Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

Memo

Date	June 18, 2019
To	Alastair Picken, Principal Planner
cc	
From	Zeb Etheridge, Senior Scientist, Groundwater

Subject: Assessment of well criteria for transfers

1 Summary

The purpose of this memo is to provide some simple criteria which can be used to determine whether a well could cause stream depletion if pumped continuously for a 150 day period. My assessment concludes that wells located at least 100 m from a stream, with a minimum top screen depth of 50 m and a 150 day average abstraction rate of no more than 10 L/s are unlikely to cause stream depletion as per the LWRP definition. I therefore recommend that these criteria should used to determine whether a stream depletion assessment is required in order to access to the proposed Transfer (T) Blocks.

2 Background and purpose

The Waimakariri Zone Implementation Programme Addendum (ZIPA) recommends that groundwater should be made available within the allocation framework for transfer of surface water and stream-depleting groundwater takes to deep groundwater. We refer to this groundwater allocation provision as a T Block.

I have used the Land and Water Regional Plan (LWRP) Schedule 9 definitions for stream depletion for the purposes of this assessment, as follows:

Water takes are not considered to be stream depleting if they meet the definition of Low stream depletion in Schedule 9. This means that less than 40%, up to a maximum of 5 L/s, of the water drawn from a well over a 150 day irrigation season comes from, or would have otherwise discharged to, a surface water body located within 2 km of the well.

The proposed rules for Plan Change 7c of the LWRP include a minimum depth requirement for deep wells. We refer to this as the “Stream Depletion Cut-off Depth” The depth requirement represents the top of the highest well screen. Any well with a highest screen top depth greater than or equal to this value will be classified as having a Low stream depletion effect and will not be required to undertake a stream depletion assessment for the Resource Consent application.

The original purpose of this memo was to determine Stream Depletion Cut-off Depth for the Waimakariri Zone. Because any well within the Waimakariri zone which meets the cut-off depth requirement (together with the other requirements for access of the T Block listed within proposed PC7) will be classified as having a Low depletion effect, we need to be confident that the proposed cut-off depth is sufficient to ensure that the stream depletion effects are Low under the wide range of hydrogeological conditions encountered within the Waimakariri Zone. My modelling work has shown that the separation distance between a well and the nearest stream and the well pumping rate are more important than merely top screen depth when estimating stream depletion rates. I therefore broadened my assessment to consider these criteria too.

3 Stream depletion theory

Barlow and Leake (2012) and PDP and Environment Canterbury (2000) provide a comprehensive discussion of stream depletion theory; the reader is referred to these documents for a detailed explanation of the subject. I focus here on the hydraulic parameters which control the magnitude of the stream depletion effect; these are listed below and shown for various aquifer conceptualisations in Figure 3-1. Barlow and Leake (2012) note that two of the most important factors that control the timing and rate of stream depletion are the separation distance between a well and the stream and the hydraulic diffusivity of the aquifer (D), defined as D = T/S for confined aquifers and D = T/Sy for unconfined aquifers.

- Q = the abstraction rate from the well
- A = the separation distance between the well and the stream
- t = the length of time over which the well is pumped;
- Kxy = the lateral hydraulic conductivity of the aquifer
- T = transmissivity
- Ss = the specific storage coefficient of the aquifer (a measure of how much water is released from the pore space of the aquifer as water pressures fall)
- S = storativity
- Sy = specific yield
- λ = the streambed conductance
- λ = K” x w x d where:
    - K‘ = hydraulic conductivity of the strata in the streambed (m/day)
    - w = width of the streambed (m)
    - d (also B” in Figure 3-1) = thickness of the streambed across which K‘ is measured (m)

