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Report on Waikato ground-surface water depletion assessment

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Report on Waikato Ground-Surface Water Depletion Assessment

- Prepared for
  Environment Waikato

- June 2010

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1.0 Introduction

Environment Waikato (EW) are progressing a water allocation variation to their Waikato Regional Plan. The plan identifies the potential for groundwater abstractions to adversely affect surface waterways. EW 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. 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);

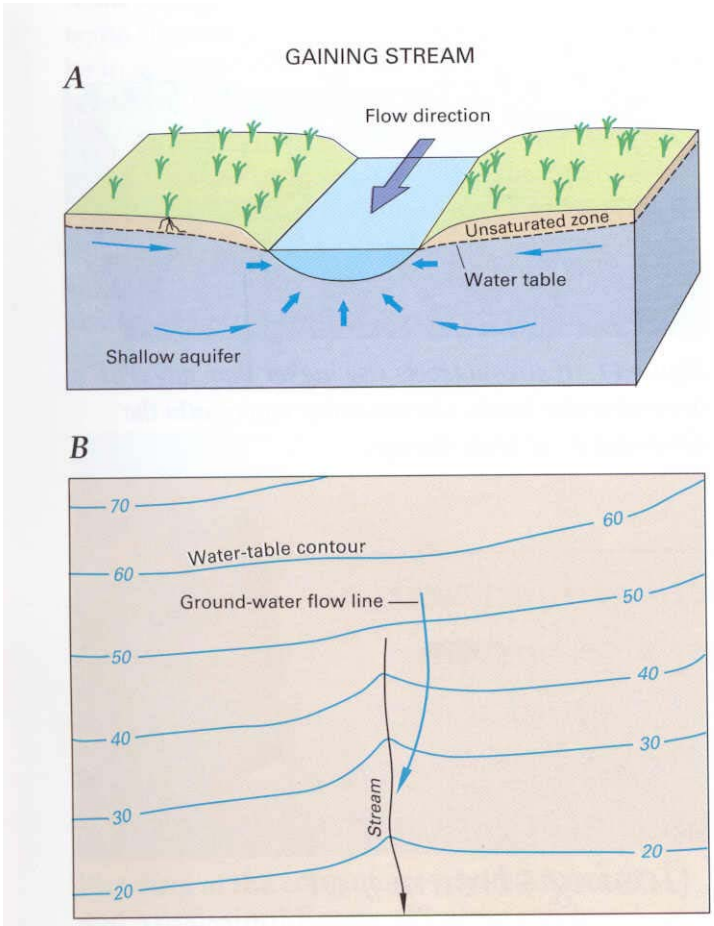


Figure 1 Gaining streams receive water from the groundwater system (A). This can be determined from water table contour maps because the contour lines point in the upstream direction where they cross the stream (B). (From USGS 1998.)

(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).

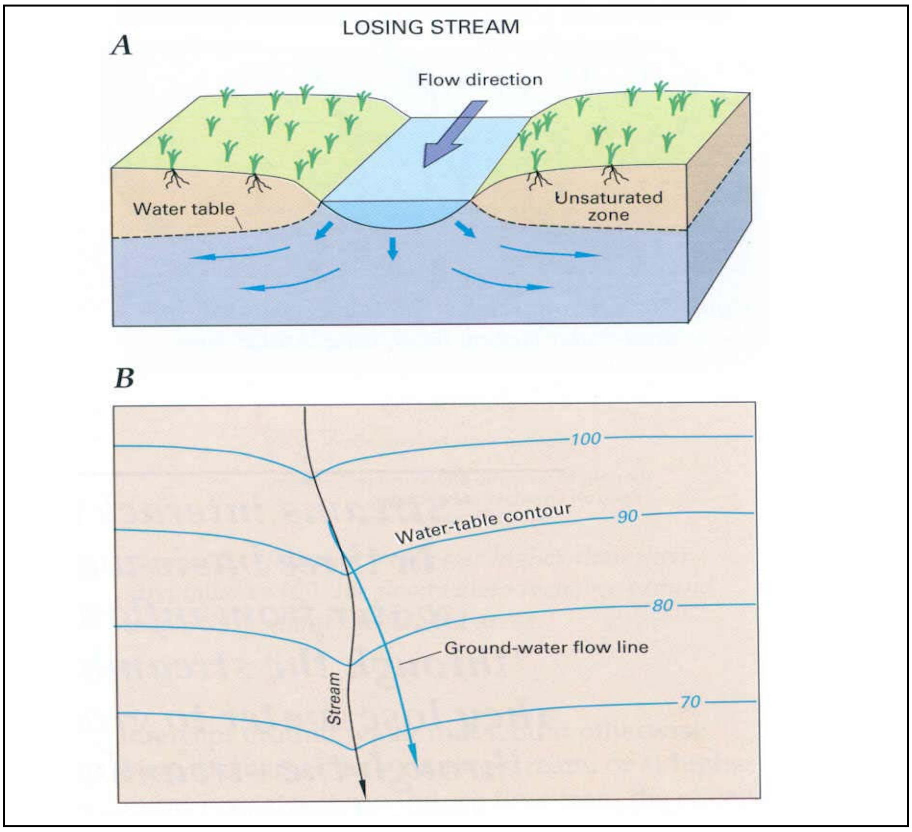


Figure 2 Losing streams lose water to the groundwater system (A). This can be determined from water table contour maps because the contour lines point in the downstream direction where they cross the stream (B). (From USGS 1998.)

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.

