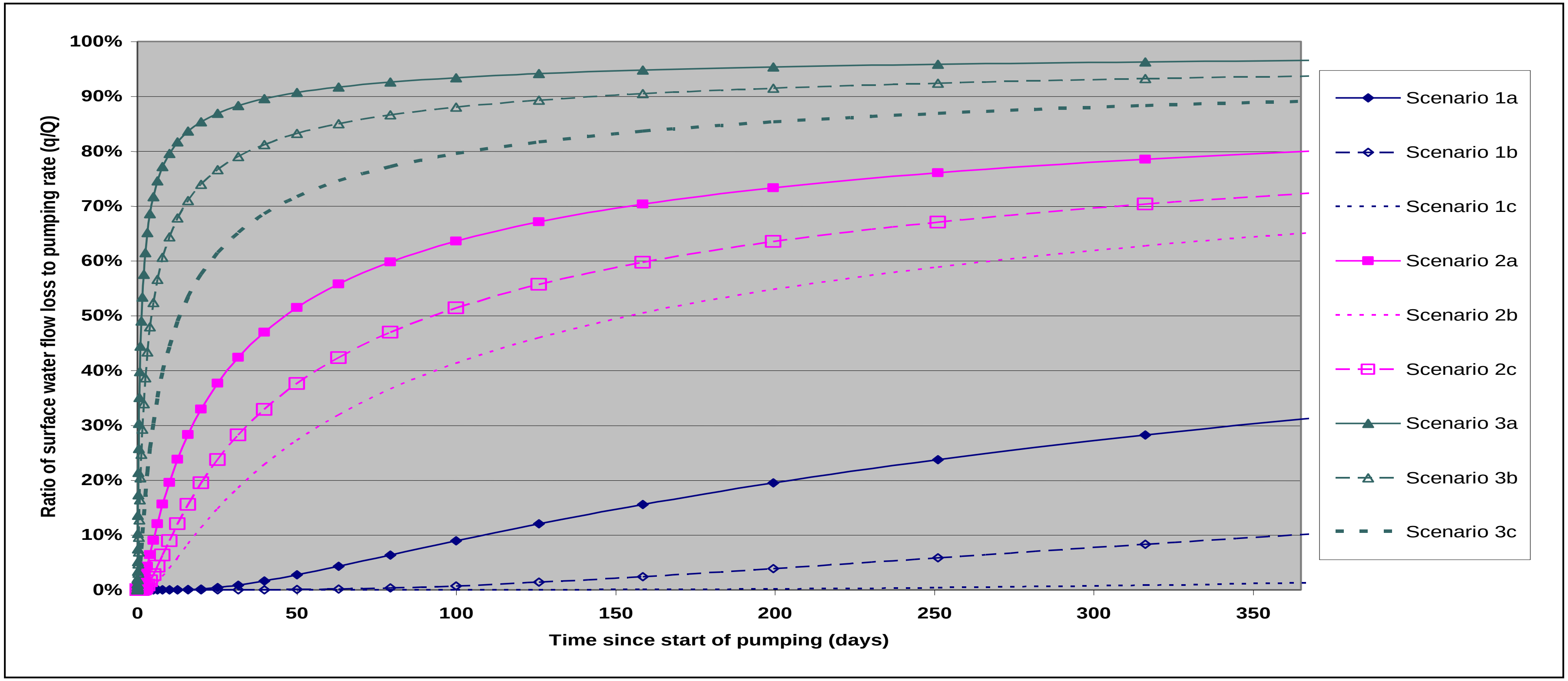


Figure 12 Effects of pumping duration on surface water depletion effects.

The results from a series of simulations are shown in Figure 13a (for 7 days pumping) and 13b (for 100 days pumping), with the aquifer parameters and surface water depletion rate (q/Q) summarised in Table 1 for three different separation distances between the pumping well and the surface waterway. The range of aquifer parameters listed in Table 1 covers a range of likely parameters defined by WRC.