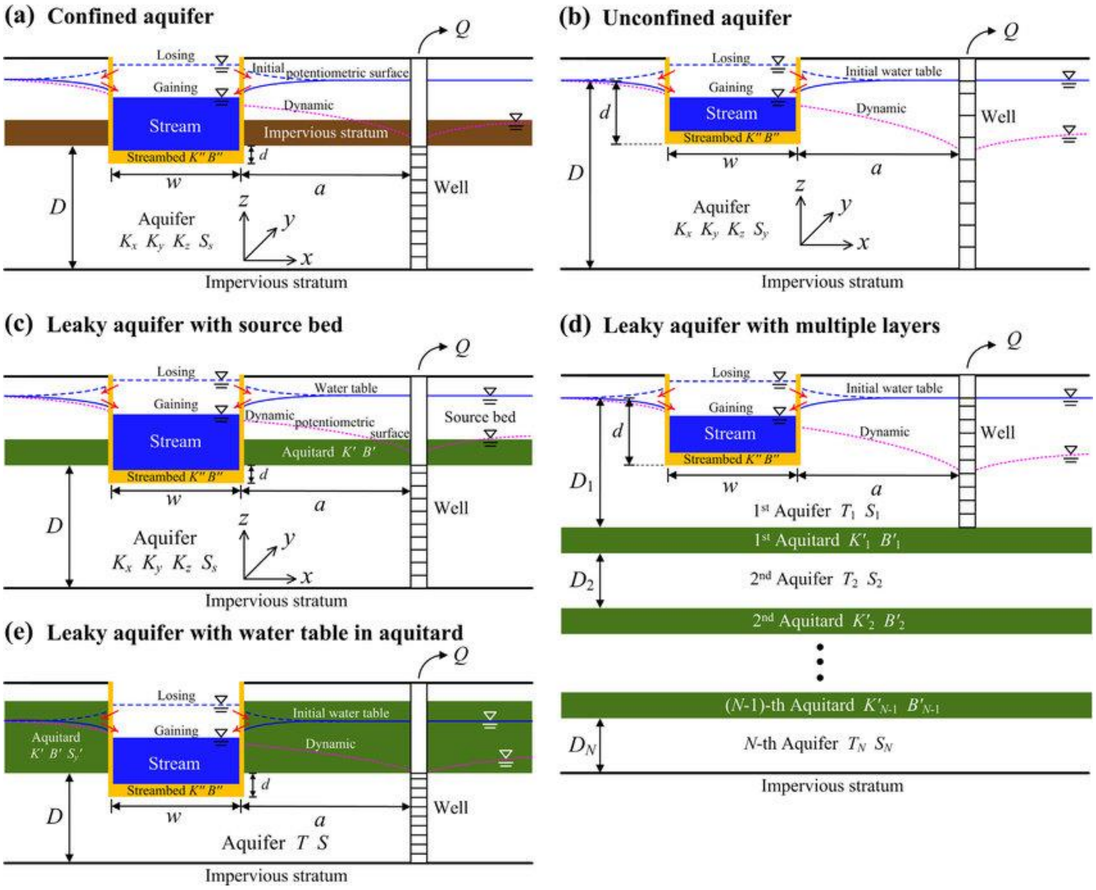

Figure 3-1 Hydraulic parameters and aquifer conceptualisations (from Huang et al., 2018)

4 Method

4.1 Modelling approach

Although the Waimakariri coastal zone aquifer system aligns most closely with a leaky multi-layered aquifer system (Figure 3-1 d), some areas outside of the coastal confining system may be more akin to the unconfined aquifer in Figure 3-1(b). I have therefore developed a simple generalised numerical model for this assessment, comprising an unconfined water table aquifer with increasing confinement with depth, based on the following assumptions:

1. Stream bed resistance is minimal (this accounts for gravel-bed streams) and hence the hydraulic properties of the stream bed are identical to those of the adjacent aquifer
2. The aquifer is isotropic in the lateral plain (i.e. Kx = Ky) but anisotropic in the vertical plain (Kxy ≠ Kz)
3. The water table aquifer extends to 5 m below the stream stage elevation with a leaky-confined system below this depth
4. The stream stage remains constant (and hence any decline in stream stage associated with stream depletion does not reduce the stream depletion rate)
5. The well pumps continuously for a 150 days period with no aquifer recharge

