3.0 Initial Screening of Sites

3.1 When is Stream Depletion Likely to Occur?

Stream depletion effects that are induced by groundwater abstraction can occur in settings where a surface waterway occurs above and/or adjacent to a productive aquifer that is used for groundwater abstraction. They will occur provided that all three of the following criteria occur:

(i) Water can flow between the surface water and adjoining groundwater resource.

(ii) The rate of water movement between these two water bodies is dependent on the groundwater gradient adjacent to the stream.

(iii) The groundwater gradient adjacent to the stream is affected by groundwater abstractions.

The typical setting in which these circumstances occur is shown schematically in Figures 1 and 2. Example locations include:

» *Waipawa River, Hawkes Bay*

» *Papawai Stream, Wairarapa*

» *Little Sydney Stream, Tasman*

» *Omaka River, Marlborough*

» *Doyleston Drain, Canterbury*

For any potential setting where stream depletion effects may occur, an initial screening of water level data, and hydraulic conductivity data should be undertaken to determine whether or not stream depletion is likely to be a significant issue. The initial screening approach is described below. Whilst each of the parameters can be considered in isolation, it is important that the final conclusion must be consistent with the conceptual hydrogeological understanding for the general area.

3.1.1 Water Level Data

The depletion of stream flow by groundwater abstraction can occur if a stream is receiving groundwater flow (i.e. nearby groundwater levels are higher than stream water levels, Figure 1), if it is in equilibrium with groundwater (i.e. stream levels and groundwater levels are equal), or in some cases if a stream is losing flow to groundwater (i.e. groundwater levels are lower than stream levels, Figure 2).

In general, if long-term monitoring data indicates a correlation between groundwater levels and stream flow then it is likely that stream depletion effects have the potential to occur.

However, if groundwater levels are significantly deeper than the stream levels then the natural seepage loss from the stream will be caused by a hydraulic gradient of 1, acting vertically downwards, and will not be affected by any further lowering of the groundwater table that may be induced by groundwater abstractions (Figure 4).

Two guideline values are provided to assess the depth to water at which stream depletion effects will not occur. It is to be expected that both these water depth criteria shall be met before a conclusion can be reached that there is an absence of a stream depletion effect.

(i) Hunt (1997) describes a flow net analysis which shows that when a stream is perched above the water table 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 ≥ 5D, as shown in Figure 17. Under these circumstances, if H is increased due to drawdown from a pumping well it will not induce extra seepage from a stream.

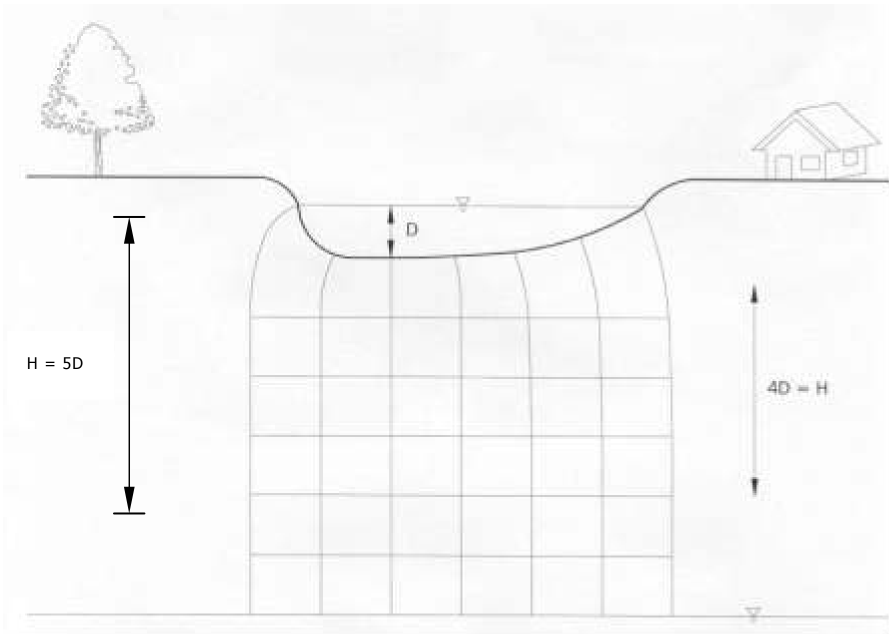
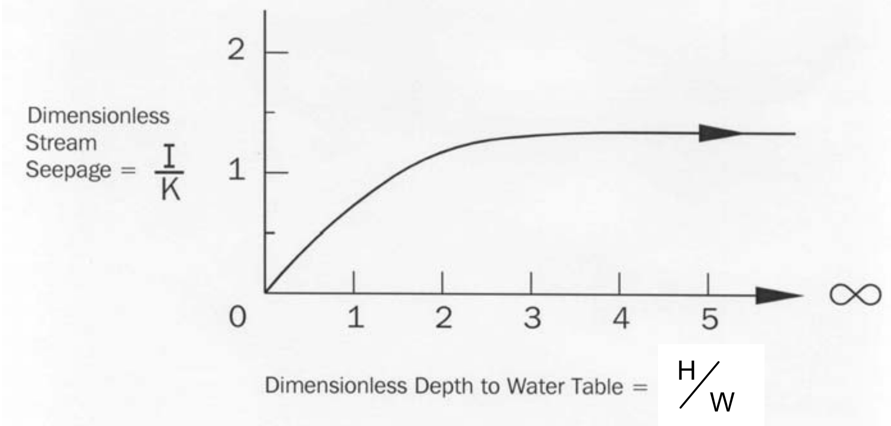


