Hydrogeological Investigation of the Southern Springs, Wairau Plains

Prepared for:

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phreatos
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1. Introduction

Natural spring outflows from the Wairau Aquifer occur along a broad transition zone between unconfined and confined aquifer conditions between Rapaura near the Wairau River through to the Doctors Creek/Fairhall area (Figure 1). The largest spring discharges occur in Spring Creek at a rate of approximately 4 m^3/sec. A series of smaller spring-fed streams also occur south of the Opawa River to the west of Blenheim. These are collectively termed the 'Southern Springs' and include Cassey's Drain, Waterlea Creek, Fulton's Creek, Murphy's Creek, the old Fairhall Creek, Yelverton Stream, the Fairhall Co-op Drain and the Doctors Creek.

The Southern Springs area was formerly occupied by an extensive swampland fed by springs and surface water inflows from the Omaka and Fairhall rivers. Drainage of the swampland commenced a century ago, which together with the diversion of influent rivers, has isolated the spring-fed streams.

The combined average flow of the Southern Springs is approximately 2.5 m^3/sec. The springs contribute in excess of 90% of the flow to the Taylor River in Blenheim and feed the entire flow during dry summer periods. The Southern Springs have a high ecological value because they sustain the aquatic health of the Taylor River and are the main source of replenishment for the Taylor River during the summer. The spring channels themselves also provide valuable freshwater habitats for fish life along the stream corridors.

It has been established that springs are sensitive to local groundwater abstractions and measurable depletions in spring and stream flows resulting from groundwater pumping have been observed in recent years. The cumulative long term effects of irrigation abstractions within the spring catchment are of particular concern but have been poorly understood to date.

This study aims to provide a hydrogeological characterisation and conceptualisation of the Southern Springs area to help understand the aquifer discharge mechanisms and their vulnerability to groundwater abstraction. This information has provided the basis for a numerical and analytical modelling analysis of the groundwater environment and the spring flow depletion effects caused by local wells to assist in the development of a management strategy for the Southern Springs Catchment. The study concludes with some possible options and methods to maintain minimum flows in the springs to ensure healthy ecosystem functioning during the summer months.

2. Wairau Plains - General Hydrogeological Setting

The Wairau Plains occupy a fault-angle depression formed along the Wairau Fault which is filled with glacial fluvial outwash deposits (Speargrass Formation) and post glacial alluvial deposits (Rapaura Formation)[1] derived from the erosion and re-working of the underlying glacial deposits. Permeable and high yielding aquifers are found in the gravels of the Rapaura Formation (the

[1] Brown, L.J. 1981. Late Quaternary geology of the Wairau Plain, Marlborough, New Zealand. New Zealand Journal of Geology and Geophysics. Vol 24: 477-490.

‘Wairau Aquifer’). In contrast, the underlying glacial outwash Speargrass Formation tends to be significantly lower yielding and less reliable in terms of water supply.

Near the coast, postglacial swamp, lagoonal, estuarine and beach deposits overlie the fluvial and outwash Rapaura deposits to create confining conditions located approximately eastwards of a line extending between Tuamarina and Blenheim. Low permeability Raupara deposits (alluvial silts and swamp sediments) to a thickness of 2-3 m also mantle the Dillon’s Point Formation and Rapaura gravel aquifers creating a semi-confined transition zone extending westwards to Springlands and Fairhall (Figure 2).

The unconfined Upper Rapaura gravels interfinger with alluvial silts/swamp deposits and with the marine deposits of the Dillon’s Point formation further to the east. Swamps formed in the topographically lower aquifer transition area due to spring discharges from the aquifer and the impoundment of surface water from the Omaka, Fairhall, Tuamarina and Spring Creeks behind prograded coastal deposits. The swamplands were extensively drained for agriculture prior to the 1930’s and the Omaka and Fairhall rivers were diverted northwards into the Opawa River. Discharge from the Wairau Aquifer in the transition zone between unconfined and confined conditions continue in the form of prolific spring flows along discrete channels.

On the southern side of the Wairau Plains a number of tributary catchments containing post-glacial alluvial fan deposits drain onto the plains. These are the ‘Southern Valleys’ of the Omaka, Fairhall, Doctors, and Taylor’s rivers. These valleys are regarded to contain shallow localised aquifers along the river channels and provide recharge to the Wairau Aquifer during the winter months.

Groundwater recharge to the Wairau Aquifer is predominantly via bed leakage from the Wairau River. Regional flows occur down-valley largely within the younger more permeable Rapaura gravels. Discharge occurs from the springs along the confined-unconfined aquifer contact and possibly through submarine discharge some distance off-shore.

A comprehensive description of the hydrogeology of the Wairau Plains is described in MDC[2].

3. Hydrogeology of the Southern Springs Area

3.1 Setting

The hydrogeological characteristics of the southern springs area is dominated by the boundary effects of the southern edge of the Wairau (Rapaura Formation) Aquifer, the unconfined-confined transition area, and the entry of southern valley aquifer systems onto the plains.

Figure 3 is a conceptual hydrogeological model for the area showing the principal hydrogeological features and groundwater flow conditions. The irregular boundary between the Raupara Formation (Wairau Aquifer) and the Speargrass Formation is the result of fluvial erosion, re-working and deposition of the younger Rapaura deposits. Along the contact zone, the Rapaura Formation thins out or merges with alluvial fan deposits of the southern valleys. The contact therefore represents the southern boundary of the Wairau Aquifer separating the permeable Wairau Aquifer to the north, and relatively impermeable Speargrass Formation to the south. The Omaka and Fairhall river valleys are eroded into the Speargrass Formation (and older sediments[1]) and contain thin alluvial deposits confined to the channel areas which provide seasonal groundwater inputs to the Wairau Aquifer.

The second major hydrogeological feature of the southern springs area is the contact zone between unconfined Wairau Aquifer to the west and the confined and semi-confined conditions to the east. The position of the contact zone has been relatively accurately located using bore log information. Semi-confined conditions where the aquitard is thin and in places absent, are more prevalent to the north of the Co-op/Doctors Creek and west of the Taylor's River (MDC, pers comm.).

Figures 4 and 5 are respectively east-west and southwest-northeast geological cross sections through the Southern Springs area. The locations of the sections are shown on Figure 3. The east-west cross section (Figure 4) illustrates the transition from unconfined to confined conditions at around Bells Road. The thin silt/clay aquitard near the surface has a spatially variable thickness (0-5m), and is absent in some areas. The underlying poor-water bearing gravels also create a lower permeability aquitard layer; again the nature of this material is highly variable. More permeable areas will allow the upward movement of groundwater to feed point source 'artesian' springs.

The southeast-northwest section (Figure 5) also shows the spatially variable aquitard sequence above the Wairau Aquifer. This section also shows the thinning of the aquifer towards the Speargrass Formation contact in the south.

3.2 Groundwater Levels and Flows

Groundwater flow patterns along the southern edge of the Wairau Aquifer in the Southern Springs area are dominated by the regional Wairau Aquifer west to east flow regime. Flow occurs parallel to the Speargrass Formation contact but is locally interrupted by inflows from the Omaka and Fairhall river valleys during the winter months. Drawdowns associated with groundwater abstractions in this area also locally distort the groundwater flow net. Figure 6 shows a series of water table – piezometric contour maps for the Southern Springs area. Figure 7 also demonstrates the local drawdown effects resulting from irrigation abstractions.

There is a general flattening of the regional flow gradient to the east of Renwick mirroring the topographic gradient. Flows also seem to converge on the spring discharge area west of Blenheim indicating that a substantial proportion of the aquifer throughflow discharges into the springs.

Long term monitoring hydrographs for several bores in the Southern Springs area are shown in Figure 8. The three monitoring bores are located at Athletic Park Blenheim (0949), Woodbourne 3010) and Godfreys Road Renwick (1000) and are shown on Figure 3. Large seasonal fluctuations in water table of about 10m are evident in bore 1000 at Renwick. Similar fluctuations are also reported in bores to the south of the Woodbourne air base[2]. Late summer drainage is characteristic of the southern margin of the Wairau Aquifer in this area and some bores are known to become completely dry. Lower aquifer storage properties, the probable existence of very permeable localised gravel channels facilitating rapid drainage to the east, and reduced aquifer recharge from the southern valleys may contribute to this characteristic.

[2] Marlborough District Council, 1988. Water and Soil Resources of the Wairau. Volume Two - Water Resources.

Hydrographs for bores 3010 (+594) immediately north of the Woodbourne base shows a smaller seasonal water table fluctuation of about 5m, whilst the Athletic Park bore (0949) shows a very small seasonal piezometric variation in the confined part of the Wairau Aquifer.

The Athletic Park monitoring exhibits very stable long term trend (Figure 8). Bore 1000 at Godfrey's Road however shows a slight consistent decline in levels since the mid 1990's in the order of 3m. The Woodbourne monitoring bore (3010) shows a similar declining trend. These declines are thought to be related to decreases in flow in the Omaka River as a result of abstractions.

Depths of water table – intersection with ground surface
The water table/piezometric surface lies above ground level in the Southern Springs area. The intersection of the groundwater level in the Wairau Aquifer with the ground surface represents the spring-line. Seasonal fluctuations in aquifer levels cause the spring line to migrate as shown in Figure 3. The Southern Springs occur in a topographic depression where both perennial and ephemeral springs occur.

4. Spring Discharges

4.1 Spring Characteristics

As groundwater enters the confined-unconfined transition zone on the Wairau Plains a divergence of flow occurs – groundwater either discharges to the surface or flows eastwards beneath the confining strata. A 'forced' groundwater discharge occurs at this boundary due to the reduced throughflow as observed by the flattened hydraulic gradient (and land surface gradient), and the reduced saturated aquifer thickness of the confined aquifer. It appears that there is an extremely small throughflow in the Wairau Aquifer east of the spring discharge zone and that the aquifer nearly entirely discharges through the springs.

The locations of the Southern Springs (spring-fed streams) are shown in Figure 9. Most are natural, or modified existing water courses. However some are artificially created drains such as the Co-op drain west of the Doctors Creek confluence, parts of Casey's Drain and Waterlea Creek.

The major spring-fed streams south of the Opawa River are:

- The Doctors Creek – Co-op drain system
- Old Fairhall Creek System
- Murphy's Creek
- Fulton's Creek
- Casey's Drain
- Waterlea Creek

All of the streams and drains are entirely spring-fed during the summer months, with some surface drainage and urban runoff occurring during rainfall periods. Numerous tile drains also feed into the spring channels – many of which flow strongly during dry periods indicating that they also are fed from spring discharge.

Flows in the larger streams have been monitored by the Marlborough District Council from early 2003. Earlier spot gauging on some streams are also available, and the Waterlea Creek has been monitored regularly since 2001. Figure 10 shows the flow monitoring undertaken on the Waterlea, Murphy's, Fulton's and Doctors creeks from January 2003 to the present. The gauging locations are shown on Figure 9.

The spring-fed streams exhibit large fluctuations in flow as a result of seasonal changes in water table and piezometric level. Summer declines in flow are accompanied by a recession in the spring line as shown in Figure 3. However, the relatively short monitoring record prevents any meaningful analysis of any long term changes in spring flow.

The largest flow of 500 – 900 L/sec occurs in the Murphy's Creek which is thought to be a relic of the Omaka River which used to flow through this channel prior to it being diverted into the Opawa River near Woodbourne in the early part of the last century. The spring is probably connected to permeable gravel channels connecting it back to the Omaka.

Doctors Creek catchment also produces a significant spring flow of between 100 and 1400 L/sec having a very strong seasonal variation. Much of the high winter flows relate to surface runoff in the upper catchment areas to the south. The peak summer flow minimum represents a spring-fed baseflow of 100-150 L/sec possibly affected by spring depletion effect of more than 100 L/sec.

The southernmost streams appear to exhibit the highest seasonal flow fluctuations (Doctors Creek/Old Fairhall Creek and Murphy's Creek) which is possibly a result of the influence of the seasonality of the groundwater throughflow received from southern valleys aquifer systems. Catchment runoff and urban runoff also contribute to the high seasonal variability in the flows. In contrast, the Fulton's and Waterlea Creeks show relatively minor seasonal flow variations.

4.2 Spring Flow Mechanisms

The properties that influence spring flows are the local topography, channel geometry, stream bed elevation, nature of channel bed deposits, underlying geology, aquifer conditions, and local groundwater levels or pressures. Choking of the channels with weed also has a significant impact on spring flows and levels.

Springs occur when groundwater levels are above the elevation of the spring outlet (i.e. stream bed). A notable feature of the Southern Springs is that they transect the unconfined semi-confined/ confined aquifer boundary (Figure 3). This gives rise to several mechanisms of spring discharge as illustrated by Figure 11:

- Continuous spring discharge along the gravel beds of streams and drains in the unconfined aquifer. This occurs in the unconfined aquifer area in the headwaters of the spring-fed streams. Ephemeral spring discharges occur where the groundwater table intersects the stream bed or ground surface. The headwaters of the spring move seasonally as the water table elevation changes. This zone has been termed the *Seasonal Unconfined Seepage Zone.*

- Point source ‘artesian’ springs occur at discrete points in the stream bed over the semi-confined/confined aquifer area. High-volume perennial point discharge springs are characteristic of the Southern Springs although the locations of many point source springs are not well characterised. This zone has been termed the *Perennial Artesian Spring Zone*.

General leakages through thin confining beds along stream channels in the semi-confined/confined areas may also occur (PDP, 2003)[3] representing a continuum between the two zones.

Figure 11 is a longitudinal section along the Co-op Drain/Doctors Creek channel using surveyed bed level data and modelled groundwater level data based upon local monitoring bores. The diagram illustrates the variable nature of spring discharge across the unconfined-confined aquifer boundary.

4.3 Relationship between spring discharge and groundwater level

Spring flow is dependent upon the difference between groundwater head in the underlying aquifer, the spring elevation and the hydraulic conductivity of the stream bed and the hydraulic conductivity of the aquifer (horizontal and vertical). Where confining conditions occur, the vertical hydraulic conductivity of the aquitard, or the properties of a point source spring conduit, is also important.

Figure 12 schematically shows the relationship between spring discharge and head for both unconfined discharges along the bed of the stream and point source discharges. It is usually acceptable to assume a linear relationship between flow and head for unconfined bed discharges. However, as the area of the Seasonal Unconfined Seepage Zone expands with increasing head, the trend indicated by line ‘a’ in Figure 12 may be more appropriate[4].