Based on the assumptions above, I constructed a numerical model using the Feflow 7.1 package as follows:

- Model domain = 20 x 20 km rectangular mesh
- Effective aquifer thickness = 150 m
- Stream represented by specified head boundary extending from the southern to the northern model boundaries, along the centreline of the model domain
- Model borders and base comprise no flow boundaries
- Element widths gradated from 3 m adjacent to stream to 100 m near model boundary
- Top layer of model has 5 m saturated thickness, with top slice defined as a free surface[1]
- 13 layers in total, all with 10 m thickness bar top layer (5 m) and two basal layers (25 m)
- Pumping wells represented as Well (Dirichlet) boundary condition defined on a single slice (not multi-layer well), to represent the short screen lengths typical of Canterbury

4.2 Model inputs

I have summarised the main inputs for the stream depletion modelling in Table 7-1. Kh has been calculated using Equation 1 :

$$\boldsymbol{Kh} = \frac{\mathbf{204.5}\ x \left(\frac{Q}{45}\right)^{\mathbf{0.94}}}{\mathbf{10}} \quad \textbf{Equation 1}$$

Equation 1 uses the transmissivity (T) versus specific capacity (SC) relationship in Figure 7-1 with an assumed aquifer thickness of 10 m to convert T into Kh and a SC value. The derivation assumes that for a 50 m well the rest water level is 3 m bgl and the pump is installed 2 m above the screen top depth, giving a 45 m available drawdown. The aim of this approach is to define the minimum Kh value required to achieve a given well abstraction rate. This avoids a model scenario which combines an assumed high abstraction rate with an aquifer transmissivity which would not, in reality, be sufficient to deliver the abstraction rate. Figure 7-2 shows T values generated with this equation (by multiplying the equation result by 10 to convert Kh to T).

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[1] Moveable slice topping an unconfined aquifer: slice elevation moves automatically with water table elevation to maintain saturation in Feflow

Table A- 1 Model inputs

Parameter	Value	Rationale
Sy	0.1	Typical unconfined aquifer value
Ss	1E-6	Typical confined aquifer storativity value divided by assumed 100 m effective aquifer thickness
Kh (m/d)	Calculated (Equation 1)	Minimum value required to yield the specified flow rate
Kv (m/d)	Kh/10 for 0-10 m depth, progressively reducing with depth	See discussion below
Q (L/s)	10 – 20 L/s	Experimental 150 day average rate range based on typical irrigation water supply abstraction rates
Separation distance	Min 100 m	Model runs showed that wells located < 100 m from a stream are likely to be stream-depleting under the other input parameters assumed for this study.

Stream depletion rates are strongly influenced by the vertical conductivity of the strata between the base of the stream and the abstraction well screen depth. I analysed K'B' and S data in our Wells database from the Central Plains area (Rakaia River to Ashley River/Rakahuri) to provide some estimates of vertical hydraulic conductivity and to determine the extent of vertical hydraulic conductivity reductions and the associated increase in confinement with depth. I used data from the Central Plains area because we only have K'/B' values from 25 pumping tests in the Waimakariri zone: this is not sufficient for depth horizon-based statistical analysis. I undertook the following steps to process these data into inputs for my model:

1. I converted K'/B' values into K' values by assuming that B' = D/2, where D = screen top depth, i.e. that half of the strata overlying the well comprises aquifer-grade material (medium-coarse sand and gravel) and the other half comprises aquitard-grade material (fine sand, silt and clay). I did this to assess the extent to which the observed decline in K'/B' with depth could be ascribed to the increasing sedimentary thickness
2. I split the aquifer properties data into 14 top of well screen depth bands (0 – 10 m, 10 – 20 m etc) and calculated the 95th percentile value for K'/B', K' and S for each band
3. I plotted these data as graphs (Figure 7-3, Figure 7-4 and Figure 7-5) and noted the following patterns:
    a. The 95th percentile storativity is around 5.0E-02 up to 30 m depth; below this it reduces by 1.5 orders of magnitude to around 1E-03. The 95th percentile hover around 1E-03 down to 120 m depth, below which they drop to 2-5E-04
    b. K'/B' values fall within the 1E-02 - 6E-02 range down to 60 m depth; below this they decline by an order of magnitude and generally sit between 2E-03 and 5E-03
    c. The estimated K' values hover around ~0.3 m/d down to 60 m depth after which they drop to ~0.1 m/d, with some variability and outliers. If we assume that B' = D/4 (i.e. only 25% of the material between the top of the well screen and the surface is aquitard-grade), this becomes ~0.15 m/d to 60 m depth and 0.06 m/d thereafter (excluding outliers). In both instances Kv therefore reduces by 60-70% below 60 m depth[2].
4. Because the 95th percentile S values for wells < 10m deep is 0.04, which indicates some degree of confinement, I assumed an anisotropy ratio of 10 for the top 10 m of sediment. The 1.5 orders of magnitude reduction in storativity below 30 m depth must be driven by a significant increase in confinement associated with lower vertical hydraulic conductivity, so I assumed that Kv reduces by 75% at this depth (giving an anisotropy ratio of 40). I then assumed that Kv reduces by a further 50% below 60 m (anisotropy ratio = 80) based on the reduction in 95th percentile Kv values observed at this depth.

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[2] This means that my analysis is not sensitive to the arbitrary B' = D/2 or B' = D/4 assumption

5. I converted the Kh values calculated from Equation 1 into Kv values using the anisotropy ratios derived from Step 4 and applied these data to the model.

5 Model results

I ran the groundwater model for a 150 day simulation period with a 10 day maximum time step length[3] for a range of well depths and flow rates with associated Kh and Kv values. The model results (provided in Table 7-1 and Figure 7-6) highlight the sensitivity of the stream depletion assessment to flow rate (and Kh and Kv by association) and well depth. In all instances, I used a minimum separation of 100 m between the well and the stream.

The results show that groundwater abstraction at an average rate of 10 L/s over 150 days from a well screened at > 50 m deep and located at least 100 m away from a stream is likely to meet the LWRP Schedule 9 definition of Low stream depletion in 95% of wells within the Waimakariri zone. Higher abstraction rates and/or shallower well depths and/or wells located closer to a stream are likely to cause > Low stream depletion in more than 5% of wells in the Waimakariri zone.

On this basis I recommend that consideration should be given to inclusion of a plan rule which does not require a stream depletion assessment for wells with a top screen depth of >50 m located at least 100 m from the nearest stream and with a maximum 150 day take rate of 10 L/s into the proposed planning rules for PC7c of the LWRP. This rule would apply only to water takes which are accessing the T Block described earlier in this memo.

6 References

Barlow P. M. and Leake S. A. 2012. Streamflow Depletion by Wells – Understanding and Managing the Effects of Groundwater Pumping om Streamflow. USGS Circular 1376

Huang, Ching-Sheng & Yang, Tao & Yeh, Hund-Der. 2018. Review of Analytical Models to Stream Depletion Induced by Pumping: Guide to Model Selection. Journal of Hydrology. 561. 10.1016/j.jhydrol.2018.04.015.

PDP and Environment Canterbury 2000. Guidelines for the assessment of groundwater abstraction effects on stream flow. Environment Canterbury report no R00/11

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[3] This maintained a model budget error of <0.1 L/s