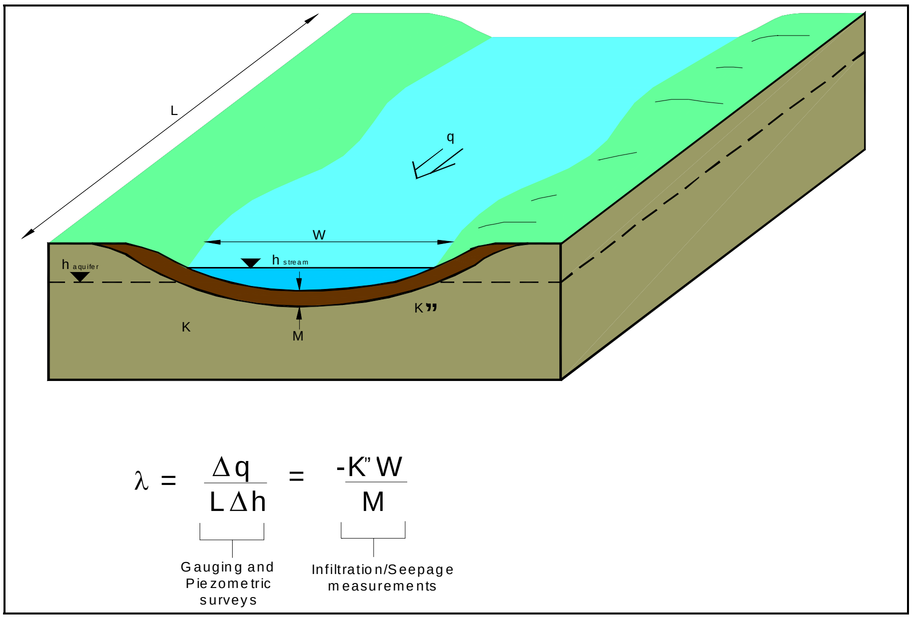


Figure 3 Schematic diagram of parameters that affect the movement of water between surface waterways and groundwater.

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.

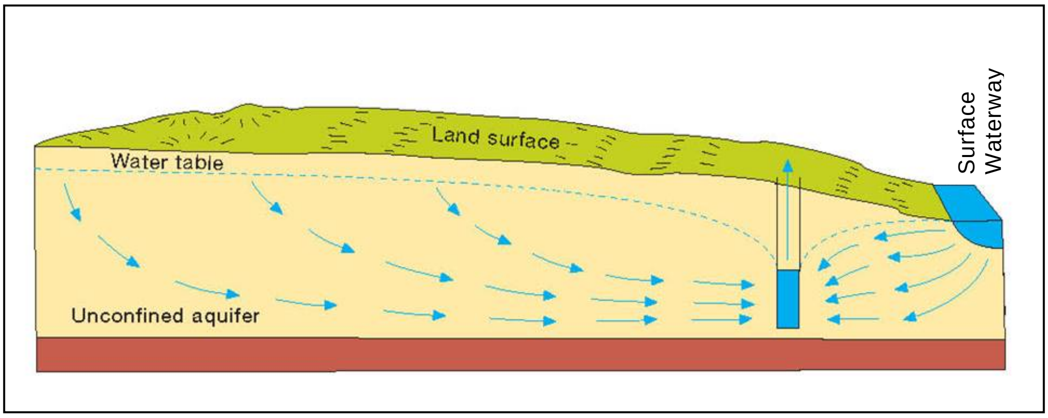


Figure 4 Surface water depletion concept.

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.

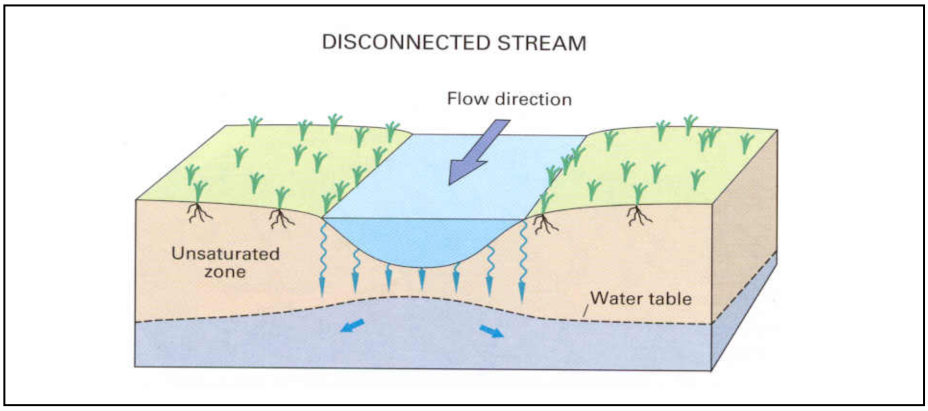


Figure 5 Disconnected streams are separated from the groundwater system by an unsaturated zone. (From USGS, 1998.)

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.