The discharge trend for point source springs is different and is taken from theory for artesian flow through a pipe which states that the discharge is proportional to the square root of the excess head. However it is probable that the relationship between flow and groundwater head in a feeder conduit through an aquitard, or a small area where the aquitard is absent, is likely to be predominantly linear until at some point the frictional losses in the spring conduit cause the linear relationship to break down as indicated by point ‘b’ in Figure 12.

The relationship between the flow in the Doctors Creek and nearby groundwater level monitoring bores is shown in Figures 13 and 14. The relationship is not linear and flows are more sensitive to fluctuations in groundwater level when the regional groundwater head is above c. 6 m amsl around the Battys Road – Athletic Park area. This probably indicates the influence of continuous bed discharges from the Season Unconfined Seepage Zone to the west of the confined-unconfined boundary and is consistent with the conceptual flows shown in Figure 12.

Figure 13 shows the temporal correlation between groundwater level and spring flow over a two year period between November 2002 and November 2004. This diagram shows that when groundwater levels are high, a small reduction in head, for example of 0.5m, produces a spring flow

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[3] Pattle Delamore Partners Ltd. 2003. Report on pumping test for John Pickering at Bells Road.

[4] Rushton, K.R. 2003. Groundwater Hydrology – Conceptual and Computational Models. John Wiley & Sons Ltd.416pp.

reduction of around 400 L/sec. When groundwater levels are lower, below about 6m amsl at the monitoring bore sites (0949 and 1384), the same drop in head causes a reduction in spring flow of about 150-200 L/sec.

The observed correlations between the flow in Doctors Creek and groundwater levels provides good baseline information to assist in the assessment of spring flow depletions resulting from groundwater abstractions.

5. Spring Flow Depletion

Spring- flow and stream depletion induced by groundwater abstractions have occurred in the Southern Springs area in recent years [5]. Reductions in stream flow during natural low flow summer conditions may result in adverse effects on the high-value aquatic ecosystems. Increasing demand for groundwater in the Southern Springs area has required that a thorough understanding of stream flow depletion mechanisms coupled with theoretical quantification of the effects of abstraction drawdowns is necessary to assist in the management of the groundwater resource.

5.1 Types of Spring Flow Depletion in the Southern Springs Area

Figure 15 schematically shows the effects of aquifer drawdowns caused by pumping on point source and unconfined streambed spring discharges. Point source springs occur because there is a permeable route through an aquitard layer through which there is an upward vertical gradient between the stream surface and the underlying aquifer (Figure 15A). A reduction in the flow from a point source spring occurs when the vertical head gradient between the stream surface and the confined (or semi-confined) aquifer is reduced as a result of nearby abstraction (Figure 15B). Spring discharge still occurs, but at a lower rate which also has the effect of reducing the overall flow in the spring-fed stream.

When a nearby bore causes large drawdowns in the vicinity of a point source spring, the vertical flow gradient may actually become reversed and the bore may draw flow from the stream (Figure 15C). At greater distance from the bore, reductions in point source springs will also occur due to change in the vertical hydraulic gradient. The rate of flow into the aquifer will increase until a unit vertical gradient is attained. At this point the leakage into the aquifer will proceed at a constant rate as indicated in Figure 12.

Figure 15D shows the effects of abstraction in the unconfined area of the Wairau Aquifer. Lowering of the water table causes a recession in the spring line – the spring-fed stream dries up to the point where the cone of depression associated with the bore (or bores) intersects the stream bed. Downstream of this point, reductions in both stream bed discharge in the unconfined area, and a reduction in point source spring flow occurs.

Cumulative abstraction drawdowns in the Wairau Aquifer which have a broader influence on the groundwater levels in the Southern Springs area, rather than the effects of individual bores, also has the potential to cause stream flow depletion and recession in spring-line as shown in Figure 15D.

[5] MDC pers comm

The widespread effects on the flow in the Southern Springs of cumulative drawdowns is of greater concern than the impacts of individual bores. Such effects are more difficult to analyse and manage.

5.2 Direct Evidence for Spring Flow Depletion

The direct stream depletion effect on the Fairhall Creek / Coop Drain system by adjacent pumping wells has been recognised for some time. Stream depletion effects have been demonstrated through pumping tests, and evidence of depletion can be seen in the short-term flow record for Doctors Creek. Figure 16 shows a continuous flow record and four manual gaugings for Doctors Creek at Battys Road confirming that stream depletion effects of pumping in the Doctors Creek catchment are considerable. The continuous flow record shows that individual abstractions can reduce stream flow by at least 40-50 L/sec.

Further direct evidence for spring flow depletion is provided by individual pumping test results during which the adjacent stream flow was monitored. Depletion effects of up to 10 L/sec have been detected as a result of abstraction from a single bore adjacent to springs.

6. Quantification of Spring Flow Depletion

6.1 Approach

Both numerical and analytical techniques have been employed to assess the depletions effects of groundwater abstractions to flows in the Southern Springs system. The cumulative depletion effects in the complex hydrogeological environment of the Southern Springs – the transition zone between confined and unconfined conditions – are most effectively analysed using numerical modelling methods. Alternative simpler analytical assessment techniques are restricted to examining the depletion effects in of individual bores and cannot be used to determine the cumulative effects of abstraction around the springs, and in the transitional unconfined-confined area. However, analytical methods are perceived to be more accurate in the examination of depletion effects for pumping bores in very close proximity and have been used to verify and supplement the numerical assessment.

6.2 Numerical Modelling

Evaluation of the cumulative effects of groundwater abstractions in the vicinity of the Southern Springs, and assessment of the spatial sensitivity of spring flow to abstraction, has been undertaken using a simple numerical model. The approach has been to develop a simple two-layer model of the Doctors Creek / Old Fairhall Creek spring system calibrated to summer ‘time-instant’ groundwater levels and spring discharges then run for a six-month period.

The conceptual hydrogeology upon which the model is based has been presented in Sections 2 and 3.

6.2.1 Model Design

To simulate a time-instant (steady-state) flow field focussed around the springs area it is necessary to extend the model boundaries to some distance so that boundary conditions will not effect short (six month) drawdown simulations in the Southern Springs area. The model domain therefore covers much of the Wairau Plains and constant head boundary conditions have been used to simulate the observed groundwater flow field around the springs and within the springs catchment.

The model has a finite difference model grid covering an area of 22km by 8km and encompassing much of the Wairau Plains (Figure 17). The grid spacing telescopes down to 50m in the vicinity of pumping wells and out to about 1km towards the model boundaries. The model has two layers to enable the simulation of the 'Wairau Aquifer', confining layers and adjoining low-permeability Speargrass Formation. The layers were configured as follows:

- A lower layer 10-20m thick representing the Wairau Aquifer in the unconfined and confined areas. This layer was assigned confined/unconfined (Modflow Type 3) layer condition.

- An upper layer also representing the Wairau Aquifer in the unconfined area, and the confining layers to the east of the springs. The upper surface is represented by the modelled position of the water table in this layer. This layer was assigned an unconfined (Modflow Type 1) layer condition.

The layer surfaces were modelled using bore information and geological cross section data (DSIR, 1981[6]).

The Speargrass Formation is represented where it outcrops around the Southern Valleys area.

Boundary Conditions
The east, west and north edges of the model have been assigned constant head boundary conditions based upon regional water table and piezometric levels and adjusted to provide an accurate summer flow field around the Southern Springs area.

All major springs across the Wairau Valley were modelled using a combination of drain cells and stream cells. The latter were used for the Southern Springs only (Doctors Creek and Old Fairhall Creek) in order to more accurately simulate spring discharges and depletion effects. Drain and stream bed conductance values were derived from the calibration process resulting in a range of values between 7,000 and 10,000 m^2/day. Since there is very little information on the locations and properties of point source springs within the Perennial Artesian Spring Zone in the confined and semi-confined aquifer areas, average bed conductance conditions were modelled. This means that the effects of individual pumping wells next to discreet point source springs cannot be accurately predicted by the model.

No recharge inputs were used as it was assumed that summer recharge conditions would be negligible.

[6] DSIR, 1981. Water Well Data, Northern Marlborough. LJ Brown, NZ Geological Survey. Report NZGS 93 ISSN 054 9784.

Stress Periods
The model as configured to run a transient simulation for 200 days with a single stress period to represent the summer irrigation period.

Abstraction Wells
Abstraction wells in the area south of Old Renwick Road and east of Renwick were incorporated into the model and activated after the calibration process to derive stream depletion volumes. The well data were derived from the Marlborough District Council consents database and the maximum consented rate was used in the model. The total cumulative pumping rate was 41,617m^3/day.

Model code
The USGS finite difference numerical code MODFLOW[7] was used to model the Southern Springs catchment. The 'Visual Modflow' data processing interface (Waterloo Hydrogeologic) was used to build the model and process the output data.

6.2.2 Calibration

The calibration process involved running six-month transient simulations in several stages:

- Initial estimation of aquifer parameters within the ranges identified from field measurements and calculations.
- Modification of parameters and manual calibration against transient groundwater levels in monitoring wells, and to water balance estimations (river losses and gains).
- Assessment of parameter uncertainty using a sensitivity analysis

The objective of the calibration was to develop a model that can reliably simulate the Southern Springs groundwater system under a range of abstraction stresses. This objective was initially achieved through manually matching modeled spring flows for the end of the simulation run with observed flows for March 2004.

The process of transient calibration involved assigning hydraulic conductivity ($k_{x,y,z}$), storage coefficient and bed conductance values to the various springs and then adjusting these parameters in an iterative process to obtain a match to observed groundwater level data in the Southern Springs area and to spring flows.

Calibration Targets
The first comprehensive groundwater level survey was carried out in March 2004 by MDC involving 43 wells. All wells locations and elevations were accurately surveyed using GPS. Figure 7 contains the contoured data.

7 McDonald, M.G. and Harbaugh, A.W. 1984. A modular three-dimensional finite difference groundwater flow model: *US Geological Survey* Open-File Report 83-875, 528pp.

The model was initially calibrated to these levels through adjustment of hydraulic parameters. Groundwater levels in the vicinity of the Southern Springs proved to be insensitive to changes in the model boundary conditions and were shown to be locally controlled by spring discharges and hydraulic conductivity. The insensitivity of the Southern Springs area to the boundary conditions provided confidence that the boundaries would not have a significant influence on predictive simulations.

Figure 18 shows the calibrated model heads at the end of the transient model run.

Flow monitoring has been carried out on the main spring channels on the Wairau Plains by Marlborough District Council over the past two years (Figure 8). This data has been used to derive spring flow calibration targets for March 2004 since the model has been set up with groundwater level conditions corresponding to this time when negligible pumping was occurring from irrigation bores. Table 1 shows the calibration targets and the modelled spring flows.

Table 1: Spring flow calibration targets and modelled flows

Spring-fed Stream	Observed Flow (March 2004) L/sec	Modelled Flow L/sec
Doctors Creek @ Taylor's confluence (Doctors/Co-op/Old Fairhall)	300	300
Murphy's Creek	650	650
Fulton's Creek	250	215
Opawa River	?	406
Spring Creek	3,500-4,000	3,560

Hydraulic Properties

Hydraulic properties for the various hydrostratigraphic units were assigned using a combination of pumping test information and specific capacity data. These were refined during the calibration process and Table 2 contains the calibrated values.

Table 2: Calibrated Hydraulic Properties

	Hydraulic conductivity k_x and k_y (m/day)	Vertical hydraulic conductivity k_z (m/day)	Storativity S_y/S_s
Wairau Aquifer (south of Old Renwick Road)	600	600	0.06 / 0.00005
Wairau Aquifer (north of Old Renwick Road)	600	600	0.06 / 0.00005
Dillons Point Aquiclude	1	0.1	0.02 / -
Upper Rapaura Fm Aquitard	300	10	0.02 / -
Speargrass Formation	0.1	0.1	

Review of pumping test data[2] shows that the average transmissivity for the Wairau Aquifer in the Southern Springs area is about 2,000 m^2/day. Given that most wells are partially penetrating and would tend to have relatively short screen lengths in comparison to the aquifer thickness, the actual transmissivity of the aquifer is likely to be somewhat greater. The effects of partial penetration are particularly pronounced in aquifers in which vertical flows are significantly lower than horizontal flows. The calibrated average hydraulic conductivity values are regarded to be representative of the aquifer and model calibration process has shown that lower values would not allow the observed spring discharge from the aquifer.

6.2.3 Springflow Depletion Assessment

Pumping scenarios have been simulated to assess the cumulative effects of abstraction on the flow in the Southern Springs and the spatial sensitivity of flows to abstraction from different parts of the aquifer. A total of 14 scenarios incorporating current abstraction bores and theoretical bores were modelled:

Cumulative effect (maximum consented abstraction rates):

1. Actual consented wells pumping (as at March 2004)

Spatial Sensitivity Analysis – Current Abstractions (maximum consented abstraction rates):

2. Only actual wells within 500m of the spring channels pumping.
3. Only wells west of Bells Road pumping.
4. Wells in the confined aquifer area only pumping
5. Actual wells in the confined aquifer between columns 31 and 41 (2586000E – 2586500E) only pumping.
6. Actual wells in the confined aquifer between columns 42 and 48 (25865000E – 2587000E) only pumping.
7. Actual wells in the confined aquifer between columns 49 and 53 (2587000E – 2587500E) only pumping.
8. Actual wells in the confined aquifer between columns 54 and 60 (2587500E - 2588000E) only pumping.

Spatial Sensitivity Analysis – theoretical wells, constant pumping from 4 theoretical wells aligned aling specified Easting co-ordinates:

9. 2584000E, total pumping rate = 10,000m^3/day
10. 2585000E, total pumping rate = 10,000m^3/day

    < confined-unconfined boundary >

11. 2586000E, total pumping rate = 10,000m^3/day
12. 2587000E, total pumping rate = 10,000m^3/day
13. 2588000E, total pumping rate = 10,000m^3/day
14. 2589000E, total pumping rate = 10,000m^3/day (east of Taylor’s confluence)

Scenario 1 assesses the impact of the total cumulative abstractions on streamflow assuming all wells are pumping at the maximum consented rate for 30 days.

Scenarios 2 to 8 examine the cumulative effects of abstraction from different parts of the springs area by turning wells on and off as specified.

Scenarios 9 to 14 is a more tightly controlled examination of spring flow sensitivity to abstractions from a moving north-south array of four bores, each pumping at 2500m^3/day (total 10,000 m^3/day).

