6.0 Collection of Field Measurements

6.1 Field Measurements to Assist Stream Depletion Assessments

The quantification of stream depletion effects can be greatly enhanced by the collection of relevant field data in the area under investigation. These field measurements are used to asses the following aspects of the stream depletion problem:

» *streambed conductance or the hydraulic conductivity of the streambed*

» *direct measurements of seepage across the streambed*

» *aquifer characteristics*

» *the flow regime between the stream and the aquifer*

There are four main types of field measurements which help the quantification of stream depletion effects. They are:

» *Gauging surveys combined with piezometric surveys*

» *Pumping tests*

» *Seepage measurements in streambeds*

» *Infiltration measurements in streambeds*

Each of the field measurement techniques is discussed in turn below.

6.1.1 Gauging and Piezometric Surveys

Combined stream gaugings and piezometric surveys involve measuring the flow of water in the stream at various locations along its length and measuring the level of water both within the stream and in wells adjacent to the stream. This gives information on the nature of the hydraulic interaction between the stream and the aquifer and allows a broad averaging of parameters because measurements are made across an extended length of streambed.

This type of survey is used to determine the streambed conductance (λ). If the width of the stream (W), the thickness of the clogging layer (M) and length of the stream reach (L) are known then the hydraulic conductivity can also be determined from the gauging survey. Streambed conductance is related to the streambed hydraulic conductivity as follows (Figure 20):

$$\text{Streambed conductance/unit length} = \frac{K'W}{M} = \frac{\Delta q}{L\Delta h}$$

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

W = width of streambed [L];

M = thickness of streambed [L];

Δq = change in flow rate in river between the upstream and downstream gauging sites [L^3/T];

L = length of streambed between the upstream and downstream sites [L];

Δh = difference in elevation between the water surface in the stream and the groundwater table adjacent to the stream (as determined from direct measurement or interpreted piezometric contours) [L].

A piezometric contour map can be constructed from a levelling survey to allow groundwater levels at the stream gauging locations to be approximated. Alternatively mini piezometers can be installed at the stream gauging location to allow direct measurement. The difference between the estimated groundwater level (as indicated from the piezometric map or measured directly) and the measured stream level at each gauging site gives Δh.

It is preferable for these surveys to be carried out during times when no pumping is taking place and relatively steady groundwater and surface water flow conditions exist.

It is also important that gauging surveys are conducted with great accuracy and that the results are interpreted with regard to the magnitude of potential errors relative to the magnitude of flow that are measured. This matter is discussed further in section 6.2.1.

6.1.2 Pumping Tests

A pump test comprises pumping water from a well whilst measuring the discharge of the well, the drawdown in the well and the drawdown in nearby observation piezometers at known distances from the pumped well. These measurements can be substituted into an appropriate well-flow equation allowing the hydraulic characteristics of the aquifer and in some cases of the stream to be calculated. Pumping tests are used in stream depletion assessments in three main ways.

Firstly, a pumping test carried out in a well that is not adjacent to a stream, allows the calculation of general hydraulic characteristics of an aquifer. In particular, the test allows a determination of:

» *the transmissivity and storage coefficient of the aquifer;*

» *the structure of the aquifer, for instance whether the aquifer is unconfined, confined or leaky, and/or has lateral boundaries;*

- *if the aquifer is leaky, a pump test can be used to determine the characteristics of the leaky low permeability layer. This helps to assess the transmission of drawdown effects through a semi-confined layer to determine the pumping influence on a shallow water table and stream.*

Secondly, where a pump test is conducted adjacent to a stream, the drawdown response in a well can be analysed using the Hunt match point method (Hunt 1999) which allows T, S and λ to be calculated.

Thirdly, in some particularly well controlled settings, pumping tests adjacent to streams can sometimes be used to directly measure stream depletion, where the stream flow is accurately gauged up and down gradient of the radius of influence of the wells pumping (as estimated by drawdown simulations). The difference between the gaugings before and after pumping can be inferred to have been caused by the well pumping. This method is best used in conjunction with the pump test analysis described above. Used alone the results can often be inconclusive because of the margin of error inherent in flow gauging surveys compared to the flow depletion rate, and also due to the changes in antecedant aquifer conditions and stream flows. These inaccuracies are discussed in section 6.2.