Table 1: Summary of Surface Water Depletion Effects (q/Q) Shown in Figures 13a and 13b

Scenario	Aquifer Parameters			Surface Water Depletion Effects					
	T (m^2/day)	K' (m/day)	σ	After 7 Days Pumping			After 100 Days Pumping		
				Separation Distance Between Pumped Bore and Surface Waterway			Separation Distance Between Pumped Bore and Surface Waterway		
				100 m	1,000 m	5,000 m	100 m	1,000 m	5,000 m
1a	5	0.05	0.03	0.3	0.0	0.0	22.3	0.0	0.0
1b			0.1	0.0	0.0	0.0	6.8	0.0	0.0
1c			0.3	0.0	0.0	0.0	0.9	0.0	0.0
2a	100	1	0.03	28.1	0.0	0.0	72.3	15.2	0.0
2b			0.1	10.2	0.0	0.0	54.4	1.1	0.0
2c			0.3	1.9	0.0	0.0	34.5	0.0	0.0
3a	3,500	35	0.03	81.7	35.3	0.0	95.1	80.4	28.2
3b			0.1	68.3	9.7	0.0	91.0	65.1	5.1
3c			0.3	50.8	0.5	0.0	84.6	43.6	0.0

The highlighted values indicate the simulations which show the most significant surface water depletion effects (i.e. q/Q >10%). These occur in the following settings:

- high transmissivity aquifers;
- low-moderate transmissivity aquifers with low storage coefficients and/or long pumping periods.

It is also worth noting that higher yielding wells will correspond to the high transmissivity aquifers which will be situations where the high surface water depletion ratio (q/Q) corresponds to a high depletion rate of the surface waterway if the pumping well is in an aquifer with a direct hydraulic connection to the surface waterway.

