Quantifying stream depletion effects

In almost all surface water settings there is movement of water between the underlying groundwater and the surface water body. This occurs in streams, lakes, wetlands, estuaries and at the sea coast. Because of this interaction there are some situations in which wells pumping from permeable aquifers can reduce the flow or volume of water in the surface water way – this is called a "stream depletion" effect.

With the increasing demand on water resources, it is becoming important to understand and assess the stream depletion effect caused by pumping from groundwater.

The interactions of water movement between groundwater and surface water are difficult to observe and measure. This creates uncertainty regarding the magnitude of any surface water/groundwater interaction, the implications of the effect and an appropriate form of management. To reduce the uncertainty, this note has been prepared by Pattle Delamore Partners Ltd as part of an Environment Canterbury project to help in quantifying the stream depletion effect. This project was supported by the Ministry for the Environment's Sustainable Management Fund.

This note describes the following:

Part A a general screening process to identify settings where stream depletion may occur.

Part B an outline of the parameters needed to calculate stream depletion effects and a graph to allow a preliminary estimate to quantify the effect.

Part C an indication of field measurements that can be used to improve the accuracy of stream depletion assessments.

Part A comprises consideration of simple observations that can be evaluated by all water users. Parts B and C describe more complex issues that should only be considered with a technical adviser.

This note is based on a more comprehensive technical guideline which is available from Environment Canterbury, P O Box 345, Christchurch (ph 03-365-3828) or from Pattle Delamore Partners Ltd, P O Box 389, Christchurch (ph 03-379-3532).

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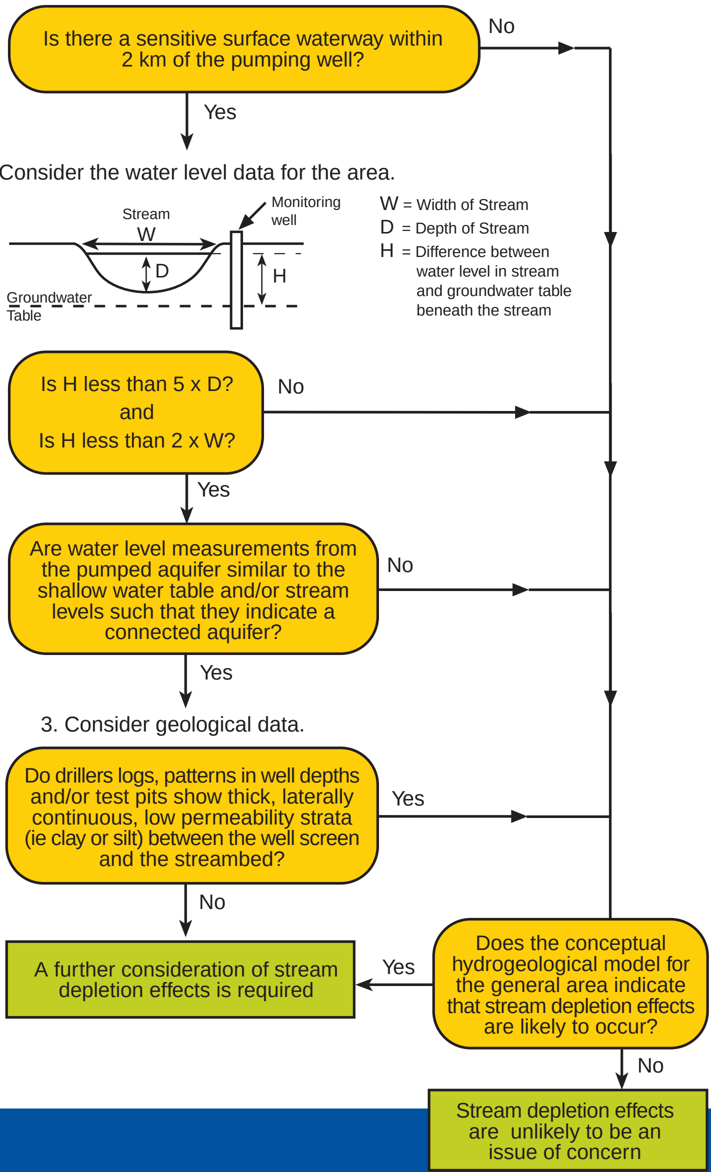
Part A – Is stream depletion a concern?

For any particular site, a review of information on well locations, water levels and borehole strata records can be used to answer the questions in the flow chart below. This helps determine whether stream depletion is likely to be an issue of concern.

Is pumping from a well likely to have a stream depletion effect?