Scenario Modelling Results
The results of the 14 abstraction scenarios are provided in Table 3. Because of the different abstraction rates used in each scenario, the results are reported both as total stream flow depletion and as the ratio of spring depletion rate to groundwater abstraction rate. Stream flow depletions are reported after 30 days of pumping.

Table 3: Model Results for Scenarios 1 - 14

Scenario	Max. pumping rate m^{3}day / Lsec	Modelled Spring flow Taylors Confluence L/sec	Modelled Spring flow loss L/sec	Ratio Loss:Abstraction
1	41,617 / 481	200	100	0.21
2	32,492 / 376	220	80	0.21
3	19,582 / 226	270	30	0.13
4	22,035 / 255	226	74	0.30
5	10,980 / 127	273	27	0.21
6	7,425 / 86	279	21	0.24
7	2,249 / 26	290	10	0.38
8	1,500 / 17	291	9	0.52
9	10,000 / 116	286	14	0.12
10	10,000 / 116	283	17	0.15
11	10,000 / 116	280	20	0.17
12	10,000 / 116	260	40	0.35
13	10,000 / 116	221	79	0.68
14	10,000 / 116	252	48	0.41

6.2.4 Scenario Modelling Conclusions

The numerical model provides an indication of the cumulative abstraction effects on springflow and the sensitivity of spring flow to abstractions in different parts of the aquifer.

The results of the scenario simulations reported in Table 3 can be summarised as follows:

- Current maximum consented abstraction appears to have a cumulative depletion effect of about 100 L/sec (Scenario 1) which represents about 20% of the total pumping rate.

- Spring flow depletion is sensitive to groundwater abstractions from the confined aquifer area. Spring flow depletion is predominantly caused by wells located within 500m of the spring channels (Scenario 2) and located within the semi-confined and confined aquifer area (Scenario 4).

- Approximately 30% of all abstractions from the Southern Springs confined aquifer area appear to be derived from spring flow depletion (Scenario 4).

- Wells located west of Bells Road in the unconfined aquifer area account for a spring flow depletion of only about 30 L/sec.

- Within the confined aquifer area, the numbers of bores and rates of abstraction decrease sharply towards the east resulting in a corresponding drop in spring flow depletion as illustrated in Figure 19A.

- Spring flow becomes increasingly sensitive to abstraction towards the east up to the Taylor River confluence as semi-confining conditions transition into confined aquifer conditions as shown in Figure 19B. East of the Taylor River confluence, depletion effects in the Southern Springs diminish although additional depletion effects in the Taylor River probably occur.

6.3 Analytical Assessment of Spring Flow Depletion

Analytical streamflow depletion methods are useful in verifying the numerical assessment and supplementing the depletion assessment for bore in very close proximity to the spring channels. It is important to recognise that the model probably underestimates spring flow depletion relating to such because the model does not accurately predict pumping drawdowns in the immediate vicinity of the bore due to the grid spacing.

Several workers have developed methods for estimating streamflow depletion. A description and discussion of the various techniques have been documented by Environment Canterbury[8]. The method developed recently by Bruce Hunt[9] from Canterbury has previously been adopted for the assessment of spring flow depletion as a result of groundwater abstractions on the Wairau Plains[10,11].

The stream depletion factor (SDF) developed by Jenkins[12] is also a useful measure for assessing the degree of hydraulic connection between a stream/spring and a pumping well. The SDF is a function of the separation distance between well and the stream or spring, the aquifer transmissivity and storage coefficient. A small SDF (expressed in time units) signifies a rapid and large interaction between the well and the stream. As the SDF becomes larger, the stream depletion effect is delayed and smaller.

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[8] Environment Canterbury & Pattle Delamore Partners. 2000. Guidelines for the assessment of groundwater abstraction effects on stream flow. Report No. ROO/11

[9] Hunt, B. 1999. Unsteady stream depletion from groundwater pumping. Groundwater, Vol. 37, No. 1, pp98-102.

[10] Pattle Delamore Partners. 2004. Stream depletion report. Marlborough District Council.

[11] MDC, pers comm..

[12] Jenkins, C.T. 1977. Computation of rate and volume of stream depletion by wells. US Geological Survey, Chapter D1, Book 4, 3rd edition.

Table 4 contains stream flow depletion assessment using the Hunt methodology for the pumping wells around the Doctors Creek/Old Fairhall Creek spring system (South of Old Renwick Road and east of Woodbourne). The calculations are based on a pumping period of 30 days and 100% the maximum consented abstraction rate. Account has also been made for confined and unconfined aquifer conditions.

The range of calculated depletion (q) ranges from about 0.1 to 43 L/sec and the combined spring flow depletion for all wells is approximately 250 L/sec. This is considerably greater than the quantity predicted using the numerical model of 100 L/sec. However, the model shows a very small depletion associated with wells in the unconfined zone, largely because the spring line would have receded to the unconfined-confined aquifer boundary during the summer months. Wells to the west would not therefore cause a direct spring flow depletion effect. The total depletion in the semi-confined / confined aquifer area has been analytically calculated to be 150 L/sec (Table 4). This is still some 50% higher than predicted by the numerical model but may provide a more accurate assessment given the limitations of the model in simulating higher drawdowns (and therefore depletion) associated with wells adjacent to the spring channels.

All wells in the confined aquifer area have an SDF of less than 10 days, with the majority being less than 1 day, indicating a very rapid connection between the well and the springs. By plotting SDF against distance from the spring (Figure 20), those wells with an SDF of less than 1 can be shown to be within 500m of the spring channels. Wells having an SDF of greater than 1 day generally show a very small depletion rate. This distance agrees with the numerical model sensitivity analysis (Scenario 2).

The analytical assessment of stream depletion can be used to provide a guideline management buffer around the springs within which groundwater abstractions should be management for spring flow depletion effects. It is suggested that this should be based upon a conservative SDF of 10 days. Figure 20 indicates that this equates to a distance of about 1000m from the spring channels.

It should however be appreciated that the complexities of the local hydrogeological environment and the predominance of point source springs (as discussed earlier) may introduce a degree of error to the analytical calculations.

CONSTANTS	
t (total)	**30**
t (off)	**100**
σ	**0.15**
Pumping Rate	**100**

definition of terms:

Q	pumping rate	q	spring/stream depletion rate
S	storativity	SDF	stream depletion factor
T	transmissivity	K'	vertical hyd. Cond. Aquitard
λ	streambed conductance	B'	aquitard thickness

Semi-confined - Confined Aquifer

			Consented					***Confined Aquifer OUTPUTS***			
Name	**P28w/**	**Dist (m)**	**Q (m3/d)**	**T (m2/d)**	**S**	**λ (m/d)**	**K'/B'**	**Q(l/s)**	**q/Q**	**q (l/s)**	**SDF**
Jowett	2309	110	22	1200	0.010	1	5	0.25	0.46	0.12	0.1
Mufaletta	2314	270	20	500	0.010	1	0.1	0.23	0.53	0.12	1.5
Jowett	3925	90	22	1000	0.010	1	5	0.25	0.49	0.12	0.1
King	2047	460	40	2000	0.010	1	10	0.46	0.34	0.16	1.1
Rhodes	3355	25	100	1800	0.050	1	10	1.16	0.25	0.29	0.0
Rose	3560	980	50	250	0.001	1	0.1	0.58	0.70	0.40	3.8
Christie	0635	220	162	2000	0.010	1	10	1.88	0.37	0.69	0.2
Gordon	1717	90	359	1800	0.050	1	10	4.16	0.23	0.97	0.2
Hogg	3603	65	120	1000	0.001	1	0.2	1.39	0.79	1.10	0.0
Weaver	0665	50	240	2000	0.010	1	5	2.78	0.41	1.14	0.0
Mafaletta	3857	20	140	500	0.010	2	0.1	1.62	0.78	1.26	0.0
Vanstone	3842	70	142	1000	0.001	1	0.1	1.64	0.79	1.31	0.0
Jolley	4105	130	210	1200	0.050	5	10	2.43	0.63	1.54	0.7
Newman	0685	90	405	1500	0.010	1	5	4.69	0.44	2.07	0.1
Jones-Shipley	2317	110	367	1000	0.010	1	0.25	4.25	0.51	2.15	0.1
Lloyd	3735	10	236	1000	0.001	1	0.1	2.73	0.80	2.19	0.0
St Clair	1025	700	289	250	0.001	1	0.1	3.34	0.75	2.52	2.0
Wiffen Vines	0995	480	289	500	0.001	1	0.1	3.34	0.79	2.63	0.5
Clifford	3782	20	300	1200	0.001	1	0.25	3.47	0.78	2.70	0.0
Skinner	1849	460	354	500	0.001	1	0.1	4.10	0.79	3.23	0.4
Marris	1426	450	354	500	0.001	1	0.1	4.10	0.79	3.24	0.4
Saul	1558	100	414	500	0.001	1	0.25	4.79	0.84	4.00	0.0
Wiffen Vines	3617	12	400	1440	0.001	2	0.25	4.63	0.87	4.03	0.0
Bishell	2511	150	520	1000	0.001	1	0.1	6.02	0.79	4.74	0.0
Couper & VdGeest	2007	380	530	500	0.001	1	0.1	6.13	0.80	4.91	0.3
Chippies & St Leonards	1475	250	703	500	0.001	1	0.1	8.14	0.82	6.67	0.1
Pickering	1428	20	1469	1600	0.010	5	10	17.00	0.80	13.67	0.0
Morrison	1731	6	2500	1600	0.010	5	10	28.94	0.81	23.38	0.0
Marris	1404	10	6480	1500	0.010	4	10	75.00	0.77	58.02	0.0
									confined tot:	**149.4**	

Table 4: Analytical Spring FLow Depletion Calculation (Hunt method)

Unconfined Aquifer

Name	P28w/	Dist (m)	Consented Q (m3/d)	T (m2/d)	S	λ (m/d)	Unconfined Aquifer OUTPUTS Q(l/s)	q/Q	q (l/s)	SDF
Donaldson	3602	1290	28	500	0.050	10	0.32	0.07	0.02	166.4
Campbell	4071	1200	30	500	0.050	10	0.35	0.10	0.03	144.0
Pilkington	3739	1070	30	500	0.050	10	0.35	0.13	0.05	114.5
Paynter	4355	340	49.6	1500	0.050	5	0.57	0.53	0.30	3.9
Bishell M D	2275	2190	1350	1500	0.050	10	15.63	0.07	1.08	159.9
Hart & Carr	3416	370	157.5	1800	0.050	10	1.82	0.63	1.15	3.8
Morice	3240	1600	270	2000	0.010	10	3.13	0.57	1.77	12.8
Rossiter & Anderson	3746	610	415	1800	0.050	10	4.80	0.52	2.51	10.3
Moonee Valley	0932	260	400	2000	0.050	5	4.63	0.55	2.54	1.7
Ashmore	3223	1500	580	800	0.010	10	6.71	0.45	3.01	28.1
Parkes	2650	470	450	1800	0.050	10	5.21	0.58	3.04	6.1
Caythorpe Trust	4164	1020	1400	1500	0.050	10	16.20	0.34	5.45	34.7
Willowhaugh	1784	70	640	2000	0.050	10	7.41	0.77	5.72	0.1
Hammond	1989	960	2500	1000	0.050	10	28.94	0.30	8.59	46.1
Gardiner	2062	390	1600	1800	0.050	10	18.52	0.62	11.51	4.2
Montana	3237	1760	3212	800	0.010	10	37.18	0.38	14.14	38.7
Hammond	0745	1110	2500	800	0.010	10	28.94	0.56	16.23	15.4
Morrison	3830	15	2500	1800	0.050	10	28.94	0.81	23.35	0.0
								Unconfined tot:	100.5	

Total calculated loss: 250

Table 4: Analytical Spring FLow Depletion Calculation (Hunt method)

7. Identifying and Addressing Adverse Spring Depletion Effects

7.1 Identifying Adverse Depletion Effects

The high ecological and recreational value of the Southern Springs – Tailor River aquatic environment requires a minimum flow threshold on Doctors Creek be maintained to ensure the health of both the springs and the Taylor River.

Doctors Creek recedes from west to east in the summer to the region between Bells Road and Batty's Road. To some extent this recession is natural, but it is enhanced by stream and spring depletion effects from groundwater pumping. The flow in Doctors Creek has been manually gauged on a weekly basis by MDC since October 2002 (Figure 10). The gauging site is located just upstream of the Doctors Creek-Taylor River confluence.

Marlborough District Council[13] has assessed the absolute minimum flow for fish habitat on Doctors Creek to be 30 L/s to maintain sufficient flow, depth and water continuity over the summer period. To obtain this, a minimum flow of approximately 150 L/s is required at the MDC gauging site upstream of the Talyor River confluence. A flow of 150 L/s at the gauging site would mean that there is some drying up of the upper reaches of the stream, and therefore loss of habitat. The middle reaches of the stream near Batty's Road would have little or no flow. The lower reaches of the stream slowly gain water from point source spring discharges, with an input from Yelverton Stream.

This study has assessed the cumulative depletion effects from groundwater abstractions to be about 150 L/sec during the summer months. Clearly, such depletion has the potential to dry up the middle reaches of the Doctors Creek and severely restrict the flows in lower Doctors Creek system and the Taylor River. Figure 10 shows that the lowest recorded flow at the Taylor Confluence is 90 L/s as a result of both natural and pumping induced seasonal reductions in flow. According to the ecological assessment of the springs[13], this would be detrimental to aesthetic and amenity values, instream life and affect the native biodiversity of Marlborough.

7.2 Options for Addressing Adverse Depletion Effects

Several options may be explored to address the issue of adverse spring flow depletions resulting from groundwater abstractions. The conceptual characterisation of the Southern Springs groundwater environment, coupled with the modelling analyses presented above, provide a basis for designing effective processes and methods for managing the health of the Southern Springs and Taylor River aquatic ecosystems.

Possible processes and methods are:

- The delineation of a '*Southern Springs Vulnerability Zone'*
- The identification of *High Impact Wells*
- Response to Low Spring-Flow Triggers
- Limiting New Takes in the Vulnerable Zone

a. The delineation of a *'Southern Springs Vulnerability Zone'*

Numerical and analytical stream depletion modelling provides evidence that the majority wells which significantly affect the flow in the Doctors Creek / Old Fairhall spring system have a stream depletion factor of less than 10 days. Figure 20 shows that this equates to a distance of approximately 1000m from the spring channels.