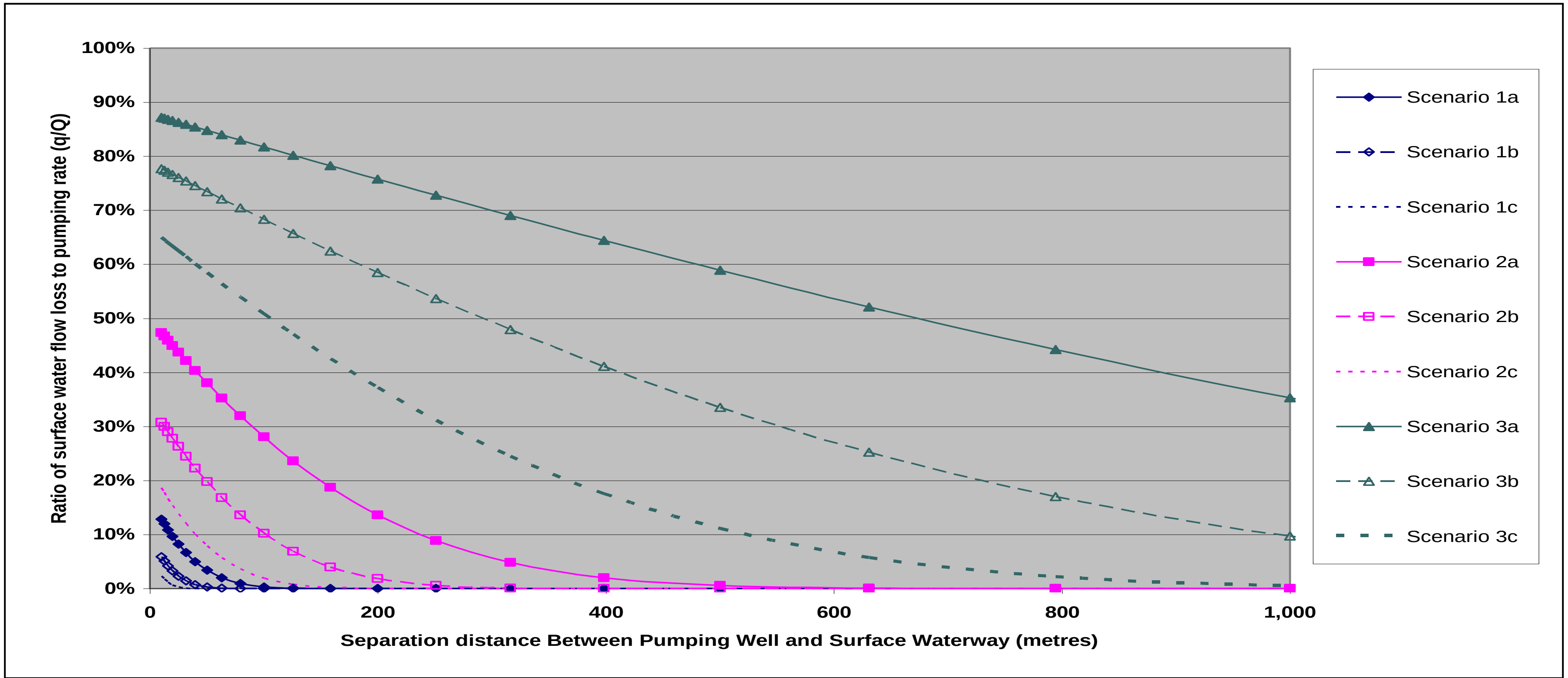


Figure 13a Effects of separation distance after a seven day pumping period.