7 Attachments

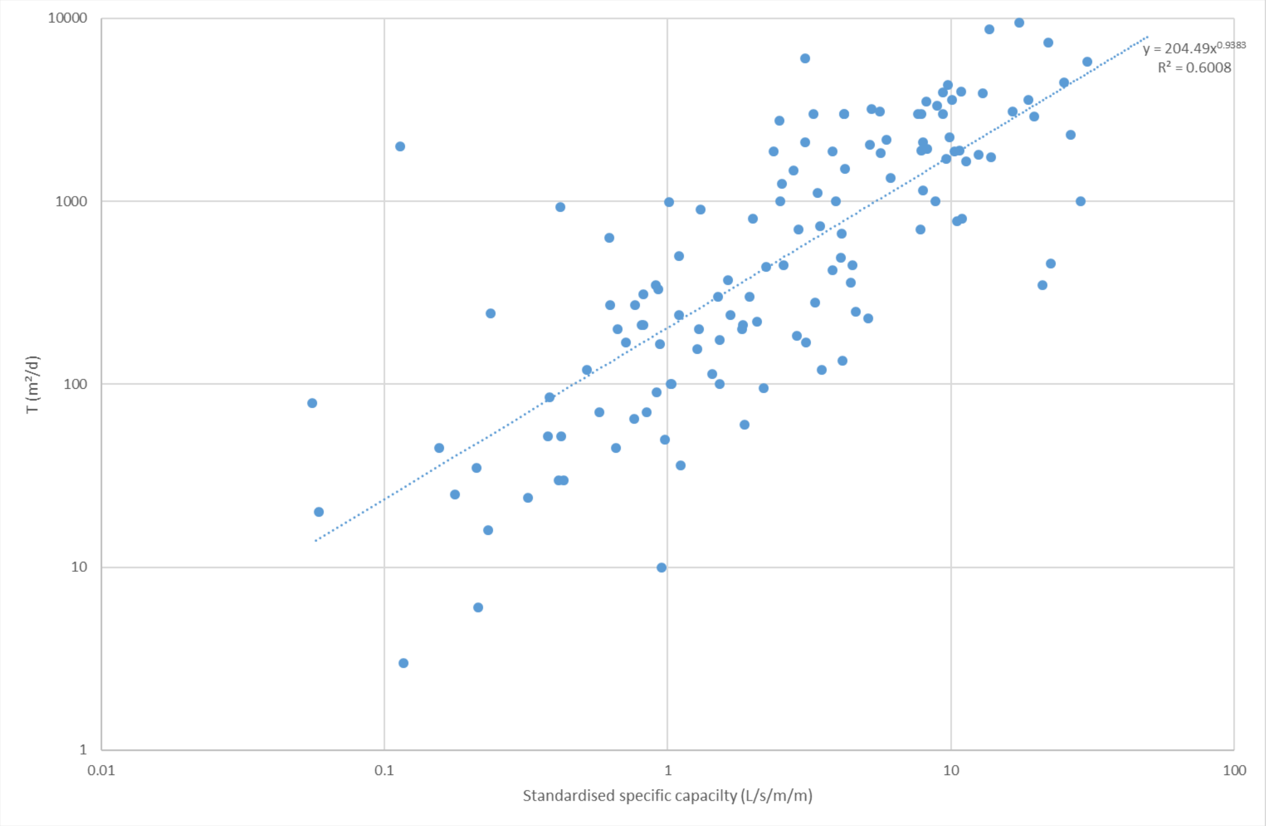

Figure 7-1 Transmissivity vs. Specific Capacity

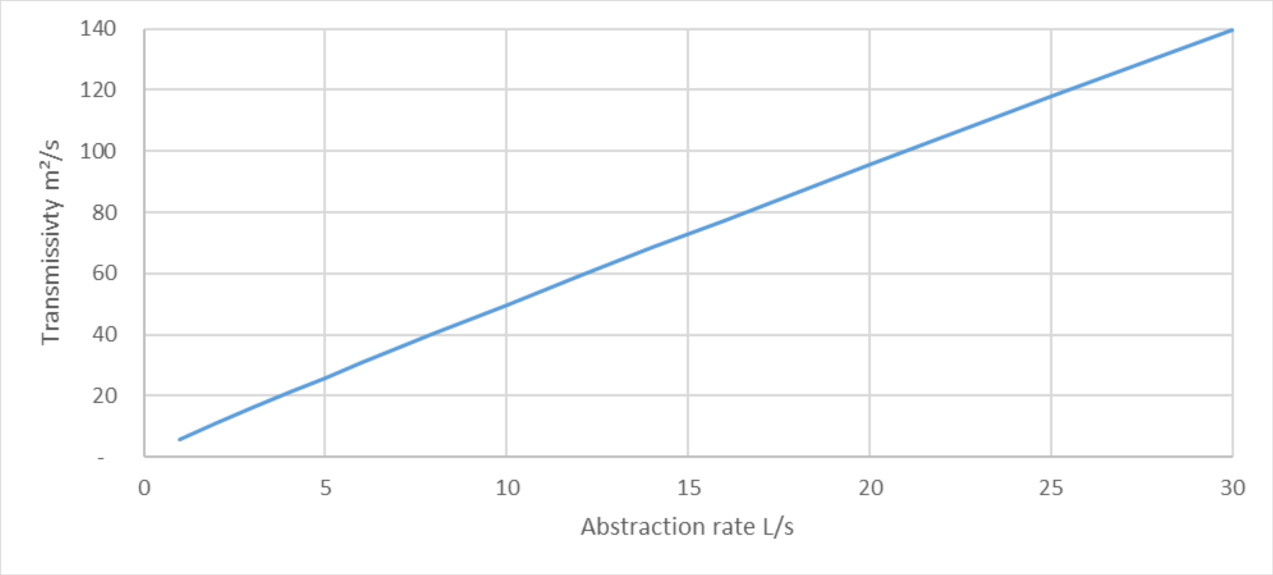