Numerical modelling has also shown that the upstream catchment of the springs within the unconfined aquifer is generally insensitive to groundwater abstractions during the summer months. This is largely because the spring line has receded to the unconfined – confined aquifer boundary at this time of year and that the Seasonal Unconfined Seepage Zone (Figure 11) is no-longer active.

The numerical model also shows that spring flow becomes progressively sensitive to abstractions towards the east within the Perennial Artesian Spring Zone (confined area).

Using this information, a 'Southern Springs Vulnerability Zone' can be delineated as shown on Figure 21. The northern and southern boundaries correspond to Old Renwick and New Renwick roads respectively. The western boundary is aligned with the Fairhall River and Grahams Road. The eastern boundary follows the Taylor River through Blenheim linking up with Old Renwick Road.

It is not necessary to extend the management zone into the Fairhall Valley since groundwater inputs from the shallow valley alluvium into the Wairau Aquifer are regarded to be seasonal (winter).

The vulnerability zone may be used to appraise and manage groundwater abstractions (*'High Impact Wells'*, see below) in order to maintain the minimum acceptable spring flows adopted by MDC[13].

b. Identification of *High Impact Wells*

The analytical spring flow depletion calculations presented in Table 4 may be used to analyse and select those bores which contribute to the bulk of the depletion effects. Additionally, field evidence (pump testing) could be used to supplement this information. These wells will essentially be high-volume users located within the Southern Springs Vulnerability Zone in close proximity to the spring channels. They can also be identified as having a stream depletion factor of less than a specified limit (i.e. 10 days).

For example, wells with a depletion factor of less than 10 days and with a calculated depletion of more than 10 L/sec may be designated *'High Impact Wells'*. Table 4 shows that only four wells would fall into this category.

[13] Marlborough District Council. 2004. Recommended low flow condition for Doctors Creek Catchment. Internal report S. Wilson and P. Hamill

c. Response to Low Spring-Flow Triggers

The adoption of minimum flow levels at the Taylor River confluence[13] could be used to assign low flow triggers. These triggers would require selected groundwater users (High Impact Users) to reduce abstraction collectively to a specified instantaneous rate. It is important that abstractions are controlled on the basis of an instantaneous pumping rate rather than a daily rate since there is good evidence to show that spring flow responds almost immediately to some abstraction bores (Figure 16).

d. Limiting New Takes in the Vulnerable Zone

Consideration may be given to restricting or limiting new groundwater takes within the Southern Springs Vulnerability Zone. These may be only those wells assessed as being ‘high impact’.

8. Summary and Conclusions

- The spring discharges across the Wairau Plains between Rapaura and the Doctors Creek are regarded to account for nearly all of the throughflow in the Wairau Aquifer from the west. The total spring discharge is approximately 6 m^3/sec.

- Spring discharges occur in the hydrogeologically complex transition zone between unconfined aquifer conditions in the west, and gradually increasing confining conditions in the east. The highly productive Wairau Aquifer is forced to discharge at this boundary through a combination of ephemeral bed seepages along the beds of streams and drains in the unconfined aquifer area, and high-volume discreet perennial artesian point source discharges in the confined aquifer zone further east.

- The springs are sensitive to groundwater abstractions and measurable depletions have been observed in the southern springs in response to pumping bores. Spring monitoring hydrographs (Figure 10) suggest cumulative summer losses in excess of 100 L/sec, and depletion effects from individual bores of 40-50 L/sec (Figure 16). Depletion of the flow in the ecologically important Doctors Creek / Old Fairhall spring system is of particular concern and has been to focus of this study.

- Groundwater abstractions can decrease spring flows through a number of mechanisms. These include a reduction in point source discharge by locally lowering the piezometric surface in the underlying Wairau Aquifer, the depletion of stream/spring flow by water being drawn from the stream channel into a bore, and the recession of the springline in the unconfined aquifer area.

- Numerical groundwater modelling of the southern springs has been carried out to assess the cumulative effects of groundwater abstractions on spring flow, to identify areas vulnerable to abstraction during the summer period, and to help delineate areas sensitive to abstraction.

The numerical model predicts the cumulative spring flow depletion to be about 100 L/sec during the summer months.

- The model shows that wells located within about 500m of the spring channels to the east of the confined/unconfined boundary (around Bells Road) dominate the spring flow depletion effects. Approximately 30% of the abstraction from wells in this zone may be derived from the spring channels.

- The model also indicates that spring flow is highly sensitive to groundwater abstractions from the confined aquifer area (east of Bells Road). Spring flow becomes increasingly sensitive to abstraction towards the east as semi-confining conditions transition into confined aquifer conditions.

- Spring flow depletion has also been assessed using analytical calculation methods for individual bores. The cumulative depletion for wells located in the confined area is about 150 L/sec. This is some 50% higher than predicted by the numerical model but may provide a more accurate assessment given the limitations of the model in simulating higher drawdowns (and therefore depletion) associated with wells adjacent to the spring channels.

- Marlborough District Council[13] has assessed the absolute minimum flow for healthy fish habitat on Doctors Creek to be 30 L/s to maintain sufficient flow, depth and water continuity over the summer period. To obtain this, a minimum flow of approximately 150 L/s is required at the MDC gauging site upstream of the Taylor River confluence. The assessed depletion rate has the potential to dry up the middle reaches of the Doctors Creek and severely restrict the flows in lower Doctors Creek system and the Taylor River. The lowest recorded flow at the Taylor Confluence is 90 L/s as a result of both natural and pumping induced seasonal reductions in flow.

- Several options are explored to address the issue of adverse spring flow depletions resulting from groundwater abstractions. Possible processes and methods are:

  - The delineation of a '*Southern Springs Vulnerability Zone'*
  - The identification of *High Impact Wells*
  - Responses to Low Spring-Flow Triggers
  - Limiting New Takes in the Vulnerable Zone

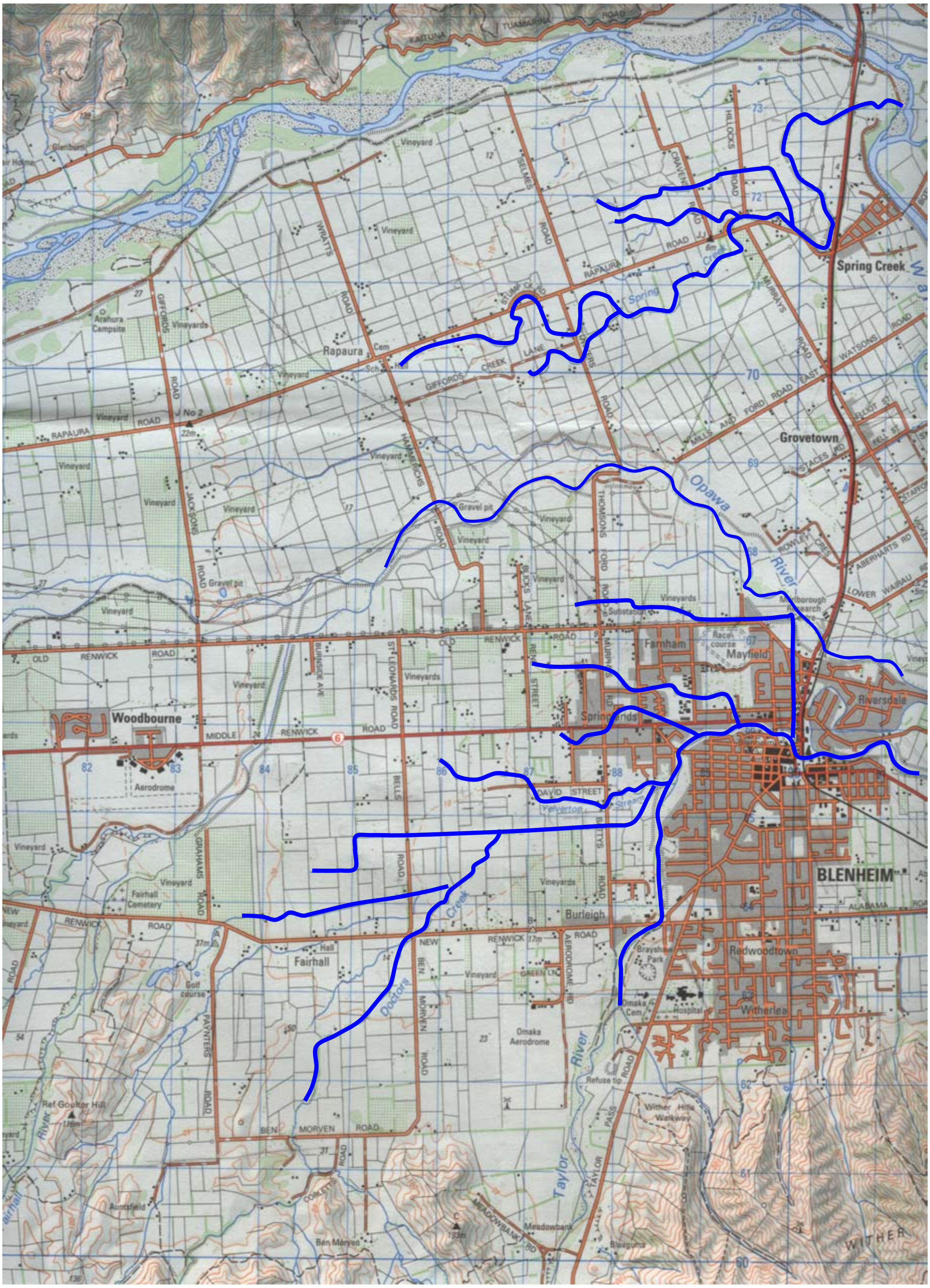


Figure 1: Location map showing principal spring channels

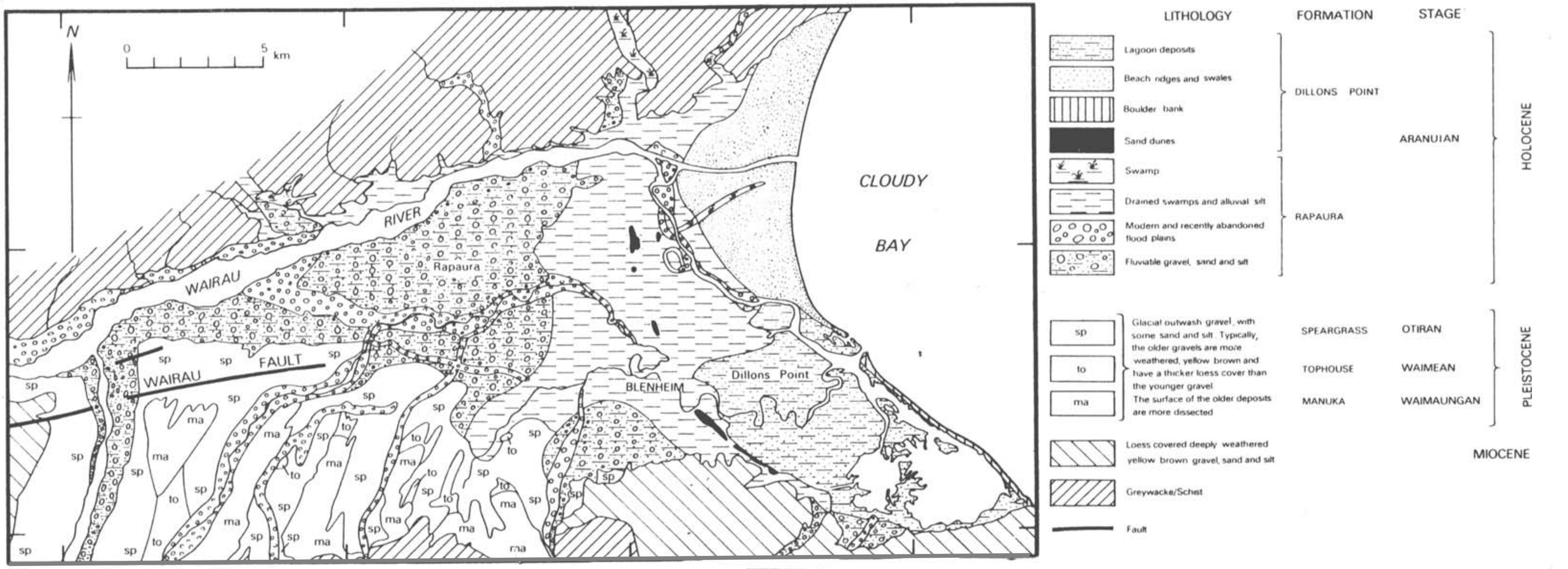


Figure 2: Geological Map of the Wairau Plains
(Brown, 1981)