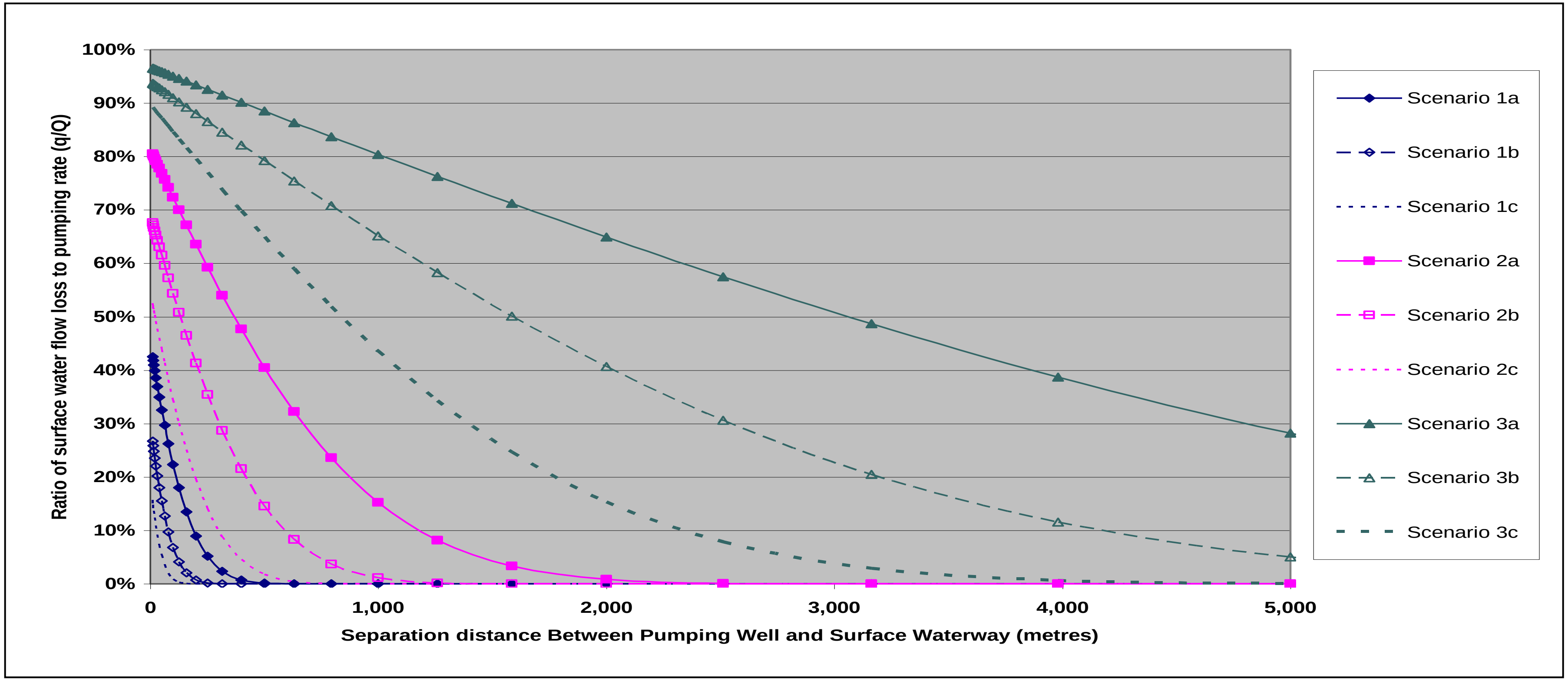


Figure 13b Effects of separation distance after a 100 day pumping period.

6.0 Management of Surface Water Depletion Effects in Chapter 3.3 (Water takes) of Waikato Regional Plan.

The simulations plotted in Figures 12 and 13 show that from the range of parameters that occur in the Waikato region there are a wide range of timeframes and distances over which surface water depletion effects occur.

Policy 10 i) of Chapter 3.3 of the Waikato Regional Plan (reproduced below) requires assessment of the nature and degree of hydraulic connection between groundwater and surface water takes, and if there is any connection this is assessed against relevant parts of Policy 11. Policy 10 i) does not give a measure of the 'nature and degree' of hydraulic connection, this is the purpose of Policy 12 w) (reproduced below).

Policy 10: How Groundwater Takes will be Classified

The Waikato Regional Council shall manage the taking of groundwater resources in a manner that meets the criteria for establishing Sustainable Yields from groundwater resources listed in Policy 4 by:

i) Notwithstanding Policies a) to g), assessing the nature of hydraulic connection (if any) between groundwater takes and surface water bodies and, if there is such a connection as defined by Policy 12 w), having regard to relevant parts of Policy 11 and Policy 12 when making decisions on groundwater takes.

Policy 12: Consent Application Assessment Criteria – Groundwater

When assessing resource consent applications for groundwater takes and/or any associated water use, the effects of these activities shall be assessed individually and cumulatively with all other existing (or currently applied for) water take and use activities. In doing so the Council shall have particular regard to the following matters:

w) The nature of hydraulic connection (if any) between the groundwater resource from which water is proposed to be taken and surface water bodies will generally be assessed on a case by case basis by evaluating:

i) *groundwater depletion of surface water bodies (i.e. the replacement of abstracted groundwater by flows from surface water bodies); and*

ii) *where no Table 3-6 Sustainable Yield has been identified for the groundwater resource, groundwater interception (i.e. the reduction of groundwater flows to surface water bodies)*

Where the case by case assessment demonstrates that there is a hydraulic connection and the assessed maximum surface water body depletion and interception loss (in cubic metres per day) calculated for the term of the consent exceeds 15 cubic metres per day then the Waikato Regional Council will assess the nature of the effect of the groundwater take on surface water bodies having particular regard to the relevant parts of Policy 11.

The nature of hydraulic connection does not need to be assessed and the groundwater take need not be assessed against Policy 11 or Policy 12(x) where:

iii) *the physical separation between the surface water body(s) and the underlying groundwater table is large enough to ensure that if there was a lowering of the groundwater table from pumping this would not impact the surface water body (as calculated for streams using the Advisory Note at the end of this Policy); or*

v) the take is allowed by s14(3)(b) of the RMA, or is less than 15 cubic metres per day (the maximum allowed by Permitted Activity Rule 3.3.4.12); or