6.1.3 Infiltration Tests

Infiltration rings can be used to estimate the vertical hydraulic conductivity across the streambed. However, as they only measure values at a specific spot they are less representative than gauging surveys or pumping tests. As a result, the more measurements that can be made over as wide an area as possible will increase the reliability of these tests.

For this field method a double ring system is typically used to create vertical flow downwards through the streambed. This involves driving two steel rings into the streambed as shown in Figure 30.

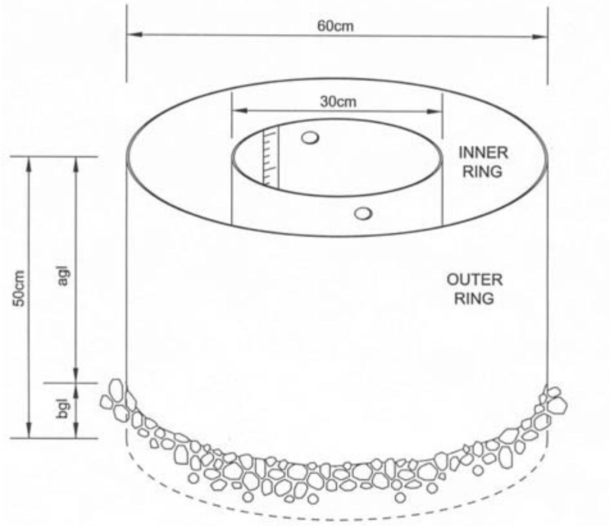

Figure 30 Double ring infiltrometer

Both rings are filled with water and the incremental volumes (V) of water required to keep the central ring at a constant level over the time of the test is recorded. The level of water in the outer ring is also kept constant but is not measured. The purpose of the outer ring is to ensure that flow from the central ring is predominantly vertical. Over the duration of the test the infiltration rate reduces and once it reaches a stable condition (i.e. a flattening of a graph of rate of water level decline vs time since start of test) the hydraulic conductivity of the streambed, K', is approximately proportional to the rate of infiltration, i.e.

$$K' = \frac{V}{t\ i\ A}$$

where K' = vertical hydraulic conductivity [L/T];

t = time [T];

V = the volume of water required to keep the water level constant over the time t [L^3];

A = the cross-sectional area of the ring [L^2];

i = hydraulic gradient [dimensionless].

The hydraulic gradient is determined by measuring the difference in head between the water in the ring and the hydraulic head in the ground along the seepage path, as monitored by a piezometer or tensionmeter. As an alternative approach, in dry streambeds this test can be carried out over areas where the depth to the water table is greater than 5 times the depth of water in the ring (as discussed in section 3.1.1) so that a vertical hydraulic gradient of 1 can be assumed.

The test can also be carried out in calm shallow water. In these circumstances only a single ring is required as the stream provides a relatively constant water level around the ring.

The analysis of the single ring test in a calm stream requires that a flow net be constructed, to determine the hydraulic gradient and hence the hydraulic conductivity from Darcy's equation. This approach was used in the Environment Canterbury and Pattle Delamore Partners Ltd study of the Ohoka Stream which is referred to in Appendix C. The construction and use of flow nets is discussed fully in many references (e.g. Craig 1992).

Because this test relies on the seepage of water from the ring into the ground it may not yield reliable data if there is an upward natural gradient acting across the test area.

6.1.4 Seepage Surveys

In areas of deeper water, the rate of seepage through the streambed can be measured directly using a seepage meter. While detailed designs differ, in essence, the seepage meter consists of a cylinder with one open end and one closed end (e.g. a 200 L drum cut in half). The open end is pressed into the streambed, so that the entire cylinder is submerged. The closed end is connected to a flexible bag (e.g. a rubber weather balloon) through which any seepage water will move (Figure 31). If the flow through the streambed is upwards then seepage water will accumulate in the flexible bag. If the flow is downwards then the bag is filled with water at the start of the test and the volume of water in the bag will reduce as the test proceeds.