Figure 17 Flow net for seepage beneath a stream, showing that uniform vertical flow is reached by a depth of 5D below the stream surface (i.e. 4D below the streambed).

(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 18). If the depth to groundwater is more than twice the stream width (i.e. H ≥ 2W) then any further lowering of the groundwater table will not significantly increase stream seepage.



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 18 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.

Bouwer's diagrams and notes regarding this work suggest that the measurement of the depth to the water table (H) can be made "at some distance" from the stream and therefore can be measured in wells which generally represent the water table elevation in the aquifer that is under consideration.

Groundwater level measurements can also be used to indicate layers of low hydraulic conductivity strata between the screened section of a well and the groundwater resource adjacent to a stream. A well which shows a water pressure that is significantly different than the water table, at the same location, provides an indication that a low permeability layer exists above the screened section of the well. Such a layer will reduce any drawdown effect that the pumping well creates on the shallow water table. These measurements would typically be supported by drillers well logs indicating the presence of low permeability fine grained layers, as discussed below.

3.1.2 Hydraulic Conductivity of Strata

The hydraulic conductivity of the strata between the stream and the screen location of an abstraction well has a significant bearing on the potential stream depletion effects. The hydraulic conductivity is primarily determined by the permeability of the strata – with coarse grained gravels having high values and fine grained silts and clays having very low values. In rock formations the hydraulic conductivity is largely determined by the number, size and continuity of fractures.

The hydraulic conductivity between the well and the stream may be reduced either by laterally extensive layers of low permeability strata extending between the screen and the stream, and/or the occurrence of a "clogging" layer within the streambed itself.

- Laterally Extensive Layers

  Laterally extensive layers would normally be indicated by several driller's logs showing the presence of fine grained strata that occur at similar depths between wells. This information can be used to demonstrate the continuity of the layer extending beneath the stream and above the screen of the pumping well. Similar conclusions on laterally extensive low permeability layers can be drawn from a consideration of the elevation of well screens. For example, well screens within a given area which occur in two discrete depth zones separated by a zone with no screens indicates low permeability strata of such an extent that abstraction from the deeper zone is less likely to have a significant effect on stream flow. This situation is shown schematically in Figure 19.

  If the low permeability layer between the well screen and the stream is likely to be leaky then pumping may affect the shallow water table and an associated stream to still create a stream depletion effect. It is the transmission of a pumping effect through to the shallow water table that will influence whether stream depletion effects occur. This must be judged by the results of other pumping tests in the area and the conceptual hydrogeological understanding for the groundwater system.