1. Consider the location of the well in relation to nearby surface waterways



Part B – Calculating the stream depletion effect

The key parameters that are used to calculate the magnitude of stream depletion effects are listed below:

- Q the pumping rate from the well (m^3/day).
- ℓ the separation distance between the well and the stream (m).
- t the duration of time that the well is pumped (days).
- T the transmissivity of the aquifer – an indication of permeability. Values of T in productive aquifers typically range from 10 – 10,000 m^2/day.
- S the storage coefficient of the aquifer – an indication of how much water is stored in the strata. Where stream depletion is an issue, values of S typically range from 0.005 – 0.3.
- λ the hydraulic conductance of the streambed which is calculated by:

$$\lambda = \frac{\text{vertical hydralic conductance of the stream bed} \times \text{width of streambed}}{\text{thickness of streambed}}$$

where stream depletion is an issue, values of λ typically range from 0.1 – 5,000 m/day.

The values of these parameters can be used in equations to indicate the effect of groundwater pumping on nearby surface waterways.

Step 1. Consider the Stream Depletion Factor

An indicator of the aquifer conditions and separation distance to the well is provided by the "stream depletion factor"

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

If the value of sdf is greater than 100 days, then stream depletion effects are likely to develop very slowly, and not be large.

Step 2. Consider the Streambed Conductance

An indicator of the streambed conductance is the parameter, λ, described above. If λ is less than 0.01 m/day then the streambed is likely to have a sufficiently low hydraulic conductivity so that no large significant depletion effect could be caused by a pumping well.

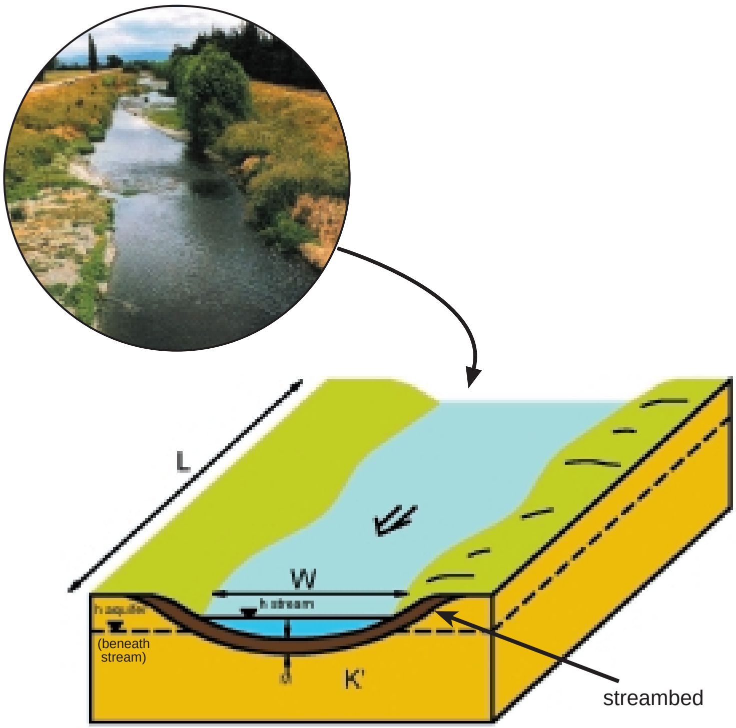
Step 3. Estimating the Stream Depletion Effect

For simple settings, where a surface waterway can be represented as a straight line passing through an adjacent aquifer, the following parameters can be calculated:

$$\frac{t}{sdf} = \frac{t^2 \times T}{\ell^2 \times S} \quad \text{and “stream bed factor” sbf} = \frac{\lambda \times \ell}{T}$$

The figures on the following pages describe this simple hydrogeological setting. The graph can be used to estimate the stream depletion effect by locating the value of t/sdf on the bottom horizontal axis and the correct sbf curve to read off a value of q/Q – the ratio of the rate of water drawn from the stream to the rate of water pumped from the well.

Some key parameters for calculating stream depletion effects



$$q = -K' \times L \times W \times i = -\lambda \times L \times (h_{aquifer} - h_{stream})$$

q	the flow of water between the stream and the aquifer (m^3/day)
K'	the vertical hydraulic conductivity of the streambed (m/day)
L	the length of the stream reach over which seepage is assessed (m)
W	the width of a stream reach over which seepage is assessed (m)
i	the hydraulic gradient between the stream and the aquifer

$$i = \frac{h_{aquifer} - h_{stream}}{M}$$

λ	the streambed conductance, a measure of the hydraulic conductivity and dimensions of the streambed (m/day)
$h_{aquifer}$	the level of the water in the aquifer (m)
h_{stream}	the level of the water in the stream (m)
M	the thickness of the streambed which has a hydraulic conductivity of K' (m)