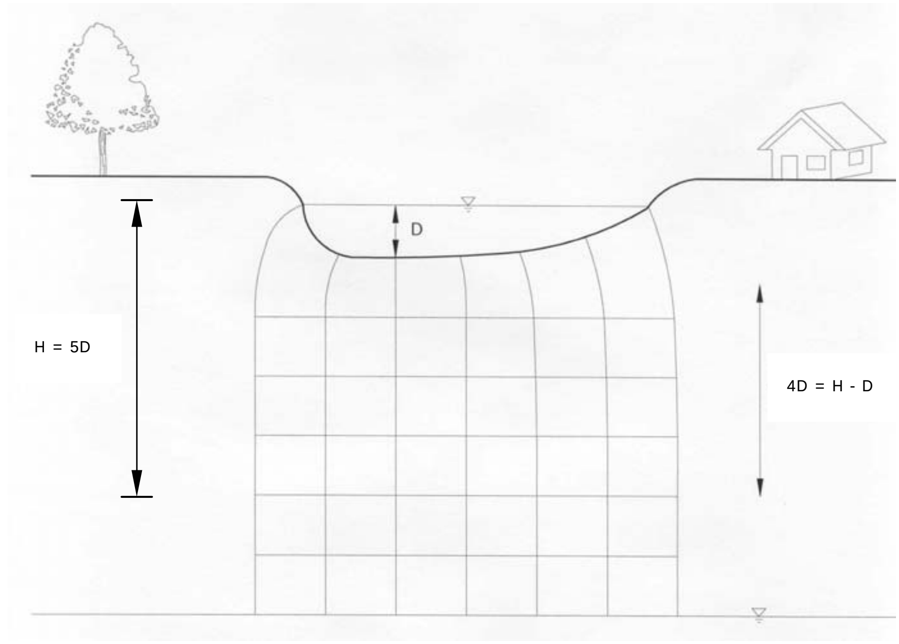
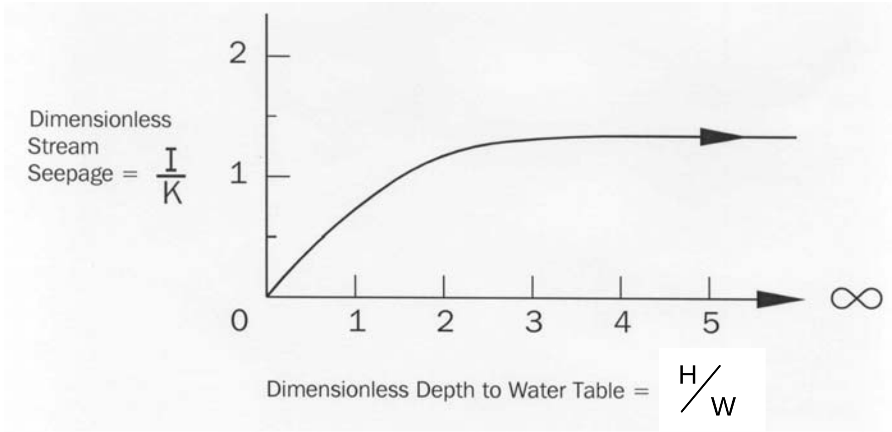


Figure 6 Flow net for seepage beneath a stream, showing that uniform vertical flow is reached by a depth of 5D below the stream surface (i.e. 4D below the streambed).

(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:

- the groundwater abstraction rate;
- the duration of the pumping period;
- the separation distance between the abstraction well and the surface waterway;
- 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');
- 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	• Direct measurement by the use of flow meters on abstraction wells • Inferred rates from pump performance curves and readings of pump electricity meters • 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	• Direct measurement linked to monitoring of flow meters and/or electricity meters • Inferred data from an irrigation design or commercial/industrial/ reticulated supply requirements • 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	• Topographic maps • Aerial photos • 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	m^2/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 m^2/day
Source of Data	• Pumping tests on abstraction wells with observation wells to monitor surrounding drawdown effects • Slug tests in low transmissivity strata • 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	• Pumping tests which utilise observation wells • 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	• Pumping tests which utilise observation wells • 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	• Pumping tests with multiple observation bores • Gauging surveys (to determine gains or losses in flow along stream reaches), coupled with elevation surveys of stage height and groundwater levels • Seepage meters • Infiltration tests • 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.

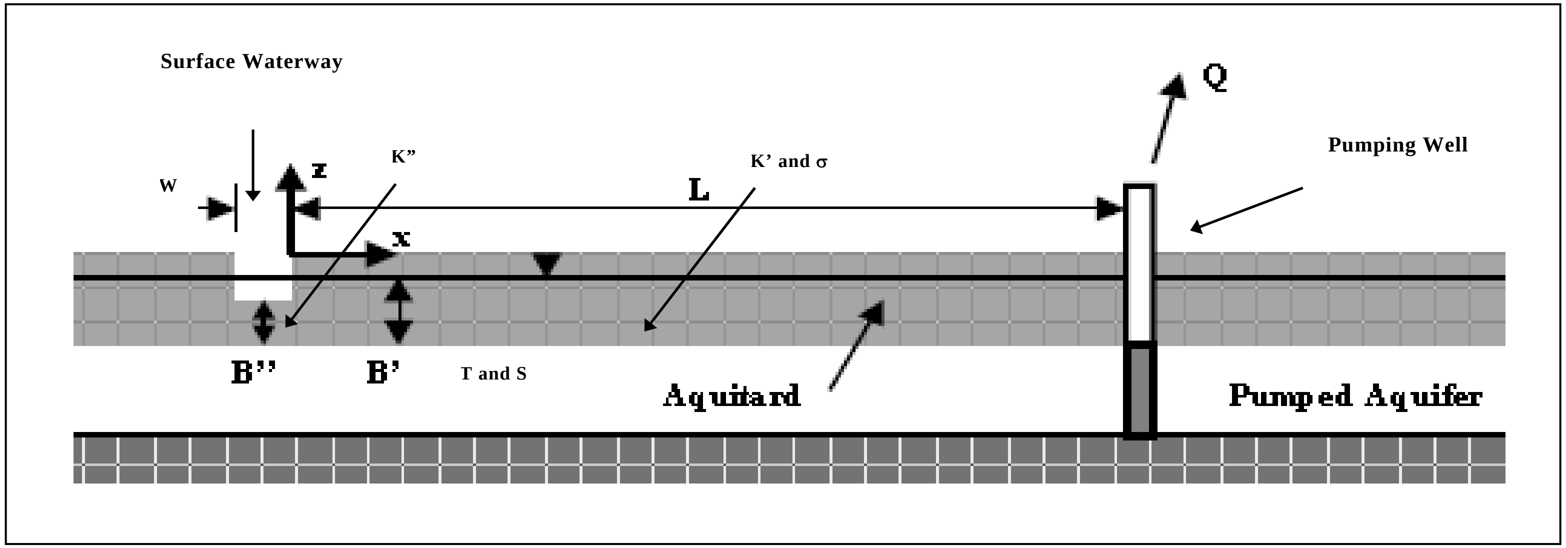


Figure 8 Geology for the surface water depletion analytical solution developed by Dr Bruce Hunt.