Figure 7-2 Abstraction rate vs. min required transmissivity

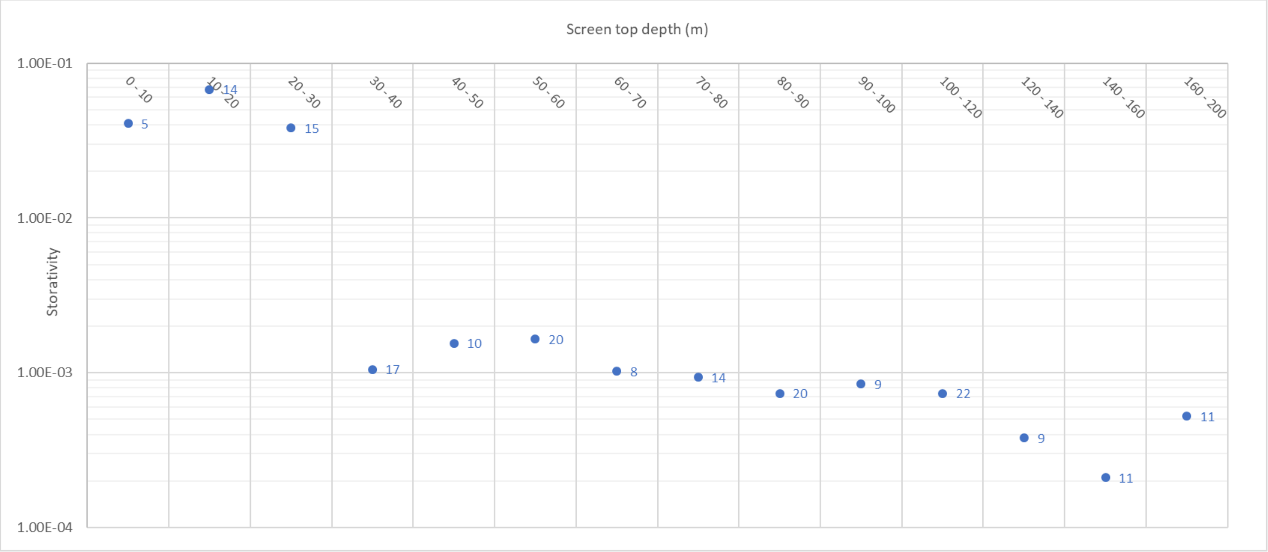

Figure 7-3 95th percentile storativity vs. depth (no. of data points labelled)