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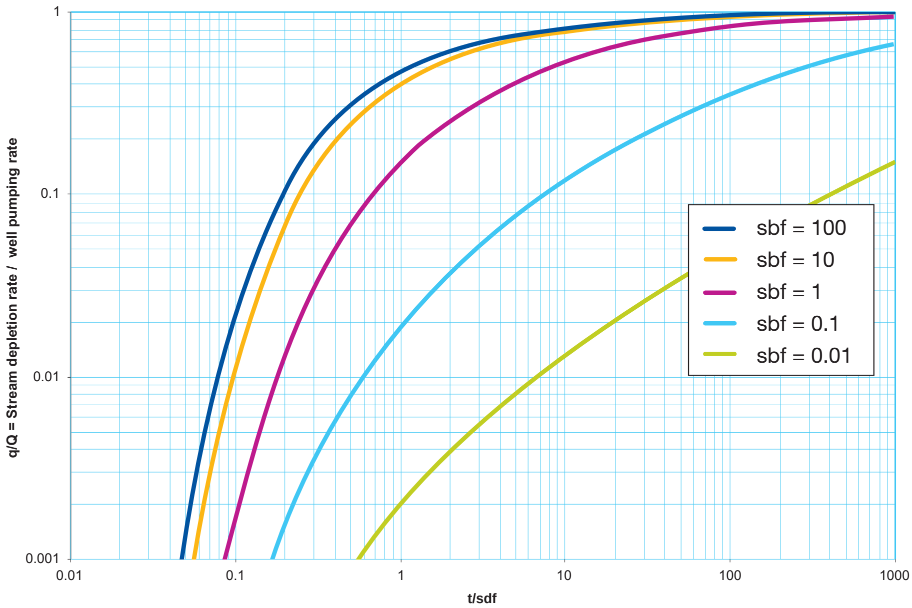
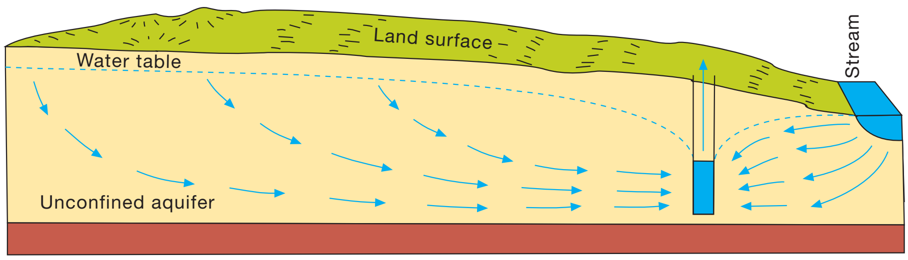
Determining the rate of stream depletion





Schematic setting for the curves shown above

For more complex hydrogeological settings, the reading from this graph may still be useful to indicate the range of stream depletion effects that may occur. However, if a more detailed assessment is required then other techniques such as numerical modelling should be used to better quantify the stream depletion effect. This may involve settings where the aquifer is not laterally extensive due to the presence of low permeability boundaries, multiple streams and/or streams that only flow in a portion of the area affected by a pumping well.

Part C – Improving the accuracy of stream depletion assessment

Groundwater systems are inherently complex and it is well recognised that attempts to quantify their behaviour requires gross simplification of the natural variability. Assessing the effect of groundwater pumping on surface waterways is no exception. However, useful quantitative assessments of effects can be made by estimating the likely range of parameters that will occur. If these estimates indicate that an improved accuracy is desirable then the following field measurements can be made:

- Improved estimates of streambed conductance can be made by:
  - Gauging and piezometric surveys to assess the natural exchange of water between the surface and subsurface environments.
  - Infiltration measurements in streambed using seepage meters or infiltrometer rings.
- Improved estimates of aquifer parameters (Transmissivity and Storage Coefficient) and aquifer structure can be obtained from carefully controlled pumping tests. The analysis of such tests must allow for the effects of nearby surface waterways.
- Improved estimates of groundwater pumping can be achieved by the installation of flow meters on abstraction wells.

Some other field measurements that have been considered to improve stream depletion estimates but have typically not proven to be successful are:

- Gauging flows in a stream to directly measure the effect of a pumping well. The accuracy of the gauging method compared to the variability in surface flow and the time over which stream depletion effects develop often make this an unreliable assessment technique unless ideal circumstances exist.
- Water chemistry analyses are typically unreliable because stream depletion effects can occur without any surface water actually reaching the pumping well (the effect can occur simply by a change to the hydraulic gradient across the stream bed caused by groundwater pumping).
- Water divining, whilst relied on by many people to site water supply wells, has not been scientifically verified to provide a source of reliable information on stream depletion effects.

As with all groundwater assessments, the carefully controlled measurement of field parameters greatly enhances the conceptual understanding and quantitative assessment of effects.

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