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).

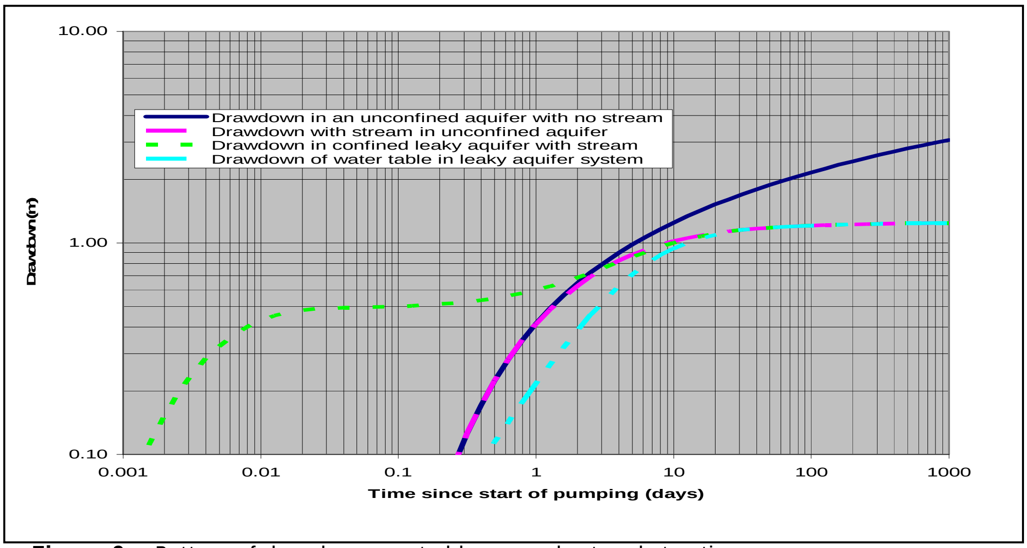


Figure 9a: Pattern of drawdown created by groundwater abstraction.

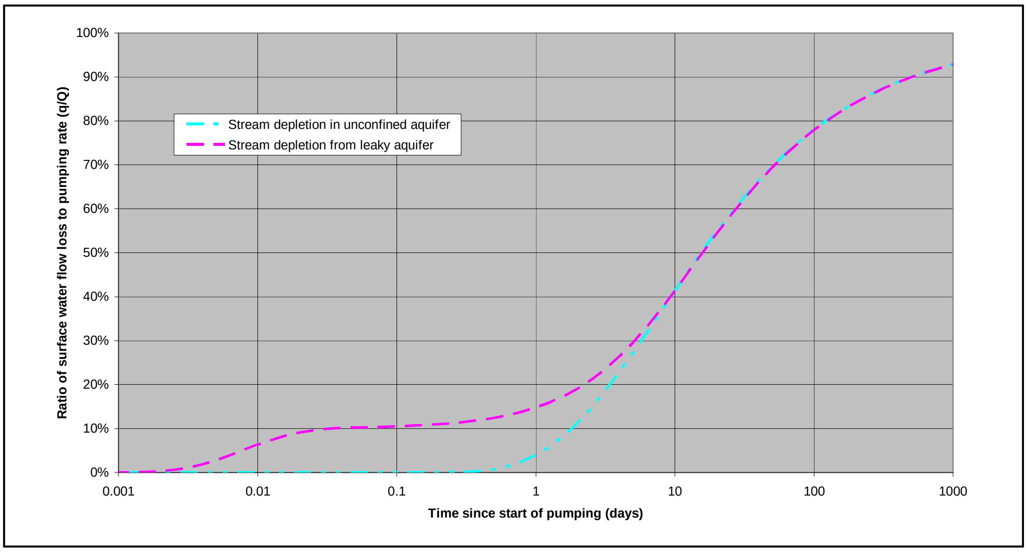


Figure 9b: Pattern of surface water depletion created by groundwater abstraction.

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

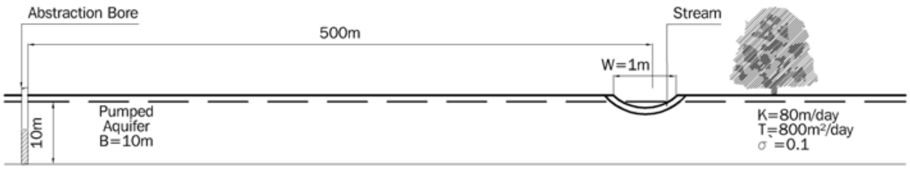
The Hunt 2003 solution provides a consistent basis for evaluating groundwater abstractions and classifying them in terms of their relative effect on surface waterways. An indicative simulation has been carried out for three situations that might commonly occur based on a well located 500 m from a stream. 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

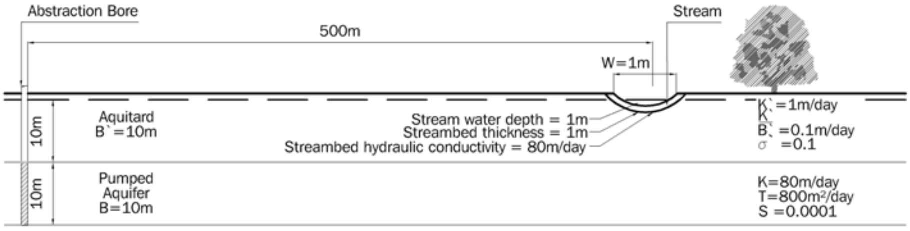
1.Unconfined Aquifer With Adjacent Stream