vi) the take is temporary and is allowed by Permitted Activity Rule 3.3.4.14; or

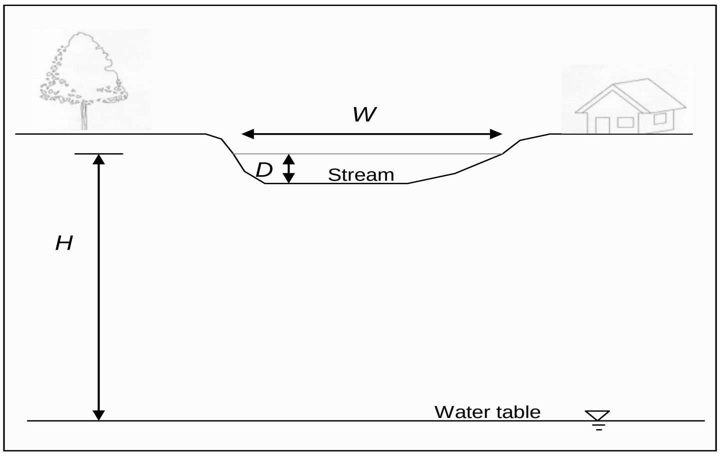
vii) the take is for well or aquifer testing and is allowed by Permitted Activity Rule 3.3.4.15; or

ix) the take is a renewal of a groundwater take consent within the Waikato River catchment upstream of the HPS mixing zone and the take was authorised at 15 October 2008*

Except in the circumstances described under (v) to (ix) above, the nature of hydraulic connection shall always be assessed for groundwater takes within the Waikato River catchment upstream of the Karapiro Dam unless a Table 3-6 Sustainable Yield has been set for the groundwater resource from which the groundwater take is to occur.

Advisory Notes for Policy 9(sa)

- *The physical separation described in Policy 12 w) iii) for streams exists when:*
    - *i. the depth to the water table (H) below a stream that occurs within the area affected by the groundwater abstraction is greater than five times the maximum depth of water in the stream (D), i.e. H ≥ 5D, and*
    - *ii. the depth to the water table below any potential affected stream surface (H) is greater than twice the stream width (W) i.e. H ≥ 2W.*
- *For the avoidance of doubt, the water table (H) is the level below the land surface at which the subsurface material is fully saturated with water.*



There are two steps in dealing with groundwater takes and the assessment of the potential impact on surface waters. Firstly, it needs to be clarified if there is a connection or not between the two resources (Policy 12 w) iii-ix)), and secondly, if there is a connection the impacts on the two resources needs to be managed (Method 3.3.4.7).

6.1 Assessing the degree of connection

Policy 12 w) and parts w) iii) to ix) were developed to let applicants know under which situations a groundwater take does not require an assessment against the relevant surface water policies. In effect determining when a hydraulic connection does not exist.

Part w) iii) requires there to be enough physical separation between the surface water body and the water table so that if there was a lowering of the water table from pumping this would not impact the surface water body. This is derived from Section 3 of this report. This is relevant for all takes from unconfined, semi-confined and confined aquifers. The advisory note provides some guidance on what is enough physical separation based on Section 3 of this report.

There is a further exception to part iii). In the catchment above Karapiro Dam an applicant cannot rely on part iii) as a reason for not doing a case by case assessment. This further exception deals with the issue that requirement iii) may be met at the point of groundwater abstraction (i.e. location of the well), but may not be met at some distance within the influence of drawdown from the groundwater take. This situation is quite likely to occur in the catchment above Karapiro. It is important to acknowledge that, even if these conditions are met in the reach of a stream nearest to the well, that the abstraction may result in stream depletion further downstream or upstream if the stream is connected to groundwater in a different location that experiences the effects of the groundwater abstraction.

Part w) v) does not require a case by case assessment if the take is allowed by section 14(3)(b). Part v) also does not require case by case assessment if the take is less than 15 m^3/d and provided for via Permitted Activity Rule 3.3.4.12. For these takes the hydraulic connection does not need to be assessed. There is no technical justification for this within this report. However, the rationale behind these provisions is that small groundwater takes which do not require consent are assumed to have a small impact on surface water and hence do not need to be assessed against the surface water policies. For example, if a user abstracts less than 15 m^3/d from groundwater the impact on the stream, if any, will also be less than the 15 m^3/d.

Part w) vi) deals with temporary takes which are short in duration and limited in the amount that can be abstracted. For these groundwater takes the hydraulic connection to surface water does not need to be assessed because any impact will be of a very limited nature.

Part w) vii) deals with takes for aquifer testing. Again these are activities of short duration and are excluded on a pragmatic basis as these activities are necessary to provide the information to assess the impacts of groundwater takes.