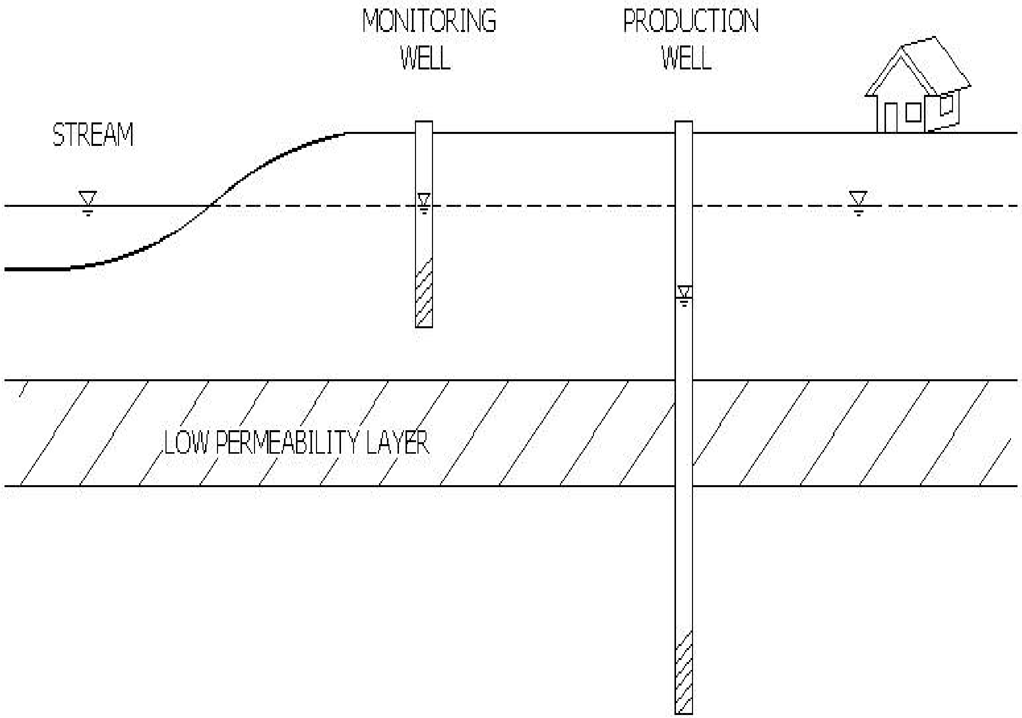


Figure 19: Indications of a deeper production aquifer that is hydraulically separated from the stream are provided by geological logs and water pressure mea

- Streambed Hydraulic Conductivity

  Clogging layers within a streambed can form either from the natural strata through which the stream flows, or through the deposition of suspended sediments from the stream. Even in gravel bedded rivers, it is possible for finer grained sediment layers to form below the surface layer of well washed gravels. The presence of such layers is a significant factor that impedes the movement of water between the stream and the surrounding aquifer.

  Evidence of such low permeability layers may come from direct observation and probing of the streambed (to verify the thickness of the low permeability sediment) and excavation of test pits adjacent to the streambed. However, even if a clogging layer is present, there may still be discrete springs which allow water to move between the aquifer and the stream. Consequently, any conclusion about streambed clogging must be consistent with the conceptual hydrogeological understanding of the area.

3.1.3 Well Depth

Consideration has been given to defining a cut-off well depth below which stream depletion effects would not be significant – however, it is difficult to define such a depth. Whilst deeper wells are less likely to have a stream depletion effect the reason for this will be because of some intervening low hydraulic conductivity strata which should be demonstrated by the type of evidence described in sections 3.1.1 and 3.1.2. However, in the absence of any other information, if the only well in a particular area is a very deep well that may in itself be an indicator that the shallower strata has a low hydraulic conductivity that could not support a productive well. Such a conclusion would ideally be supported by a descriptive well drillers log.

The screening process described in section 3.1 has been summarised in a flow chart which is contained in the summary brochure of this guideline document which is presented in Appendix E. It sets out the consideration of geographical data, water level data and geological data which should be used to screen sites.

3.2 Parameters which Determine Stream Depletion Effects

The key parameters which indicate the magnitude of the stream depletion effect are:

» *Q – the abstraction rate from the well;*

» ℓ *– the separation distance between the well and the stream;*

» *t – the length of time over which the well is pumped;*

» *T – the transmissivity of the aquifer (a measure of how permeable the aquifer is)*

» *S – the storage coefficient of the aquifer (a measure of how much water is released from the pore space of the aquifer as water pressures fall)*

» *λ – the streambed conductance (a measure of the permeability and dimensions of the streambed and the hydraulic gradient across the streambed).*

The following panels have been prepared to describe these parameters and to indicate the range of values that are likely to occur if stream depletion effects are likely to be significant. This range of typical values can also be used as an initial screening procedure to determine whether stream depletion effects are likely to occur in any particular setting.