Streambed thickness = B"=1m
Streambed hydraulic conductivity = K"=80m/day

$$\lambda = \frac{K''W}{B''} = \frac{80\text{m/day} \times 1\text{m}}{1\text{m}} = 80\text{m/day}$$

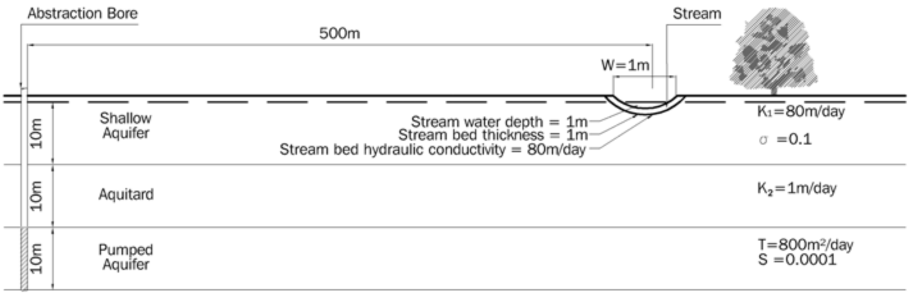
2.Confined Aquifer With Stream In Confining Layer



$$K'' \text{ Equivalent Beneath Stream} = \frac{\text{total saturated strata thickness beneath stream}}{\text{sum of } \frac{\text{thickness}}{Kv} \text{ for each layer}} = \frac{9\text{m}}{\frac{1\text{m}}{80\text{m/day}} + \frac{8\text{m}}{1\text{m/day}}} = 1.123\text{m/day}$$

$$\lambda_{\text{Effective}} = \frac{K''W}{B''} = \frac{1.123\text{m/day} \times 1\text{m}}{9\text{m}} = 0.1248\text{m/day}$$

3.Confined Aquifer With Stream In Overlying Aquifer



$$K` \text{ equivalent} = \frac{\text{total saturated strata thickness beneath stream}}{\text{sum of } \frac{\text{thickness}}{Kv} \text{ for each layer}} = \frac{20\text{m}}{\frac{10\text{m}}{80\text{m/day}} + \frac{10\text{m}}{1\text{m/day}}} = 1.975\text{m/day}$$

$$\frac{K`}{B`} = \frac{1.975\text{m/day}}{20\text{m}} = 0.0988\text{day}^{-1}$$

$$K'' \text{ equivalent Beneath Stream} = \frac{\text{total saturated strata thickness beneath stream}}{\text{sum of } \frac{\text{thickness}}{Kv} \text{ for each layer}} = \frac{19\text{m}}{\frac{1\text{m}}{80\text{m/day}} + \frac{8\text{m}}{80\text{m/day}} + \frac{10\text{m}}{1\text{m/day}}} = 1.879\text{m/day}$$

$$\lambda_{\text{Effective}} = \frac{K''W}{B''} = \frac{1.879\text{m/day} \times 1\text{m}}{19\text{m}} = 0.0989\text{m/day}$$

Figure 10

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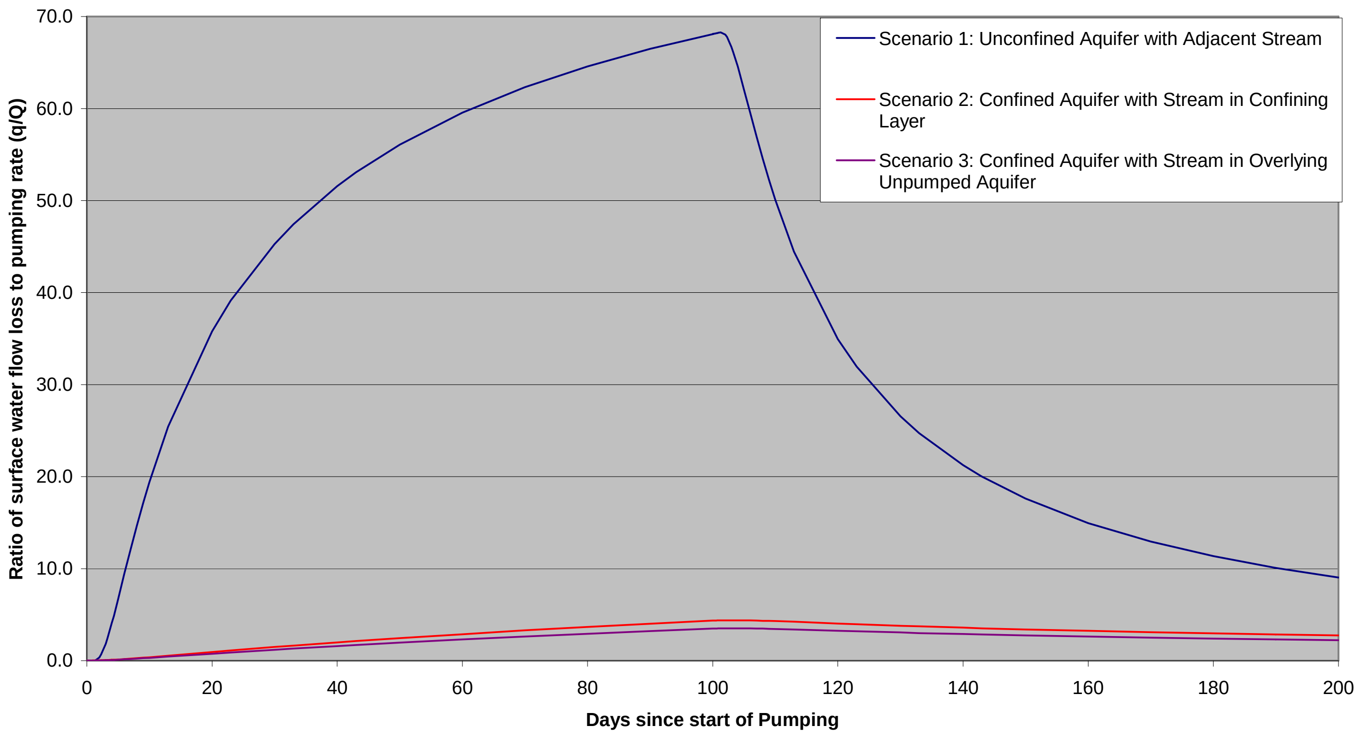