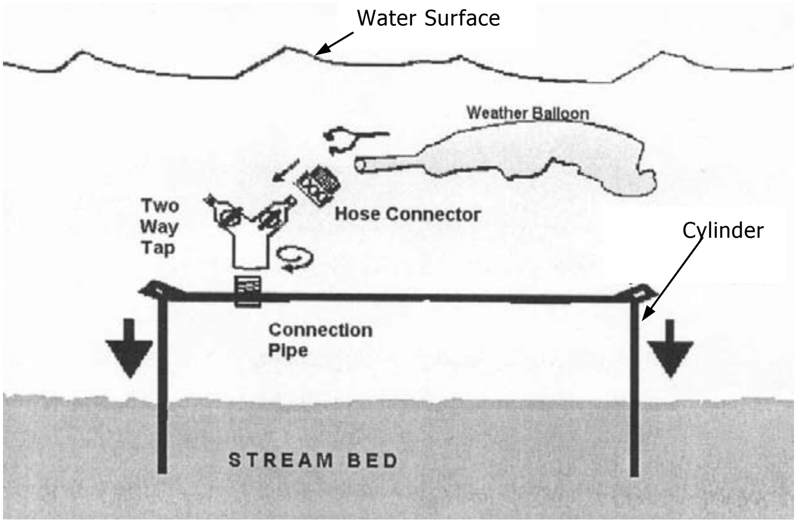

Figure 31 Seepage meter. (from ECan)

The hydraulic conductivity, K′, of the streambed is determined using Darcy's equation:

$$K' = q / i A$$

where q = flow rate determined by seepage meter [L^3/T];

A = area of seepage meter [L^2];

i = $\Delta h/M$ = vertical hydraulic gradient, measured by the head difference between groundwater and the stream divided by the vertical distance (M) over which the head difference is measured [dimensionless];

K′ = vertical hydraulic conductivity [L/T] .

The aquifer pressure beneath the stream may be measured by mini-piezometers within or adjacent to the streambed, or from nearby wells. However, the more distant the groundwater monitoring point (both laterally and vertically) the greater the level of uncertainty in the measurement of gradient.

As with the infiltration rings, seepage meters only make measurements at isolated points in the streambed, and a large number of measurements over a wide area of the streambed will increase the reliability of the results of these tests.

Appendices A – D have been prepared to present examples of field measurements and stream depletion assessments that have been made in different Regional Council areas of New Zealand.

6.2 Field Measurements that May Not Assist Estimates of Stream Depletion Effects

The field measurements described in section 6.1 are considered to be the most reliable means of gathering the key hydrogeologic data to allow an accurate assessment of stream depletion. This section briefly outlines some other field measurements that could be made, but may give misleading results due to incorrect assumptions.

6.2.1 Inaccurate Gauging Surveys

It is conceptually appealing to assess stream depletion effects by simply pumping a well for a period of time and monitoring the flow in a nearby stream to see the change that occurs.

Float methods and current meters can be used to measure the water flow rate and when this information is combined with the cross-sectional area of the flow channel, the flow rate can be estimated. However, this has not been found to be a reliable method of assessment due to measurement inaccuracies coupled with background fluctuations in stream flow compared to the relatively small effect from a pumping well, particularly over short pumping periods (i.e. less than 48 hours).

The Australian Water Resources Council note that under the most favourable conditions, margins of error in float measurement are about 10%. If non-uniform conditions occur within the stream (which is a more typical situation) then margins of error of 25% or more can be expected. A well designed current meter survey under favourable conditions may be able to achieve margins of error of about 5% to 10%.

An example of the background variability that occurs in streams is demonstrated from data reported in Weir (1999) on the Doyleston Drain which is presented as a case study in Appendix D. Figure 32 shows background monitoring results of stream flow and groundwater levels around the time of a carefully controlled pumping test. Weirs were installed in the stream to measure the stream flow as accurately as possible during a controlled pumping test. The results detect a measurable reduction in stream flow during the pumping period and this has been attributed to the stream depletion effect.

However, even under this most carefully controlled condition there is uncertainty due to the recovery of flow in the downstream weir before pumping stopped (perhaps due to external effects on the stream or to a timing offset in the flow recording device) and the larger reduction in stream flow after pumping stopped (perhaps due to changes in barometric pressure). This example is probably the best experimental field data that is available for the assessment of stream depletion effects, yet the uncertainties listed above highlight the difficulty of using gauging assessments over a pumping test as a means of producing convincing data to quantify stream depletion effects.