Parameter	Pumping Rate (Q)
Typical Units	m^3/day or L/s
Description	The average abstraction rate from a well over a fixed period of time. Note: The principle of superposition applies to stream depletion rates, 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 time period (e.g. an irrigation season) provides a useful estimate of stream depletion in many cases.
Typical Values	100 – 10,000 m^3/day Stream depletion effects increase with larger pumping rates.
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 are typically specified on resource consent applications.

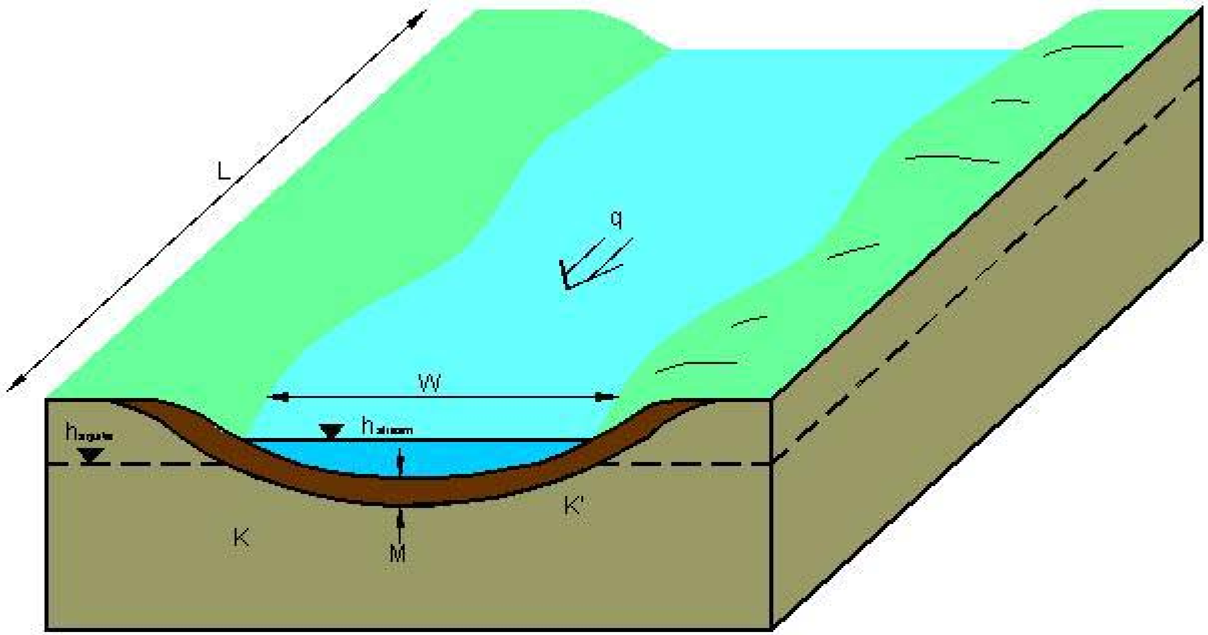
Parameter	Separation Distance (ℓ)
Typical Units	metres (m)
Description	The lateral separation distance from the abstraction well to the nearest edge of the stream water, measured perpendicular to the stream flow.
Typical Values	1 – 2,000 m Stream depletion effects increase with smaller separation distances. Where separation distances are greater than 2,000 m, stream depletion effects are unlikely to be significant.
Source of Data	• Topographic maps. • Aerial photos. • Direct measurement on the ground. Note: This measurement is clear cut for many streams, but is not so straightforward for braided rivers. In a braided river a judgement should be made as to the average location of the nearest river edge during the period of time over which the stream depletion effect is to be calculated. For example, if an assessment is being undertaken for a 35 year irrigation abstraction consent, it would be reasonable to assume that for at least one irrigation season the river may be at the closest edge of its braided bed width.

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 on page 32).
Typical Values	1 – 120 days (for irrigation wells). Continuous for pubic supply and industrial wells. Stream depletion effects increase with longer pumping periods.
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 are typically specified on resource consent applications.