Figure 11 Simulation of Three Typical Scenarios.

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).

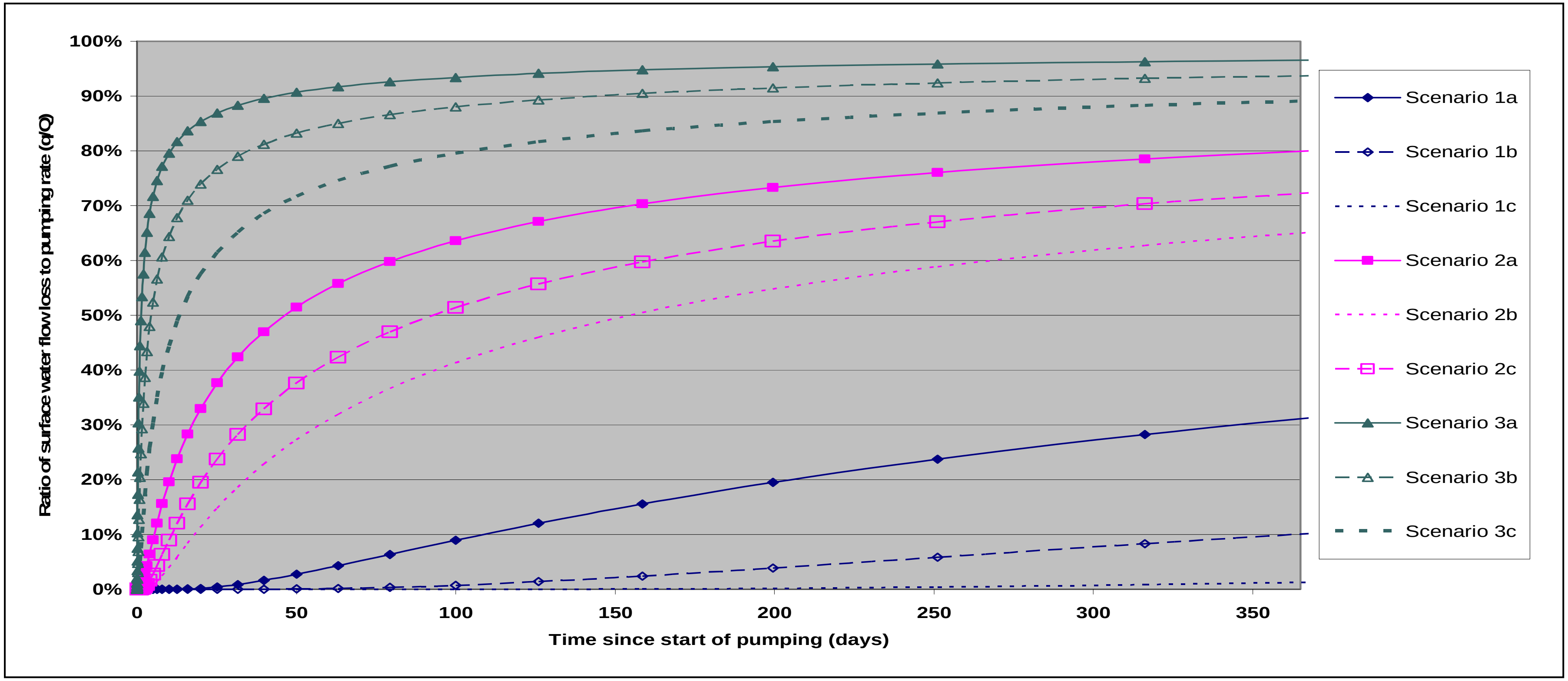

Figure 12 Effects of pumping duration on surface water depletion effects.

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 EW.

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: Separation Distance Between Pumped Bore and Surface Waterway			After 100 Days Pumping: 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.