The fact of the matter is that stream flow is naturally quite variable and stream depletion effects from wells typically build up over a prolonged period of pumping (i.e. several days). Over the period of time that stream depletion effects occur it is likely that the background fluctuations in stream flow will be of sufficient magnitude to swamp the attempted stream depletion measurement, particularly when allowance has to be made for the inaccuracies in the gauging method. All these factors should be assessed before contemplating any gauging measurements to assess stream depletion effects.

6.2.2 Water Chemistry Analyses

Consideration may also be given to measuring the change in water quality characteristics that occurs between the surface water body and the groundwater. If such a parameter could be found then monitoring of the water quality in the pumped well could detect a change in the proportion of surface water being pumped from the well. For instance, a common example of the change in water chemistry between surface water and groundwater occurs in the pH value of the water:

Groundwater	Surface Water
low pH	high pH
$H^+ + HCO_3^-$	$H_2O + CO_2$ (gas)
$\equiv$	

One difficulty that exists with such chemical indicators of surface water is that many of the chemical parameters will typically undergo chemical transformation as they move through the streambed and into the subsurface environment. Consequently, by the time any water that originated from the surface water body reaches a well, its chemical composition will have been modified so that it can no longer be directly compared with the chemical composition of surface water.

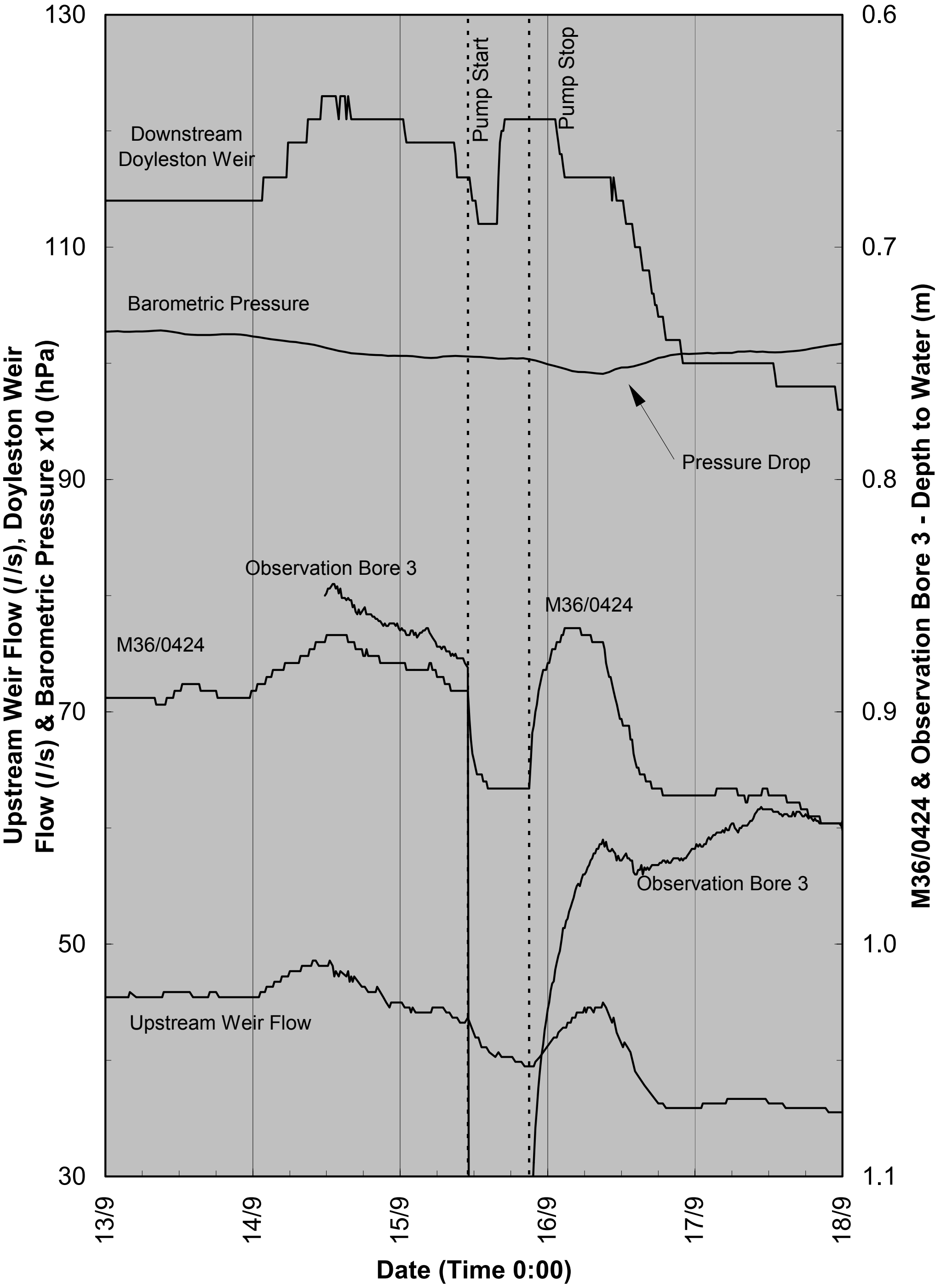

Figure 32: Variations in Stream flow (from Weir, 1999)

Of even greater significance though is recognition that stream depletion effects can occur without any stream water reaching the well. The stream depletion effect is caused by a pumping well creating a change in hydraulic gradient adjacent to the streambed which results in a loss in stream flow, or an equivalent reduction in groundwater seepage that would otherwise enter the stream.

This effect can occur without any surface water actually been drawn into the well. As a result, sampling the water quality of the pumping well for surface water indicators cannot be used as a reliable measure of stream depletion effects.

6.2.3 Pumping Test Results Near Streams

Pumping test are a common hydrogeological field technique to determine aquifer transmissivity and storage characteristics. They involve the pumping of an individual well at a constant rate for a period of several hours whilst the drawdown in water levels is measured both in the pumped well and in surrounding "observation wells", as described in section 6.1.2. These tests are typically analysed using methods that assume the aquifer is of infinite extent. However, if such tests have taken place in aquifers where stream depletion effects are expected to occur then it may be inappropriate to use aquifer parameters that have been analysed using the assumption of an infinite aquifer. In such circumstances it will be more appropriate to re-analyse the test data using the approach described in Hunt (1999).