Parameter	Transmissivity (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	10 – 10,000 m^2/day Stream depletion effects increase with higher values of transmissivity. Transmissivity values less than 10 m^2/day are unlikely to be sufficiently permeable to cause significant stream depletion effects.
Source of Data	• Pumping tests on abstraction wells – constant rate or step-drawdown. • Slug tests. • 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 stream into account (see section 6.1.2 and 6.2.3). Where multiple measurements of transmissivity are available from surrounding wells it is most appropriate to use the geometric mean of the values.

Parameter	Storage Coefficient (S)
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	0.0005 – 0.3 Stream depletion effects increase with smaller values of storage coefficient. However, aquifers with values of S less than 0.0005 are likely to be confined. Under these circumstances there is unlikely to be sufficient hydraulic connection to a stream to cause significant stream depletion effects unless the stream channel penetrates the low permeability confining layer or there are discrete springs penetrating the confining layer.
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.

Parameter	Streambed conductance (λ)
Typical Units	m/day
Description	A measure of the vertical hydraulic conductance through the streambed to the underlying aquifer. Streambed conductance can be defined as: $$\lambda = \frac{K'W}{M}$$ where K' is the hydraulic conductivity of the strata in the streambed (m/day) W is the width of the streambed (m) M is the thickness of the streambed across which K' is measured (m) The relationship of these parameters is shown schematically in Figure 20.
Typical Values	0.01 – 5000 m/day Stream depletion effects increase with larger values of streambed hydraulic conductance. If the streambed conductance is less than 0.01 m/day then it is unlikely that stream depletion effects will occur.
Source of Data	• 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.



$$\lambda = \frac{\Delta q}{L\Delta h} = \frac{-K'W}{M}$$

Gauging and Piezometric surveys

Infiltration/Seepage measurements

Figure 20: Streambed Conductance (λ)

3.3 Quantified Screening Criteria

If a stream and an adjacent aquifer have similar water levels (section 3.1.1) and are connected by permeable strata (section 3.1.2) then they fit the conceptual hydrogeologic settings in which stream depletion effects can occur.

To quantify how readily these effects will occur requires a consideration of the parameters described in section 3.1.3. For screening purposes, all the physical parameters of a site (excluding the abstraction schedule for the well, i.e. Q and t) can be combined into two screening parameters – the stream depletion factor (sdf) and the streambed conductance (λ).

3.3.1 Stream Depletion Factor (sdf)

The stream depletion factor was defined by Jenkins (1977) to describe the hydraulic connection between the stream and the pumping well. This term combines the aquifer parameters T and S with the separation distance to determine whether stream depletion effects will readily occur:

$$\text{sdf} = \frac{\ell^2 S}{T}$$

where ℓ is the separation distance between well and stream when the stream is approximated by a straight line [L]

T is the aquifer transmissivity [L^2/T]

S is the aquifer storage coefficient [dimensionless]

The effect of the sdf is shown graphically in Figure 21 for a well that pumps for 30 days and then is turned off for 30 days. (The data in Figure 21 assumes that the streambed offers no impedance to the flow of water between the stream and the aquifer (i.e. λ = 100 m/day)).

For settings with a small sdf the interaction between a pumping well and a stream is rapid and large (i.e. most of the well water is derived from the stream aquifer interaction within a short time from the commencement of pumping). However, as the sdf becomes larger, the stream depletion effect is more delayed and smaller. In some management situations an sdf value of 100 days has been used to differentiate between groundwater abstractions that can be managed to achieve some benefit in stream flow (sdf $\leq$ 100 days) and other abstractions that are less well connected to the stream (sdf > 100 days). Figure 21 shows that at a sdf value greater than 100 days the stream depletion rate is less than 20% of the well pumping rate after 30 days and the effect of shutting off the pump does not create an immediate benefit to the stream.