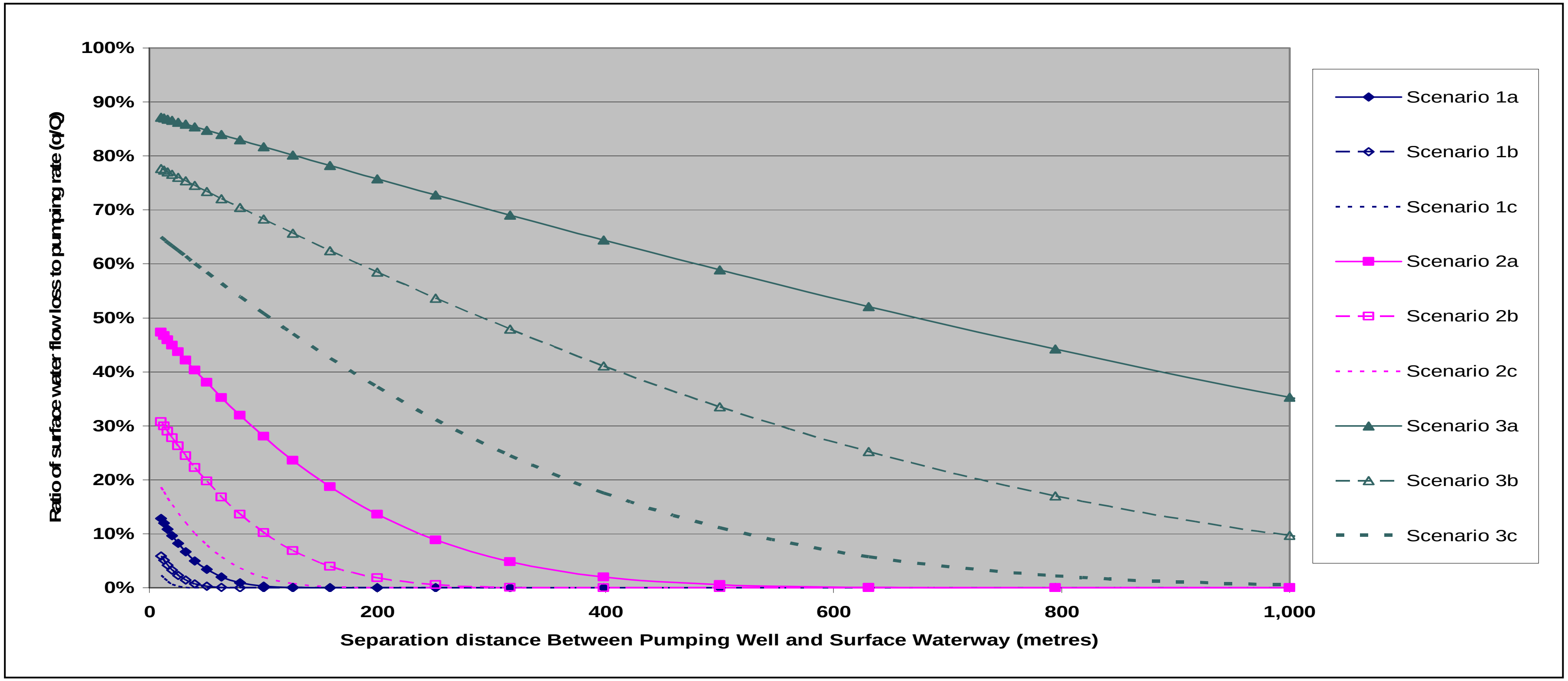

Figure 13a Effects of separation distance after a seven day pumping period.

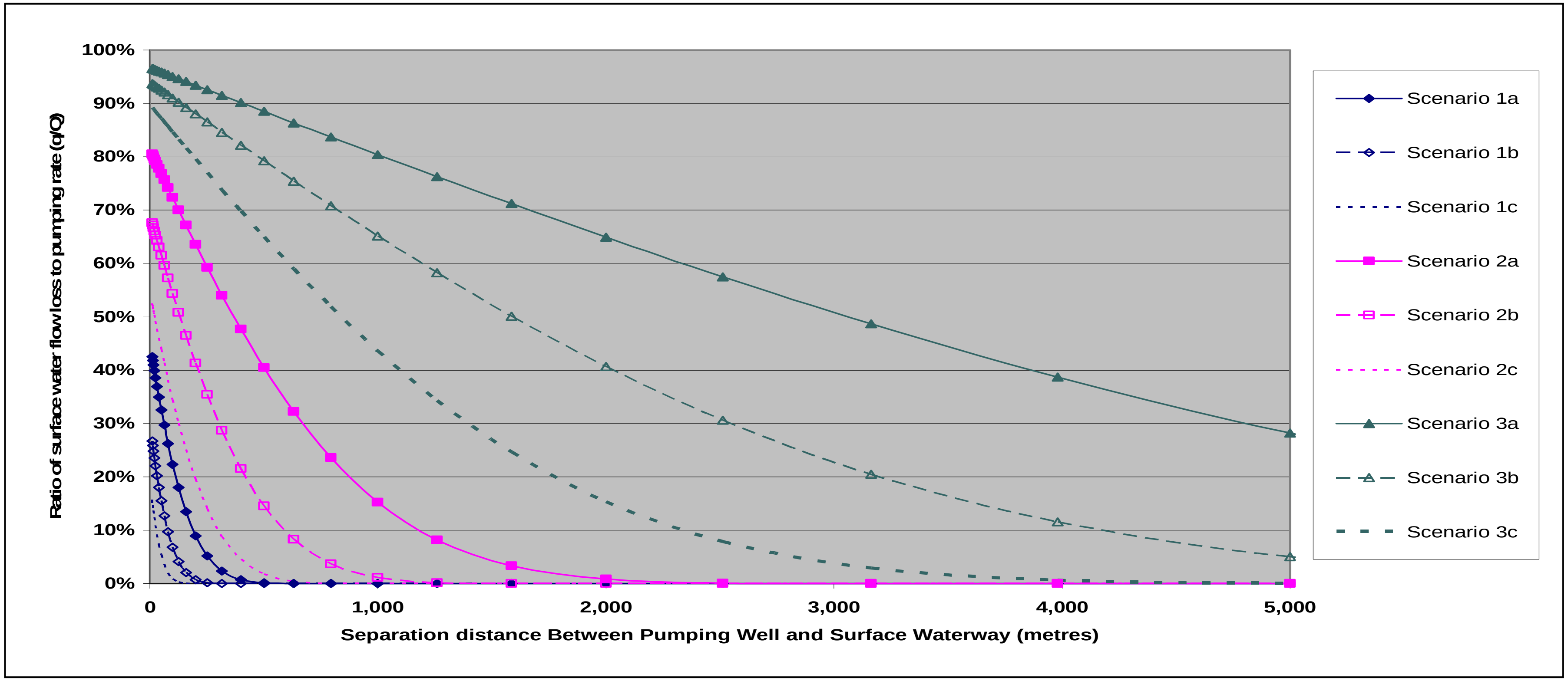

Figure 13b Effects of separation distance after a 100 day pumping period.