It has also sometimes been misleadingly reported that because pumping tests have created very small drawdowns, there must be no stream depletion effect occurring. However, it is often the recharge from a stream that causes the small drawdown effects during pumping.

6.2.4 Water Divining

Water divining or dowsing is claimed to be a technique available to a few "gifted" people who have the ability to "divine" groundwater flow paths. This is most often carried out by the use of forked sticks, wire rods, hoops, pendulums or similar instruments. The instruments are typically held in a position where a small change in muscular tension (either deliberately or subconsciously) results in a deflection. The nature of the deflection is claimed to indicate the depth, direction and/or rate of water flow beneath the ground. These deflections occur as the diviner walks across the area of interest and/or surveys a map or aerial photograph of the area.

Whilst many wells have been successfully "divined" this has typically occurred in areas where groundwater can successfully be found without the help of a diviner. In fact, successful divining seems to rely on a general knowledge of existing geological and well performance characteristics in an area. Williamson notes that a book entitled, "The Modern Dowser: A Practical Guide to Divining", advises that, "It is useless to look for water where geology tells us there cannot be any. The dowser then must have a special knowledge of geology and especially that of the country where he is working." Williamson also states, "it has been found that the most successful diviners are those who are good observers and well experienced in the area in which they operate, their failures becoming less frequent as their experience increases. In fact, if the groundwater conditions are particularly favourable, they may not have had any failures at all".

Bowden et al. (1983) express the view that reliance on divining has "led to a great deal of wasted time and money". They state that, "to demonstrate their worth, diviners would have to show a success rate significantly better than that of a groundwater geologist, an experienced driller or indeed random chance. This has never been done and in fact the opposite is true. There is no acceptable scientific evidence that water divining works; whenever controlled tests have been done, the claims of the diviners have been disproved."

This view is clearly not shared by diviners and many others who have used their services to find successful groundwater sources. However, the lack of verifiable scientific evidence to support their claims means that divining does not provide reliable information on the movement of water between streams and pumping wells. On this basis it cannot be used to help in the assessment of the issues presented in this guideline.