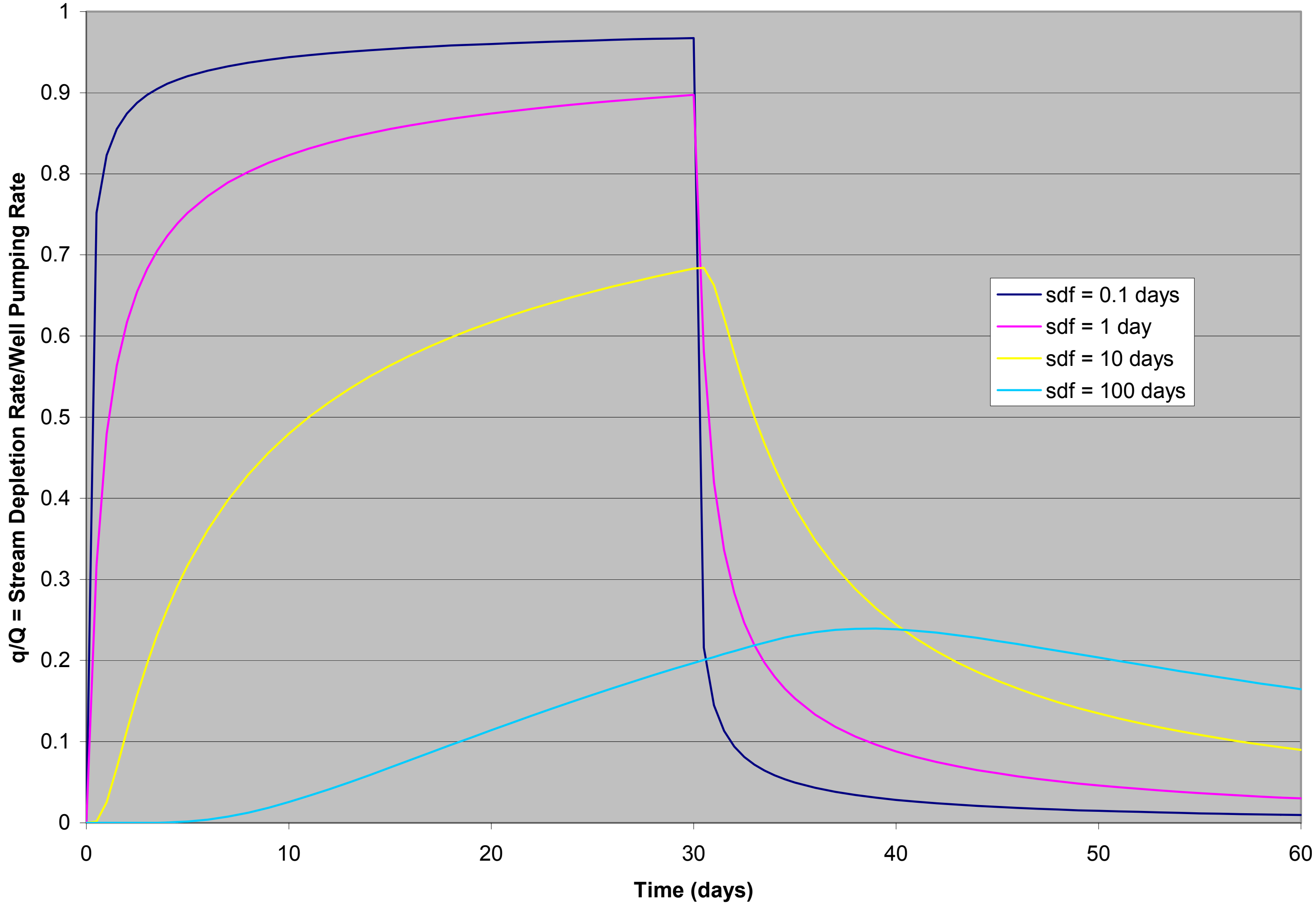


Figure 21: Relative stream depletion rate for a range of stream depletion factors (30 days pumping followed by complete shutdown, with lambda = 100 m/day)

3.3.2 Streambed Conductance (λ)

Streambed conductance is the term combining the factors that describe clogging in the streambed.

$$\lambda = \frac{K'W}{M}$$

where K' is the hydraulic conductivity of the streambed [L/T];

W is the width of the streambed [L];

M is the thickness of the streambed [L].

The effect of λ is shown graphically in Figure 22 for a situation with a permeable aquifer (i.e. sdf = 0.1 days) and a well that pumps for 30 days and is then turned off for 30 days.