6.0 Management of Surface Water Depletion Effects

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.

It is difficult to directly manage surface water depletion effects that build up gradually over a long period of time. Therefore, effects that are still small after a 100 day pumping period are perhaps best managed by the application of catchment-wide allocation limits. This involves the definition of a “groundwater allocation zone” and defining a volumetric limit for the defined area of aquifers over a fixed time (e.g. a volume that can be abstracted over an irrigation season or over an annual period).

Volumetric allocation limits are sometimes based on a proportion of the annual recharge to the aquifer. Alternatively the limits can be based on the potential cumulative effects of abstraction on the discharge from a groundwater basin, or they can be set by a consideration of both recharge and discharge effects.

For more direct effects on surface waterways (i.e. those that happen over a quicker timeframe and are of a bigger magnitude), it may be appropriate to manage the effect in a similar manner to a surface water abstraction effect. From a management point of view, it is most straightforward to define a fixed distance around a surface waterway at which groundwater abstractions are either included or excluded from surface water management restrictions. Otago Regional Council utilise an approach whereby distances are defined based on the groundwater abstraction rate, however 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. Even if small magnitude effects were to be excluded (and managed by a groundwater allocation approach), 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 . Therefore, in our view, it is best for surface water depletion effects to be managed via a case by case assessment of individual effects. A classification of these individual assessments which is similar to one that has recently been proposed by PDP for Horizons Regional Council’s One Plan is set out below. This is presented as an example of the style of management approach that can be adopted, although it is expected that EW will want to make some modifications to tie in with their own regional approach to water resources management.

Table 2: Classification of Surface Water Depletion		
Classification of Groundwater Effects on Surface Waters	**Degree of Connection**	**Management Approach**
Class 1: Riparian	Any groundwater abstraction screened within the geologically Recent river bed strata of a surface waterway.	The groundwater abstraction is subject to the same restrictions as a surface water abstraction, unless there is clear hydrogeological evidence that demonstrates that the effect of pumping will not impact on the surface water way.
Class 2: High	The surface water depletion effect is greater than the "Negligible" classification and calculated as greater than or equal to 90% of the maximum consented groundwater pumping rate after seven days of pumping, or greater than or equal to 50% of the average groundwater pumping rate after 100 days of pumping.	The groundwater abstraction is subject to the same restrictions as a surface water abstraction.
Class 3: Medium	The surface water depletion effect is greater than the "Negligible" classification and calculated as less than 50% and greater than or equal to the lesser of: • 20% of the groundwater pumping rate after 100 days of pumping; • or 1% of the minimum flow for the surface waterway.	The calculated loss of surface water is included in the surface water allocation regime, but no specific low flow restrictions are imposed on the groundwater abstraction because the effect is not direct.
Class 4: Low	The surface water depletion effect is greater than the "Negligible" classification and calculated as less than 20% of the groundwater pumping rate after 100 days of pumping, or less than 1% of the minimum flow for the surface waterway (whichever is the smaller).	No surface water management rules required because the effect is small and delayed. This type of take may be managed via a groundwater allocation limit that is set in part to manage these small and delayed effects on surface water flows.
Class 5: Negligible	The effect is not classified as riparian and the calculated surface water depletion effect after 100 days pumping is less than either 1% of the minimum flow for the surface waterway or 5 L/s (whichever is the smaller).	No surface water management rules required because the effect is small. This dispensation for small abstraction effects recognises the uncertainties associated with trying to quantify surface water depletion effects. This type of take may be managed via a groundwater allocation limit that is set in part to manage these small and delayed effects on surface water flows.

Those effects that are classified as “Low” or “Negligible”, will still have a potential surface water depletion effect, however these small and delayed effects can be managed by a catchment-wide groundwater allocation limit, rather than direct management based on the state of the surface water resource.

The classification system is based on the ratio of the surface flow depletion rate to the groundwater pumping rate, which provides an indication of the degree of hydraulic connection between the point of groundwater abstraction and the surface waterway.

However, the key significance of the effect will depend on the magnitude of the depletion effect relative to the size of the surface waterway. By bringing the surface water depletion effect into the surface water management regime in the Riparian, High and Medium categories, the magnitude of the effect can be correctly managed. For the Low or Negligible classification, a threshold involving a proportion of the minimum flow may be relevant to ensure that all effects of any significance are incorporated into the surface water management strategy.

One significant implication of a surface water depletion strategy based on Table 2 is that for surface waterways that are fully allocated, it may not be possible to have any groundwater abstraction for takes that are classified as Riparian, High or Medium.

What this assessment also demonstrates is that there is a continuum of surface water depletion effects over different pumping periods and separation distances between abstraction bores and surface waterways, so the cut-off between classification criteria show in Table 2 is quite arbitrary and could be adjusted to suit Waikato conditions. However, in general terms, the overall philosophy and approach described in Table 2 is considered realistic.

7.0 Conclusion

Groundwater abstractions affect surface waterways to differing degrees depending on:

- the separation distances between the abstraction point and the surface waterway;
- the magnitude and duration of abstraction, and
- 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:

- groundwater abstraction effects that are significant and direct should be managed by surface water allocation rules;

- 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;
- 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.