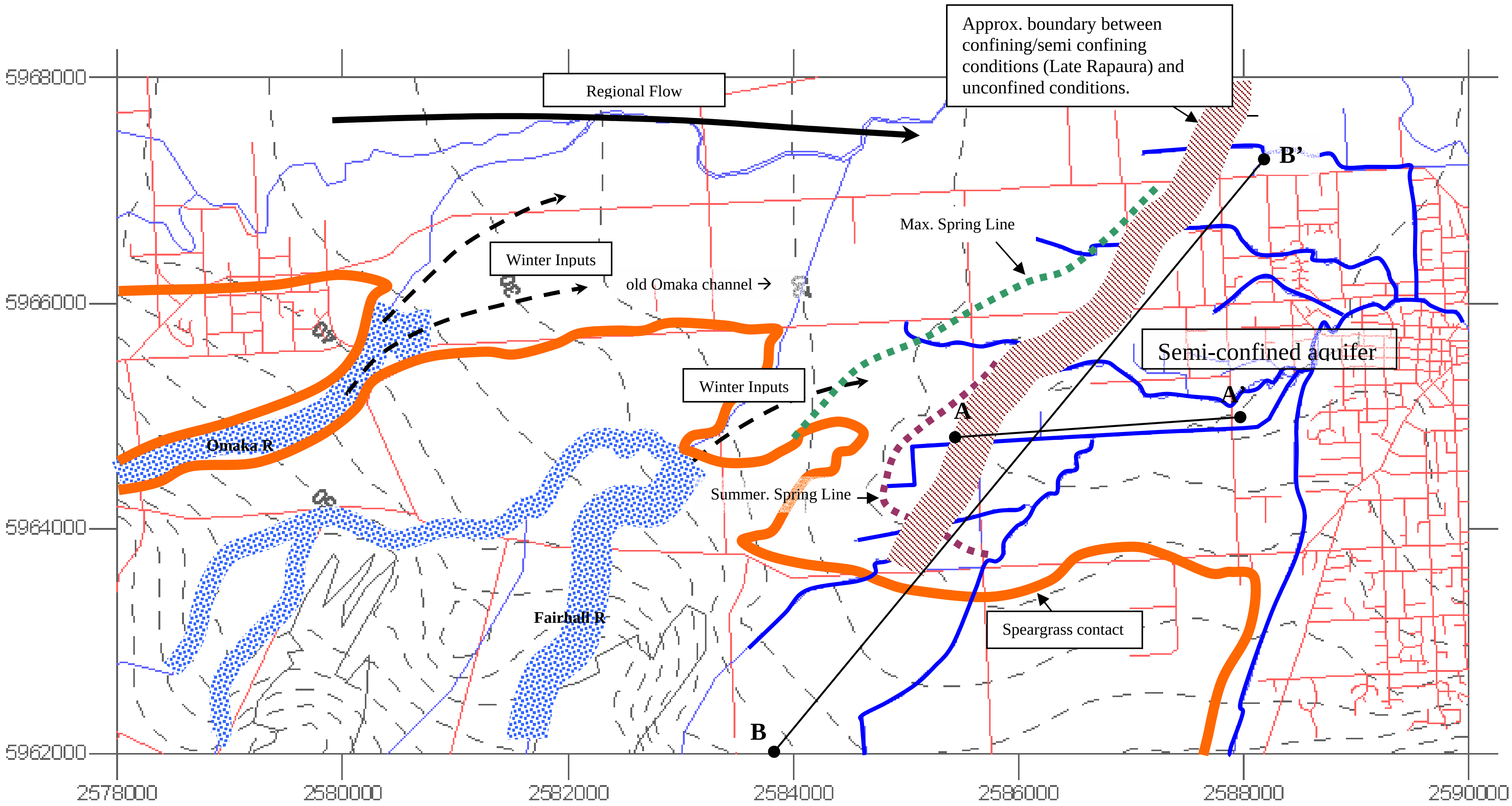


Figure 3: Conceptual Hydrogeological Model – Southern Springs

(ground level contours shown in m amsl)

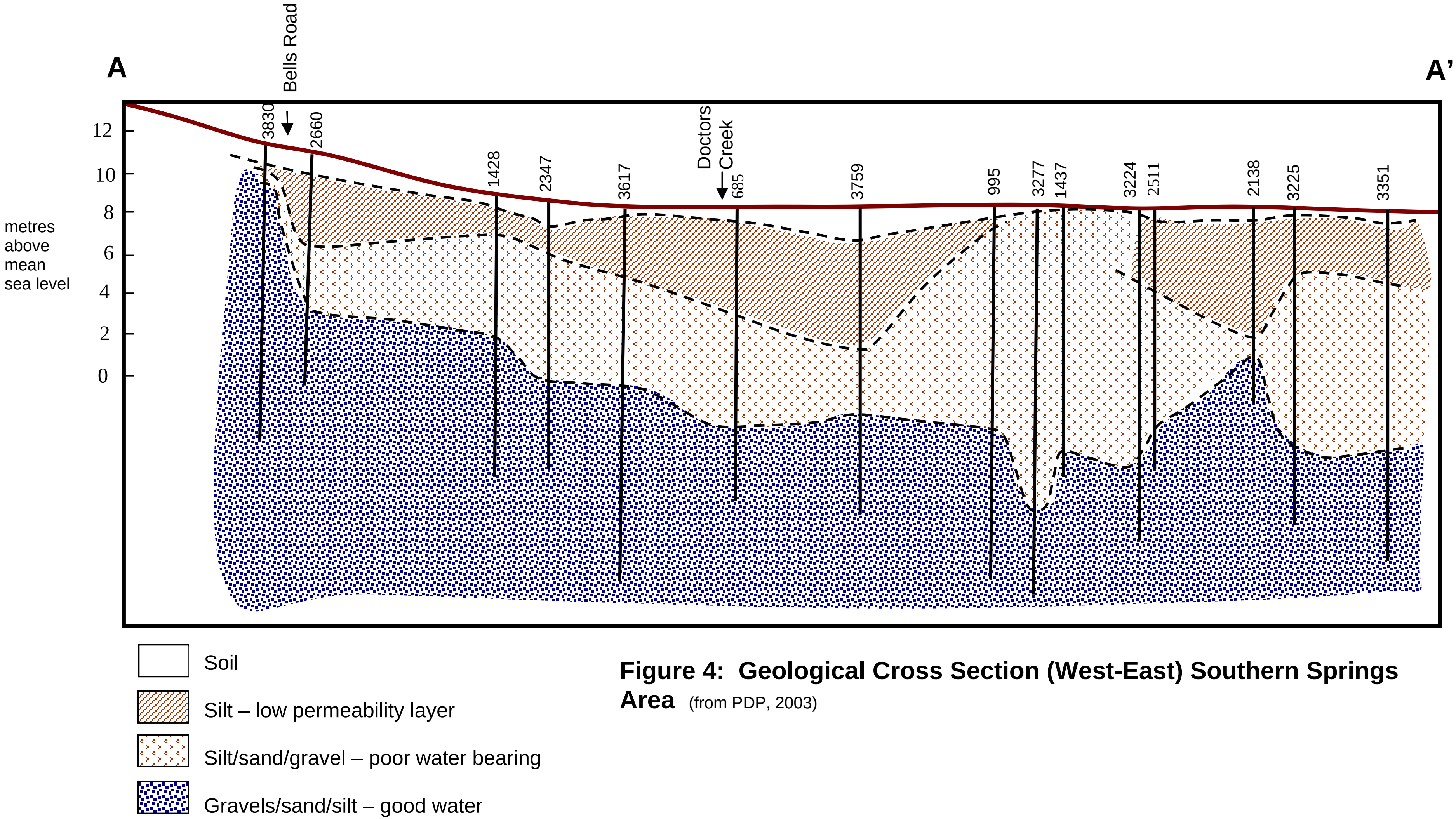


Figure 4: Geological Cross Section (West-East) Southern Springs Area (from PDP, 2003)

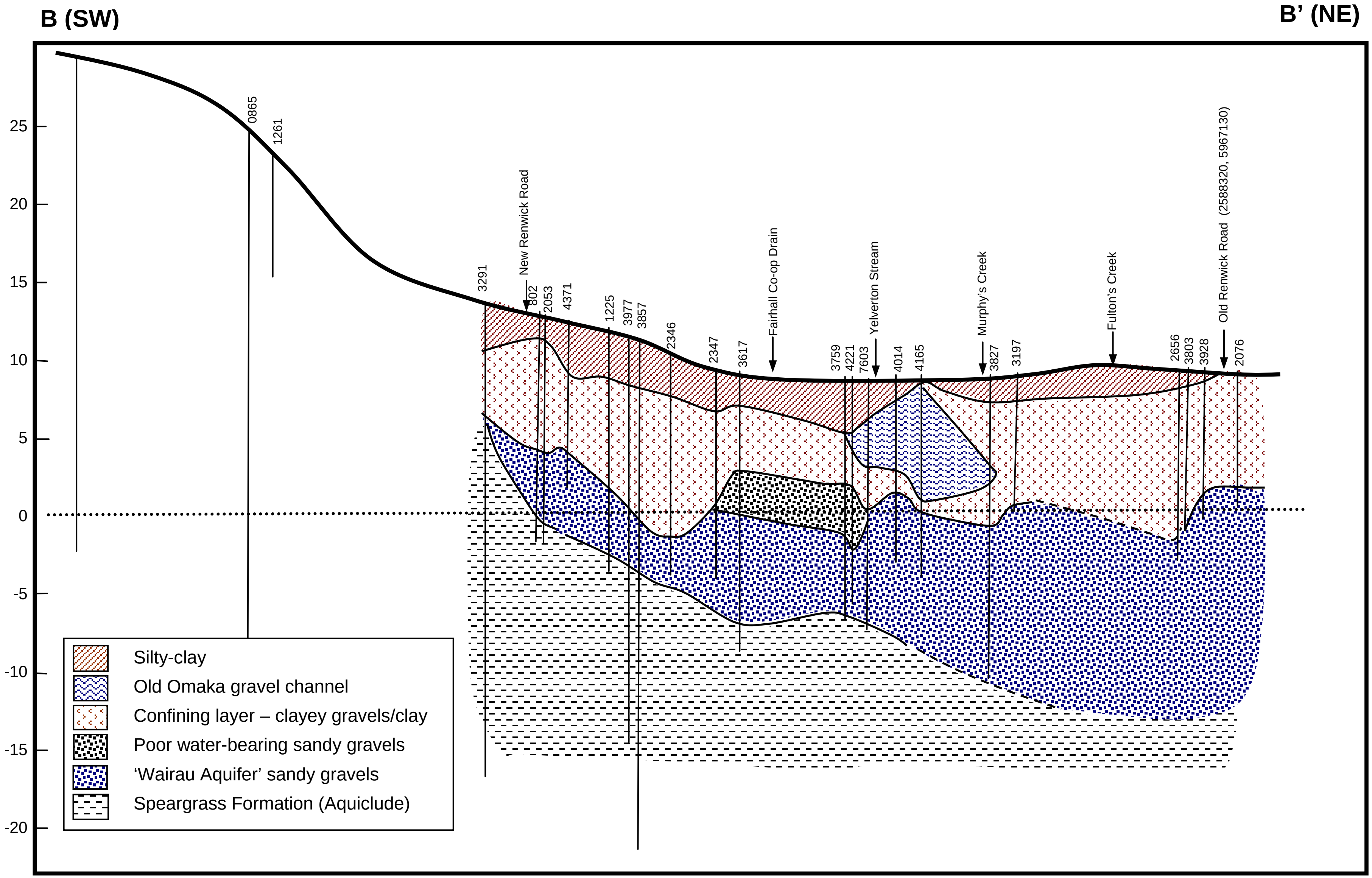


Figure 5: Geological Cross Section B-B' (Southwest – Northeast) Southern Springs Area, Wairau Plains

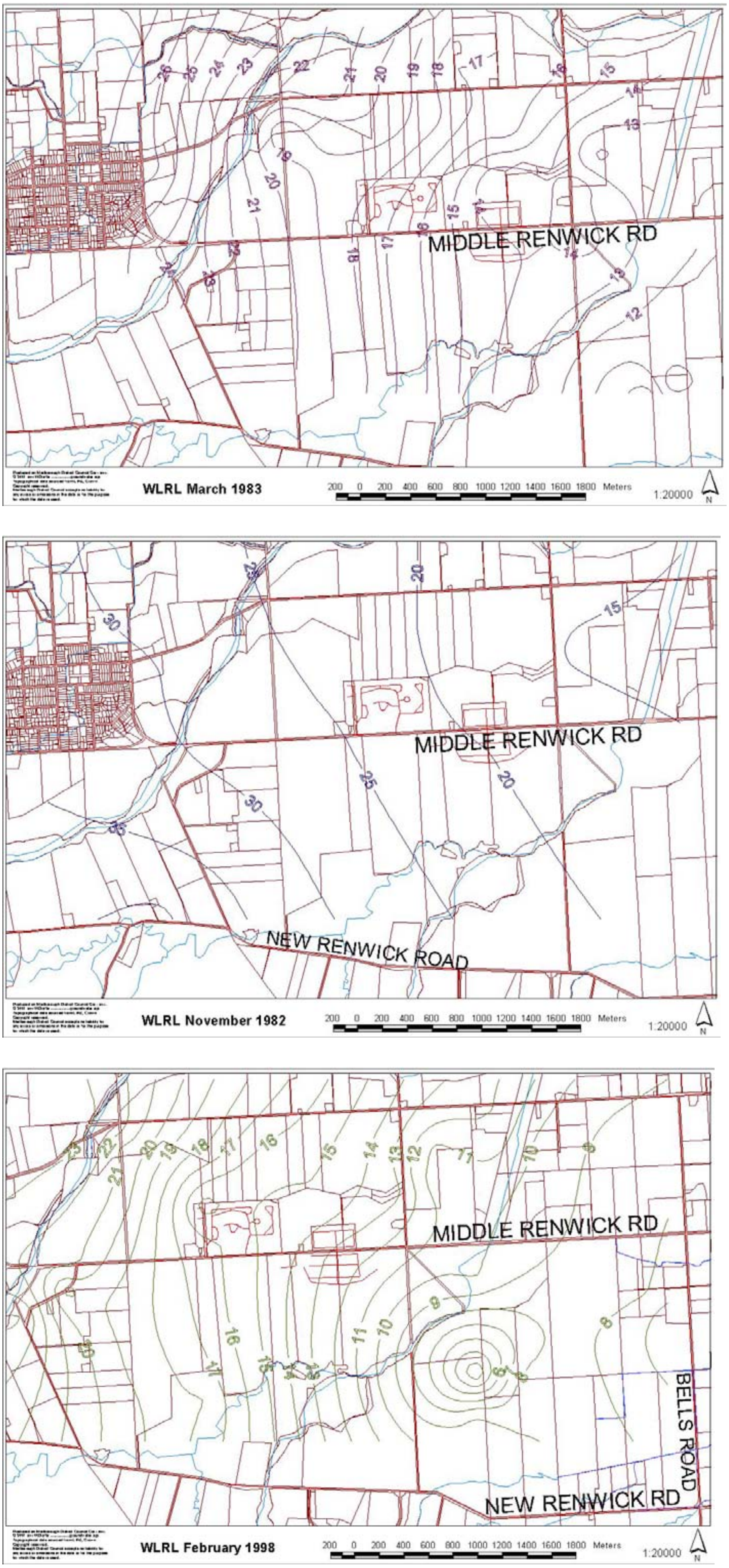


Figure 6: Groundwater level contour maps for Southern Springs area (1982 & 1998)