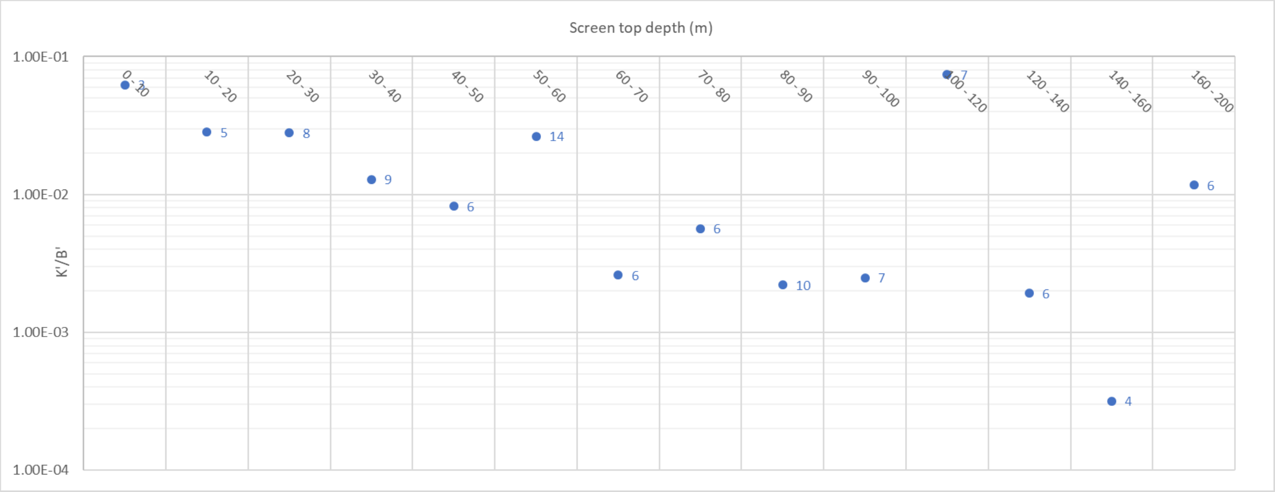

Figure 7-4 95th percentile K’/B’ vs. depth (no. of data points labelled)

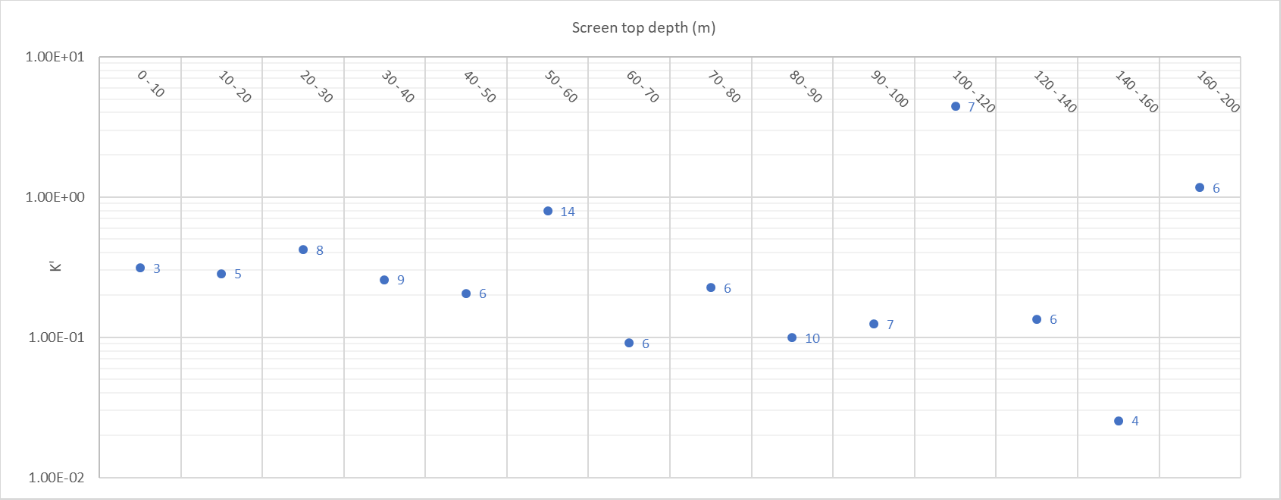

Figure 7-5 95th percentile K’ vs. depth (no. of data points labelled)