The curves show how the stream depletion rate reduces as λ decreases. This reduction becomes most noticeable when λ values are less than 10 m/day. When values of λ decline below 0.01 m/day it is unlikely that any significant stream depletion effects will occur.

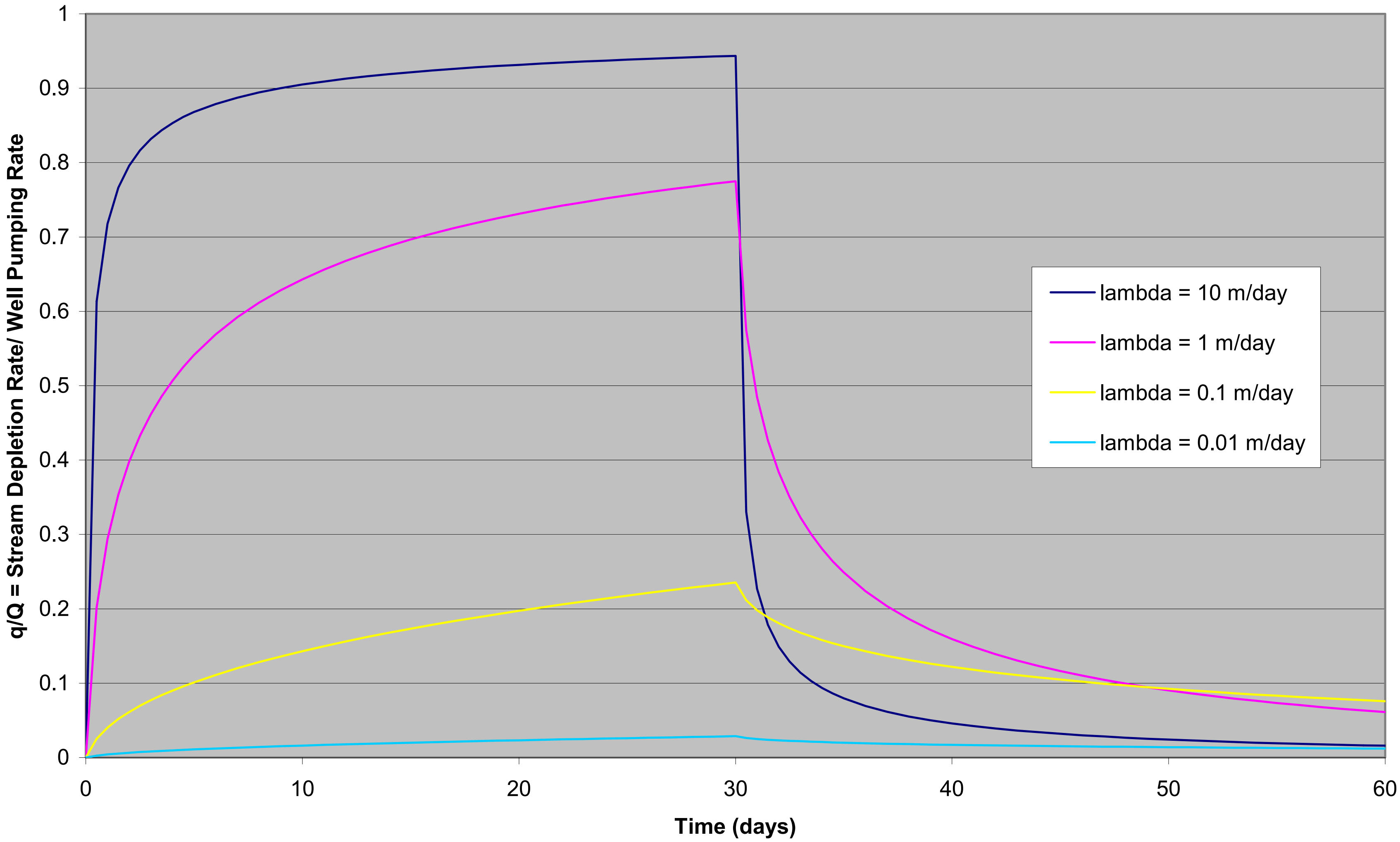


Figure 22: Relative stream depletion rate for a range of streambed factors (30 days pumping followed by complete shutdown, with sdf = 0.1 days)