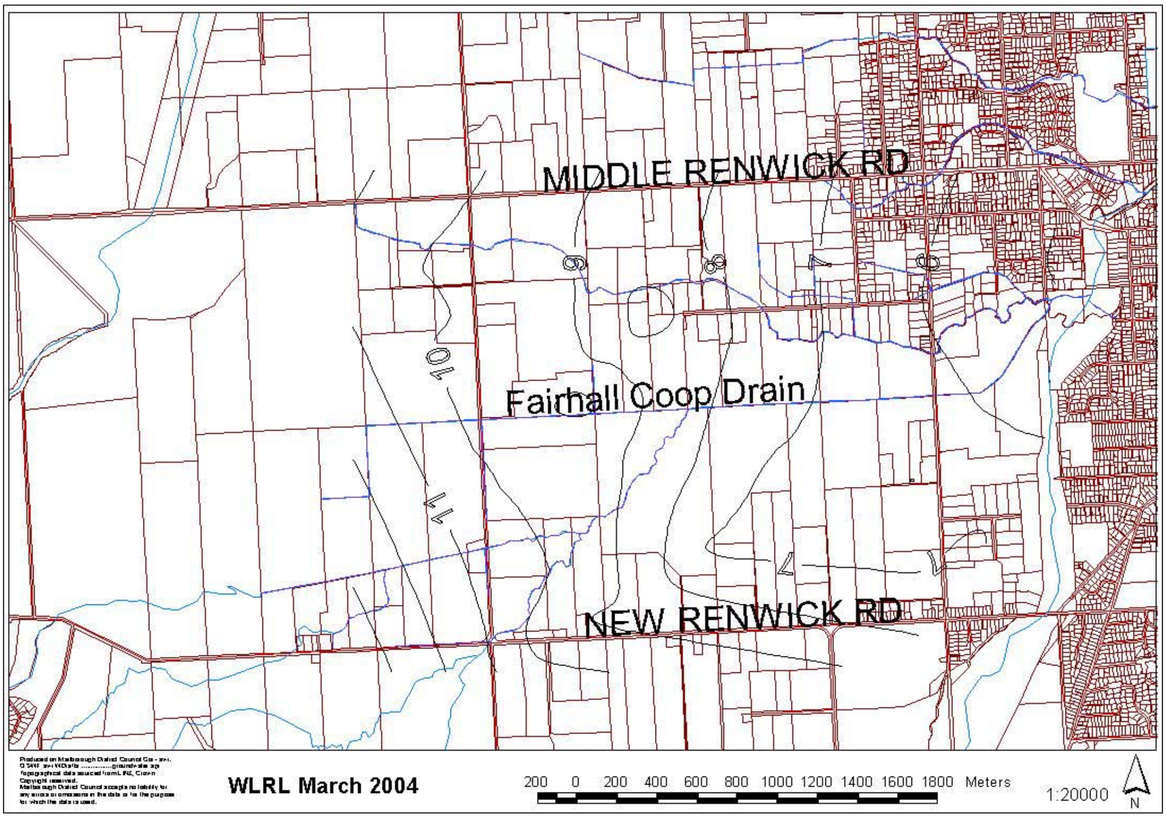


Figure 7: March 2004 groundwater levels

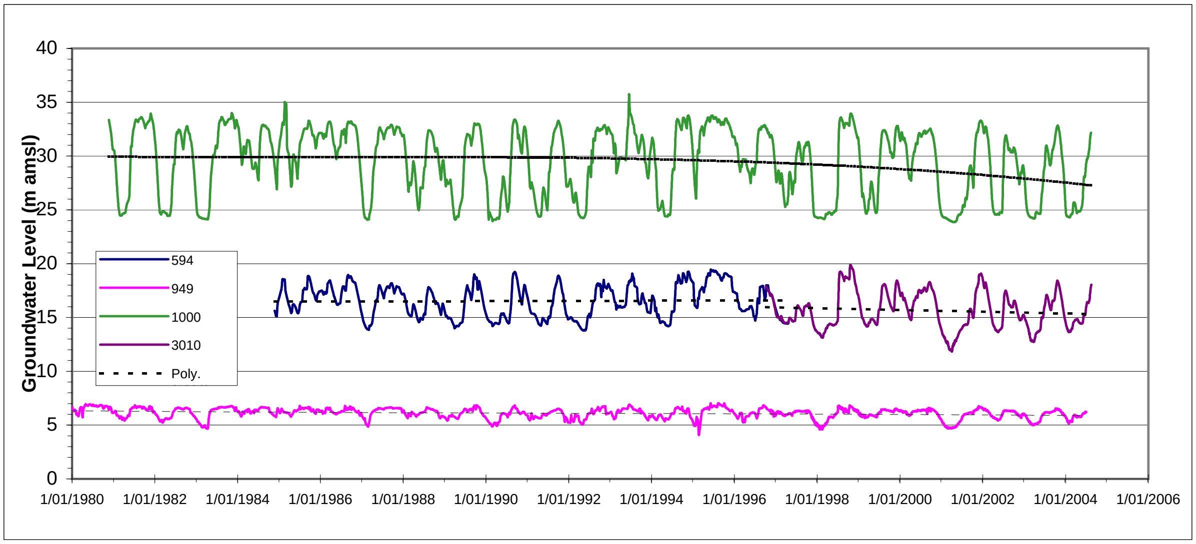


Figure 8: Monitoring Hydrographs - Southern Springs Area

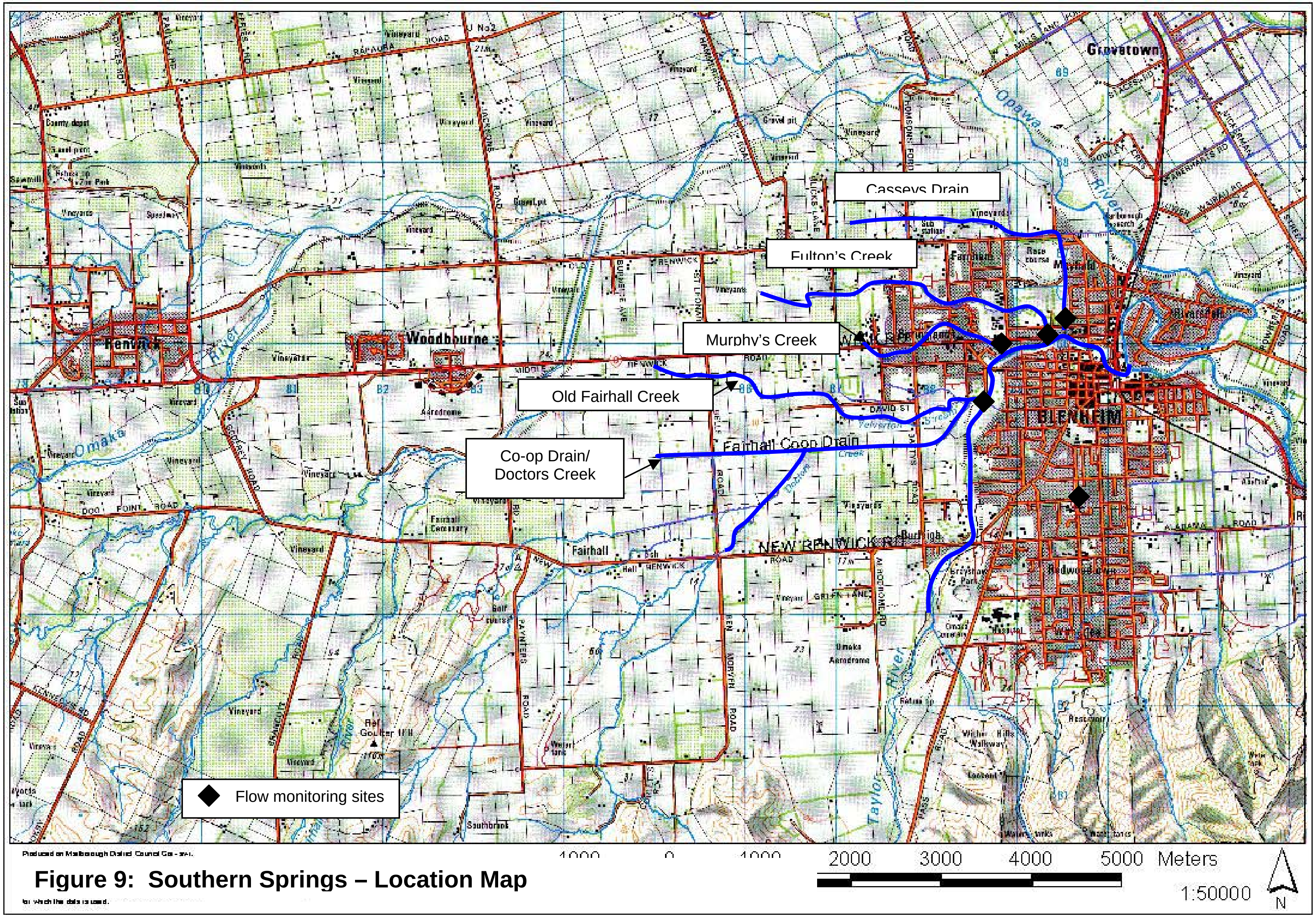


Figure 9: Southern Springs – Location Map

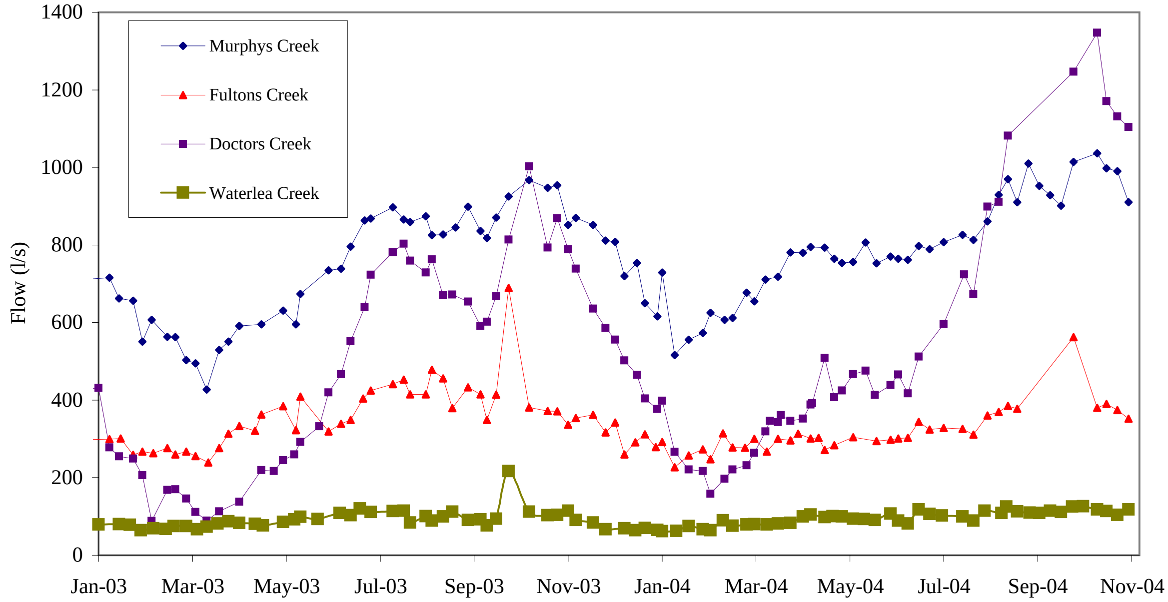


Figure 10: MDC Spring Flow Monitoring Data

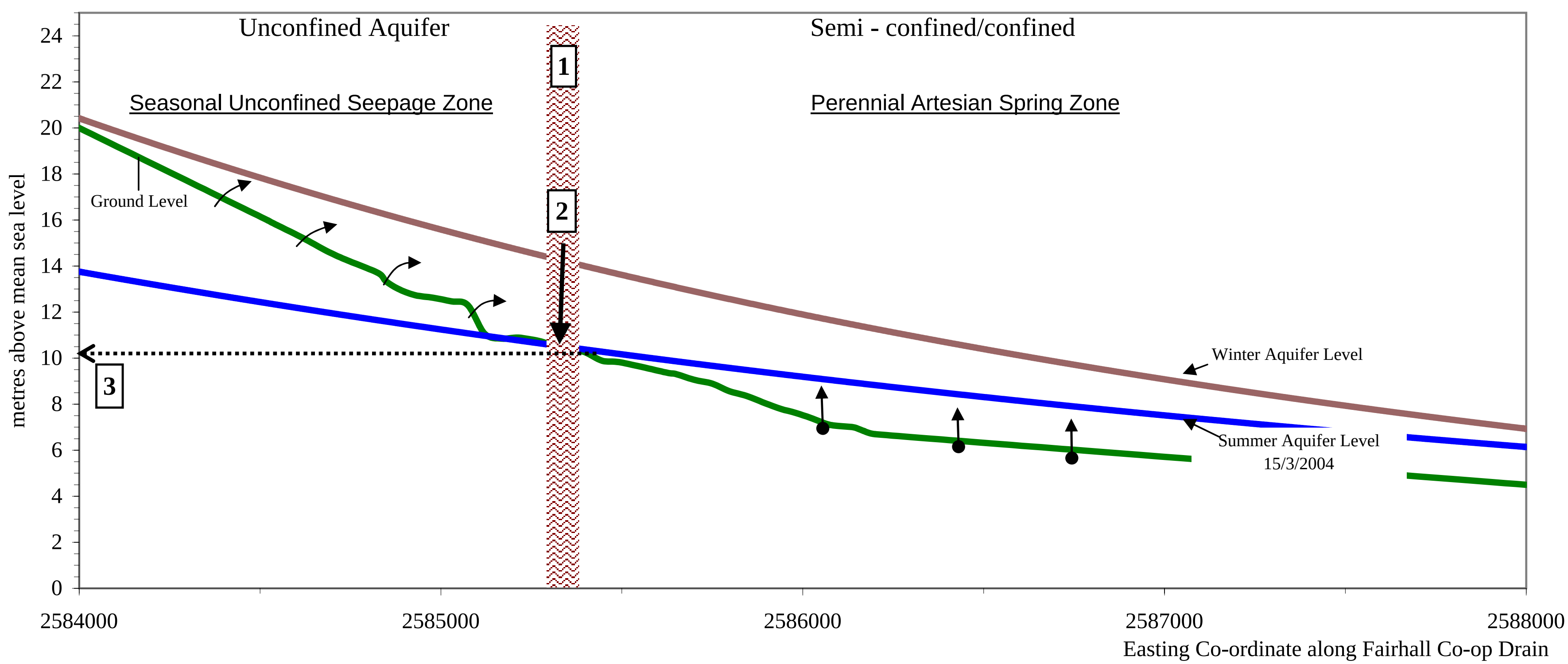


Figure 11: Co-op Drain Doctors Creek Spring Discharges: Conceptual Model

1. Approx confined/unconfined boundary
2. Summer spring line - point source springs occur only downstream of this point
3. Groundwater level at 2 = 10.0m amsl

Notes in summer spring flow depletion caused by groundwater abstractions:

- Abstractions in the semi-confined/confined area that reduce the piezometric pressure beenath the drain will affect point source spring flow.
- Upstream abstractions in the unconfined area will only result in spring depletion in the summer if they result in a drawdown at Point 2.