Table 7-1 Model results

Well depth m	Separation m	Q m^3/d (L/s)	Kxy m/d	Kz m/d	Ss	Sy	Stream Depletion L/s	Aquifer storage depletion L/s	% SD	SD = Low?
30	100	864 (10)	5	Variable	1.00E-06	0.1	4.15	5.85	41%	No
30	100	1296 (15)	7	Variable	1.00E-06	0.1	6.82	8.18	45%	No
50	100	864 (10)	5	Variable	1.00E-06	0.1	3.59	6.41	36%	Yes
50	100	1296 (15)	7	Variable	1.00E-06	0.1	5.99	9.01	40%	No
60	100	1296 (15)	7	Variable	1.00E-06	0.1	5.60	9.40	37%	No
70	100	1296 (15)	10	Variable	1.00E-06	0.1	5.31	9.70	35%	No

Red shading shows stream depletion > 5L/s or 40% and hence not meeting definition of Low depletion in Schedule 9 of the LWRP

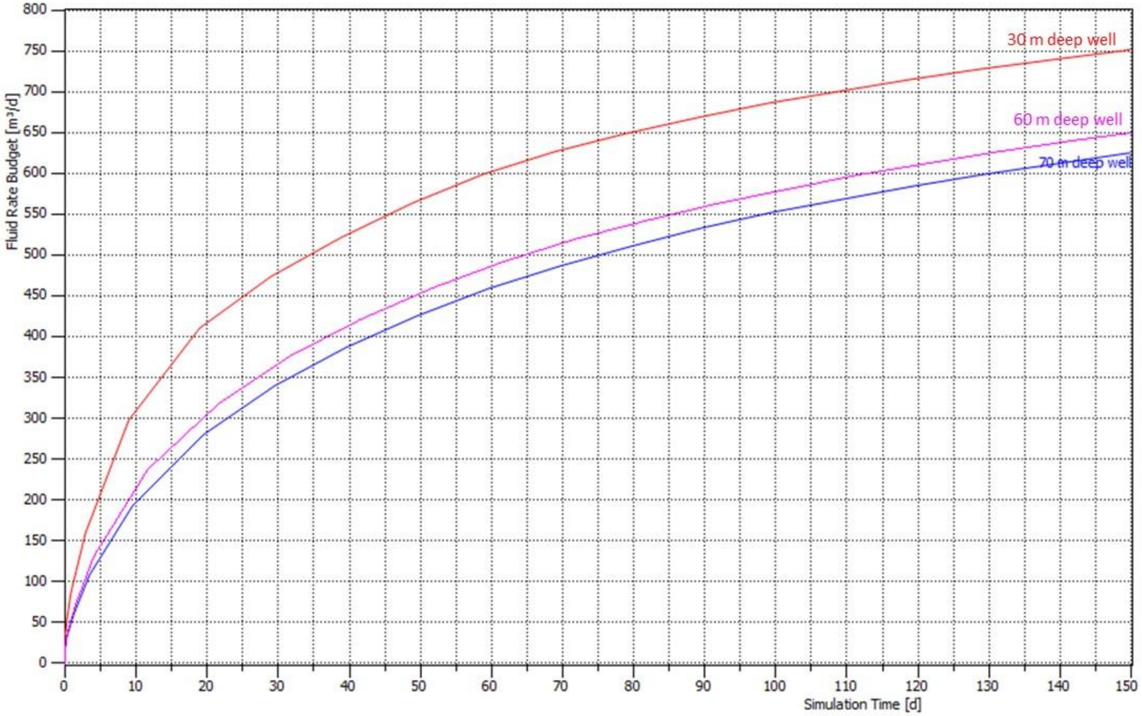

Figure 7-6 Stream depletion rate over time for 15 L/s abstraction rate

Reviewed by:	Jens Rekker, JH Rekker Consulting Ltd	27 May , 2019
Approved for release:	Tim Davie, Chief Scientist	18 June 2019