Part w) ix) deals with pre-existing groundwater takes whose effects were not quantified at the time of their granting and they were not specifically accounted for in setting the 5% of Q_5 for surface water allocation at Karapiro Dam. This provision provides for their continued operation without the need for an assessment of their impacts on surface waters.

If an applicant is unable to met the criteria iii) to ix) as discussed above they are required to assess their impact on surface waters. If the assessment shows a loss of less than 15 m^3/d from surface waters the application does not need to be assessed against Policy 11. However, if the assessed impact is greater than 15 m^3/d the application needs to be assessed against Policy 11, and via Method 3.3.4.7 will be accounted for within the surface water allocation and may be restricted in a similar manner to a surface water take. Section 4 of this report discusses methods for quantifying the effect of groundwater pumping on surface waterways. The Environment Canterbury website under 'Groundwater tools' also provides links to many of these tools for assessing effects on streams.

6.2 Managing the degree of connection

Where there is a hydraulic connection as determined by Policy 12 w) iii)-ix), Method 3.3.4.7 then determines if restrictions will be applied to the groundwater take to protect the hydraulically connected surface water body and how the amount of water allocated is distributed between the surface or groundwater resource.

3.3.4.7 Groundwater Depletion of Surface Water

Waikato Regional Council will manage the surface water depletion effects identified by Policy 10 i) and Policy 12 w) using either one or both of the following methods.

a) A groundwater take will have surface water restrictions imposed where there is a hydraulic connection between the two systems, and a restriction of the groundwater take will result in an increase in surface water flows during times of restrictions.

b) Where a groundwater take is assessed under Policy 10 i) as impacting on surface water resources and this cannot be solely managed with restrictions on the groundwater take, the reduction in surface water flow occasioned by the groundwater take will be quantified and included in the surface water allocation regime used for assessing the cumulative allocation for the surface water takes in Chapter 3.3. The remainder of the groundwater take (the actual rate of take less the amount quantified as being a reduction in surface water flow) will be allocated against the sustainable yield in Table 3-6.

Takes which are highly connected to the surface water body can largely operate as surrogate surface water takes. In this situation they are given surface water restrictions if it is likely that these will be effective in protecting the surface water minimum flows from allocation during summer low flows (Method 3.3.4.7 a)). The method does not set specific thresholds (e.g. depth, distance or aquifer type) to determine which takes will have restrictions[1], but describes the management approach that is to be achieved. That is, if the case by case assessment shows that restricting the groundwater take during surface water low flow conditions will be of some benefit to the surface water body then the groundwater take will be restricted.

Method 3.3.4.7 b) then determines how the quantum of water allocated to the groundwater takes is distributed between the surface or groundwater resource.

7.0 Conclusion

Groundwater abstractions affect surface waterways to differing degrees depending on:

π the separation distances between the abstraction point and the surface waterway;

[1] Given the range of aquifer parameters that have been defined for the Waikato region, there are no obvious cut-off distances that can be defined. Figure 13b shows that in high transmissivity strata, significant effects can extend over large distances such that it is difficult to specify absolute cut-off distances beyond which surface water depletion effects become less significant.

- π the magnitude and duration of abstraction, and
- π the hydrogeologic parameters of the groundwater system and the bed of the surface waterway.

These are also the factors that determine how groundwater levels change as a result of the pumping.

For the range of parameters that occur in the Waikato region, there is a continuum of possible effects that develop over a wide range of timeframes and separation distances. Therefore, a classification of effects caused by individual abstractions is best used to determine the way in which this effect should be managed. The classification should be used to define the following:

- π groundwater abstraction effects that are significant and direct should be managed by surface water allocation rules;
- π groundwater abstraction effects that are significant but more delayed in time such that they need to be included in surface water allocation regimes but there is no significant environmental benefit in applying surface water flow restrictions;
- π groundwater abstraction effects that are small and/or delayed in time to such an extent that they should be managed in terms of overall groundwater allocation rules rather than explicit surface water management tools.