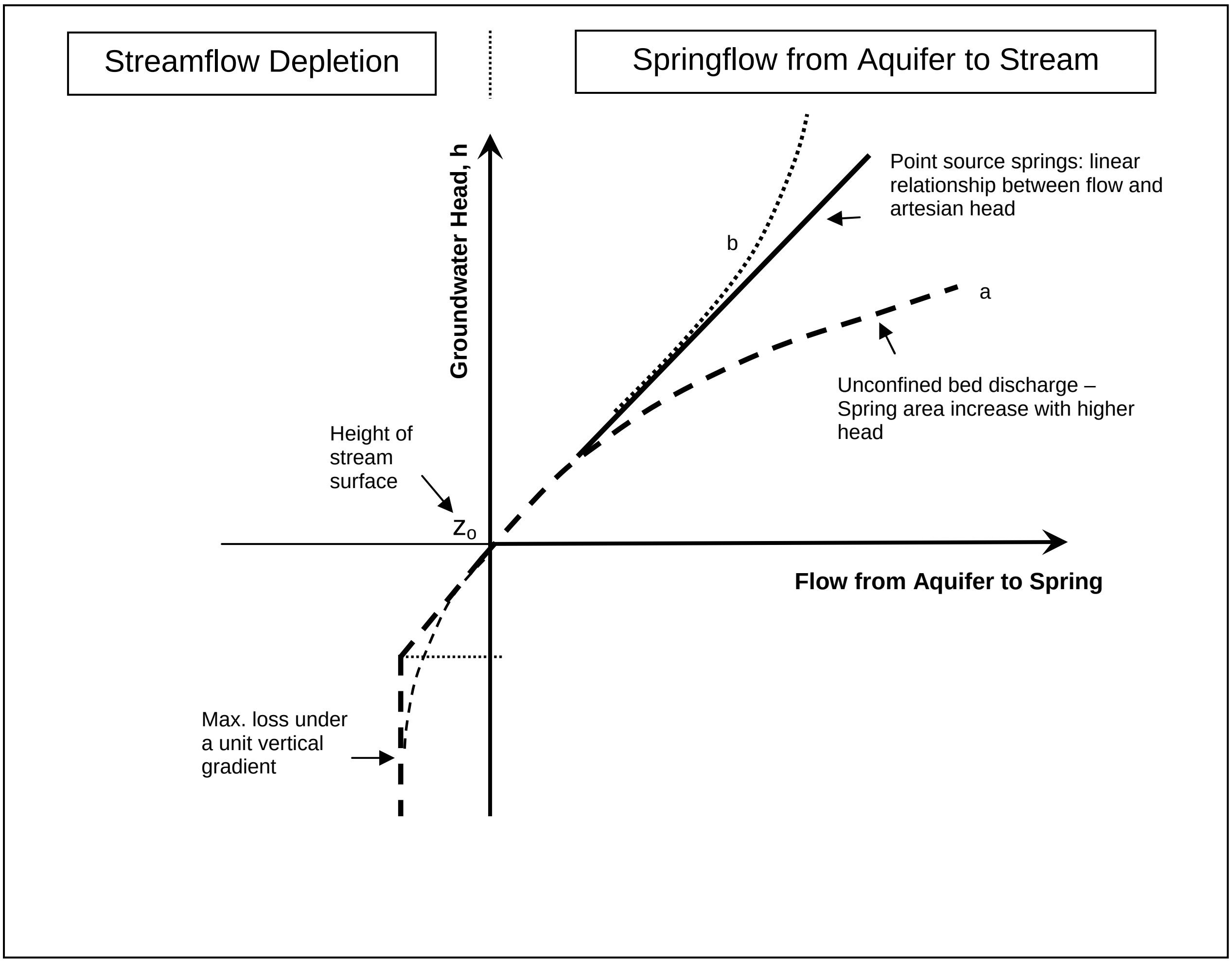
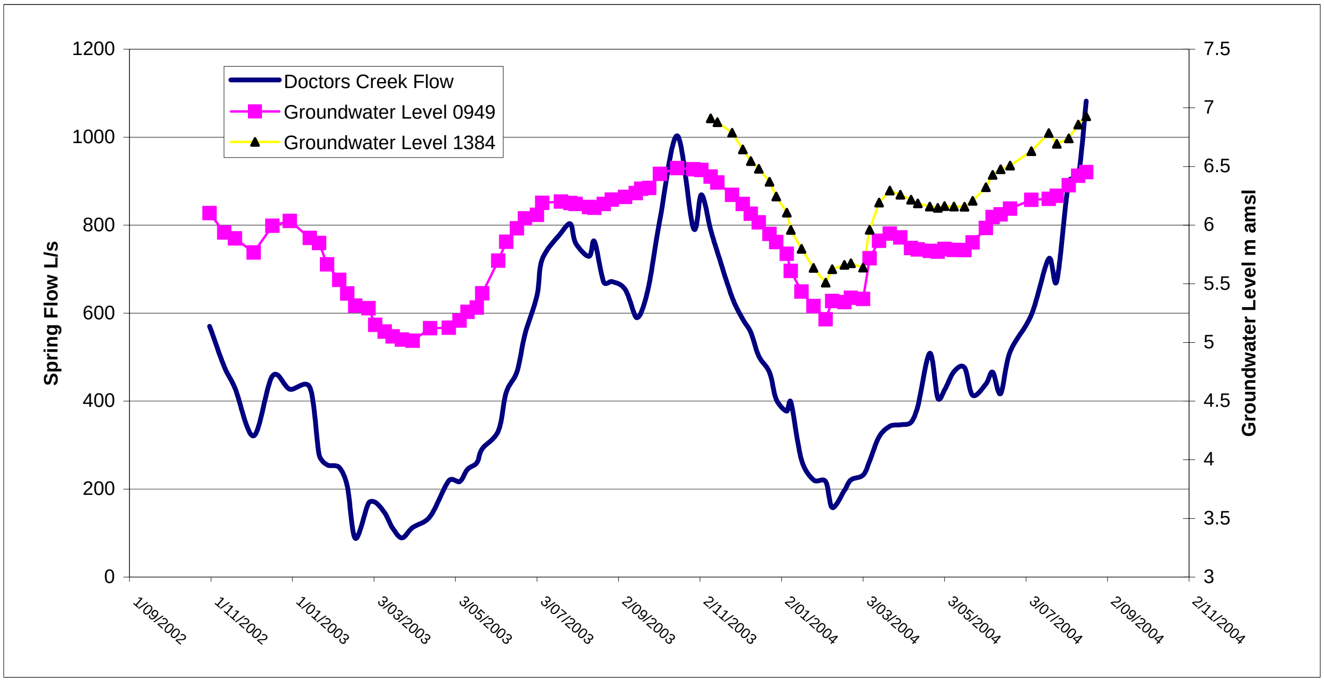


Figure 12: Theoretical relationship between groundwater head and spring flow (adapted from Rushton, 2003)



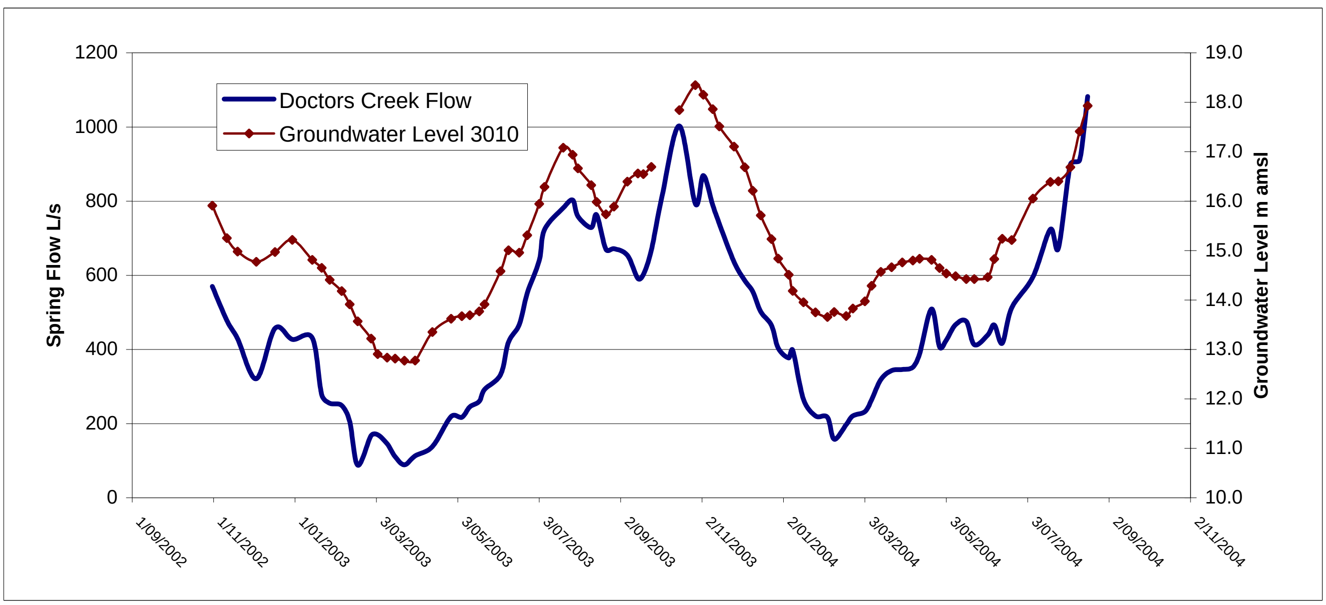


Figure 13: Relationship between groundwater level at 0949 (Athletic Park), 1384 and Doctors Creek flow

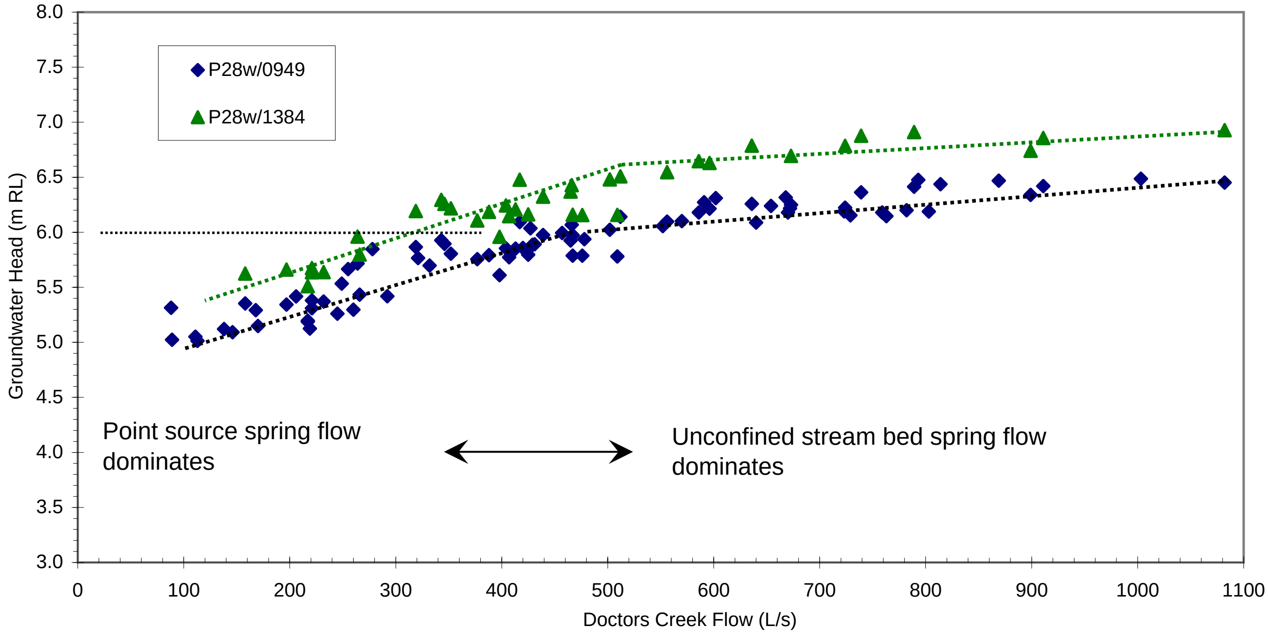


Figure 14: Correlation between Doctors Creek flow and groundwater level in monitoring bores 0949 and 1384

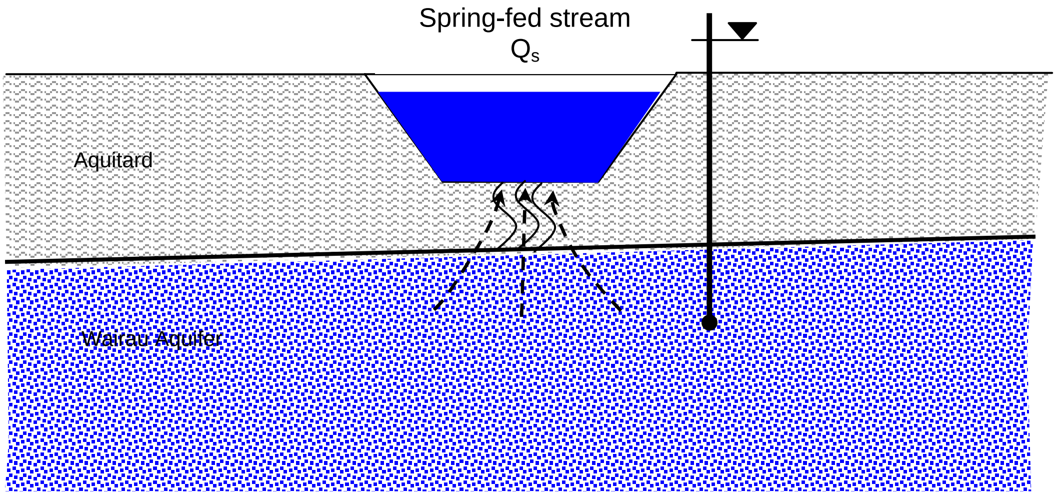


Figure 15A: Point source spring discharge to spring-fed stream.

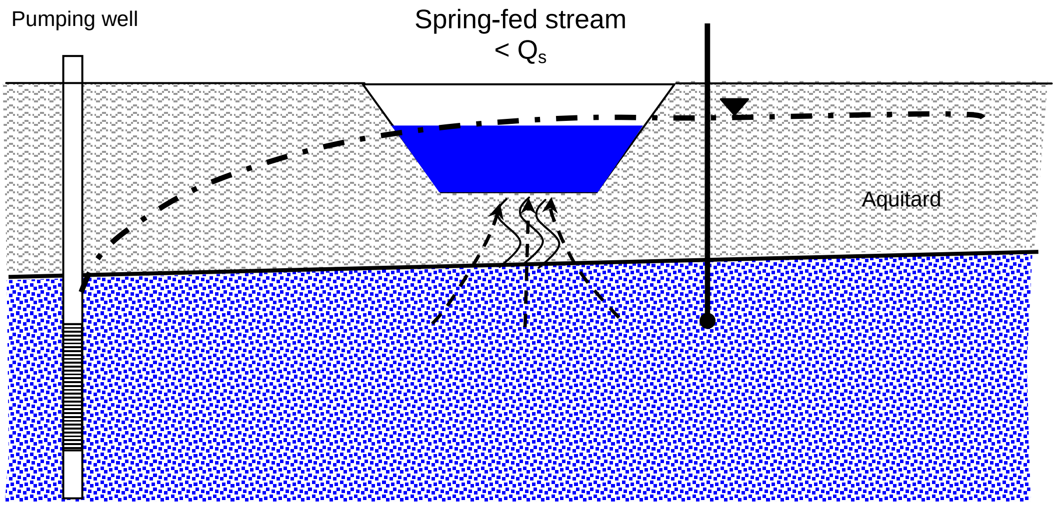


Figure 15B: Point source spring flow reduction caused by abstraction and lowering of piezometric level

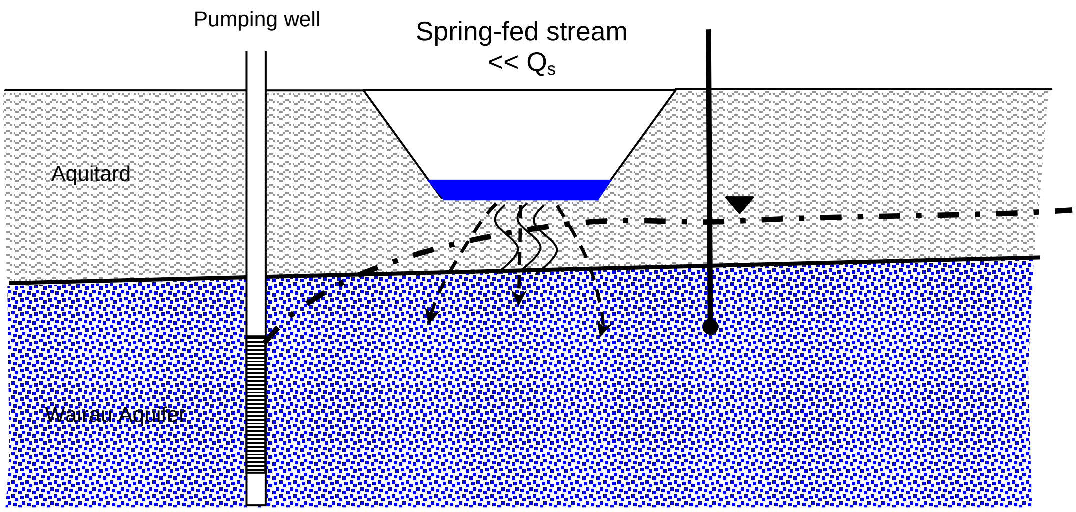


Figure 15 C: Spring-fed stream flow depletion caused by abstraction and severe lowering of piezometric level locally, and spring flow reduction at distance along channel.

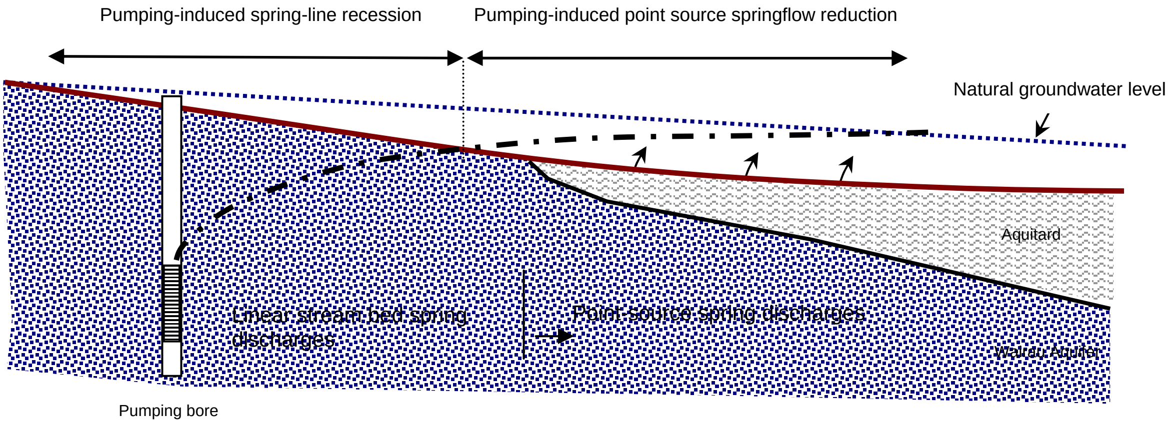


Figure 15D: Effects of pumping drawdowns on spring-line and point source discharges

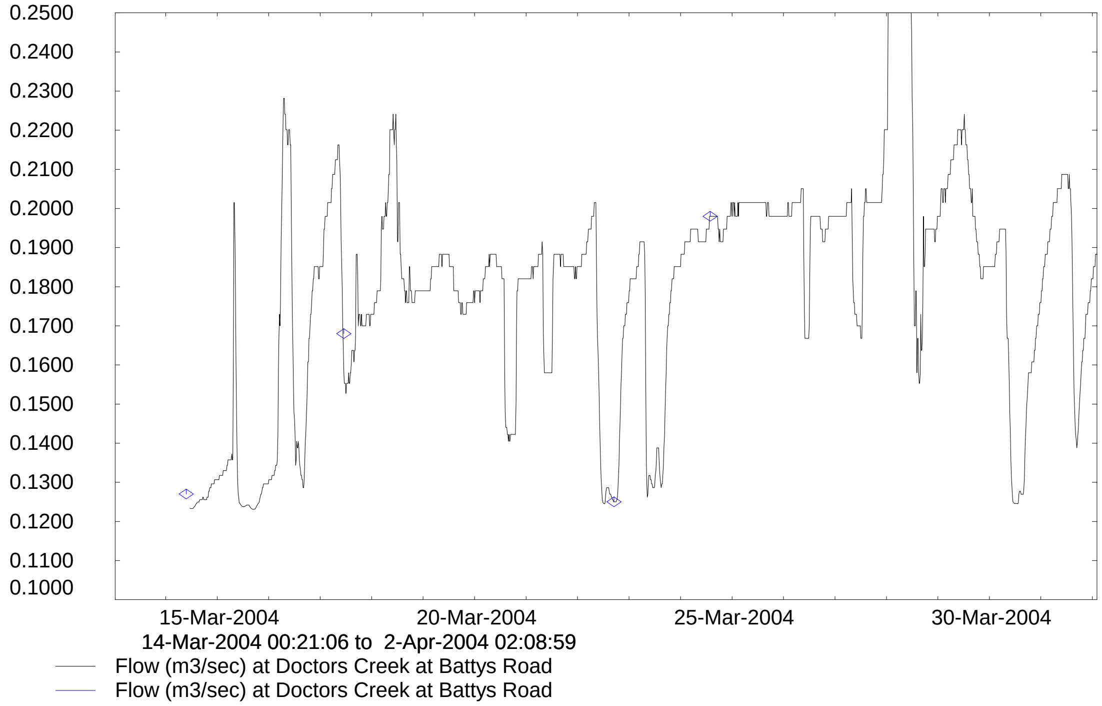


Figure 16: Spring Flow Monitoring on Doctors Creeks at Batty's Road During March 2004.

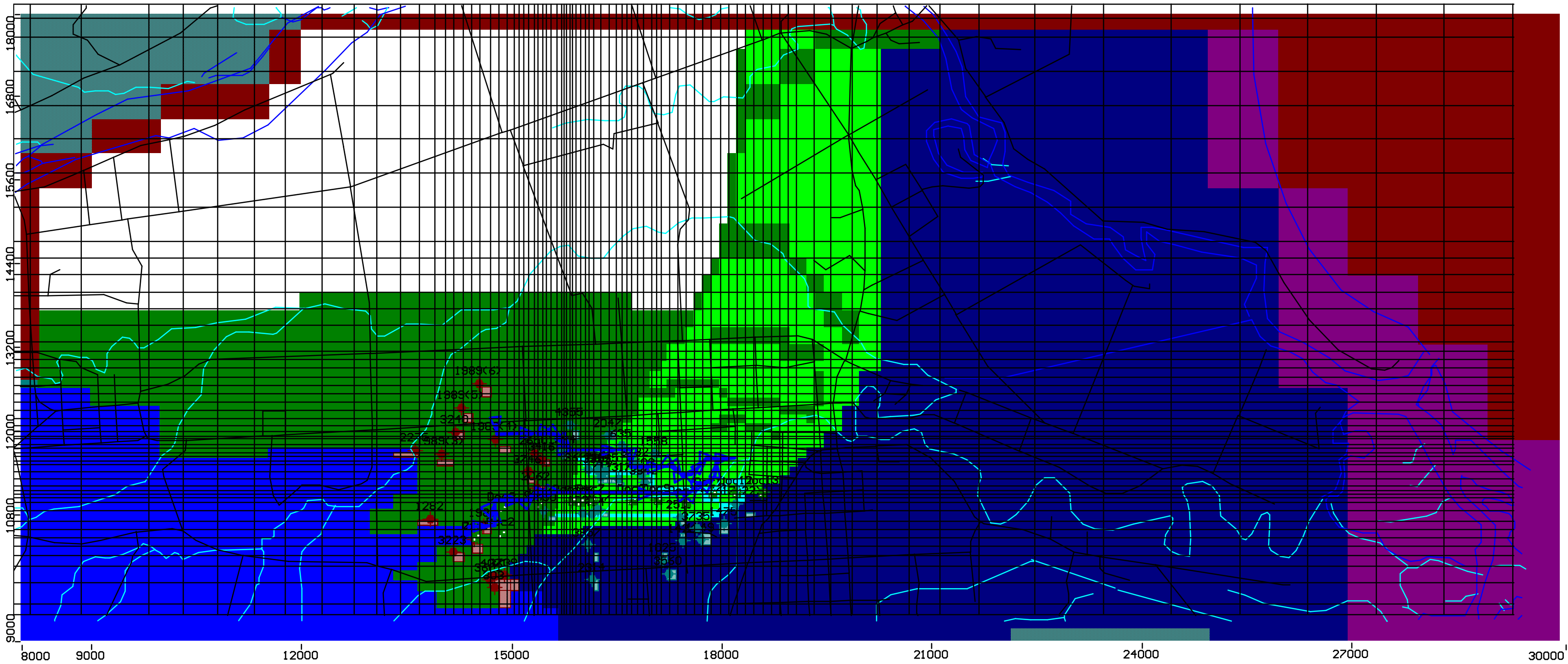


Figure 17: Model Grid, hydraulic conductivity zones, and constant head boudaries (red) for Layer 1

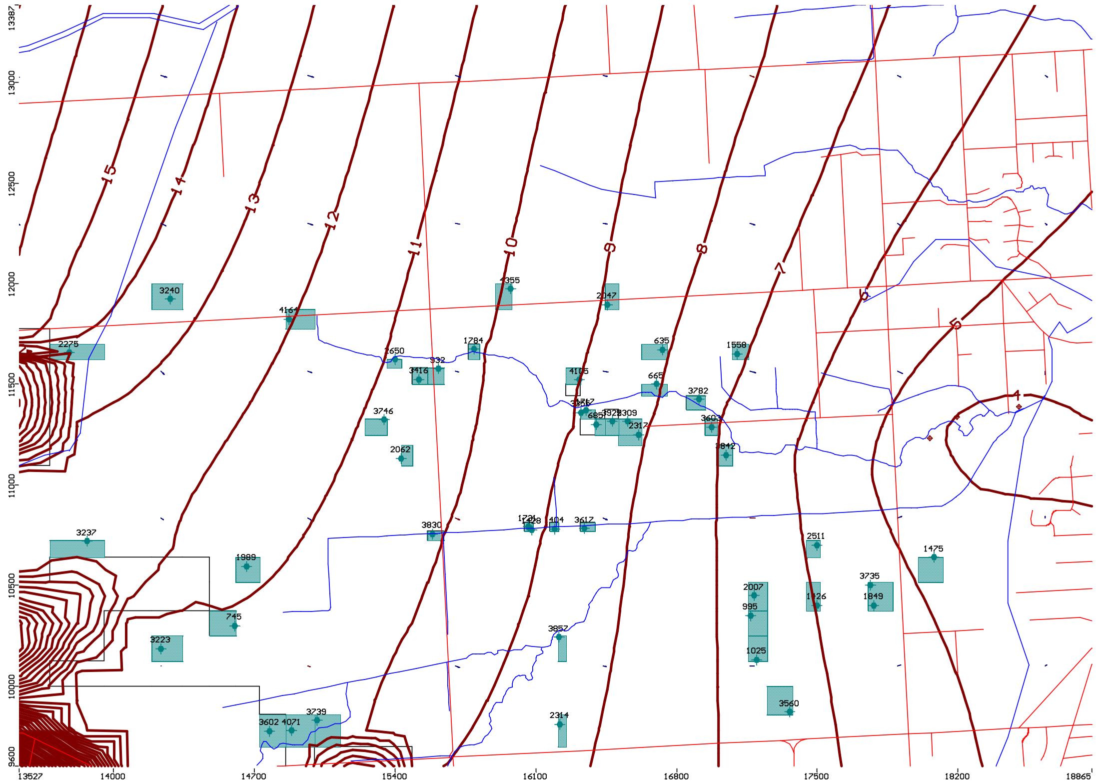
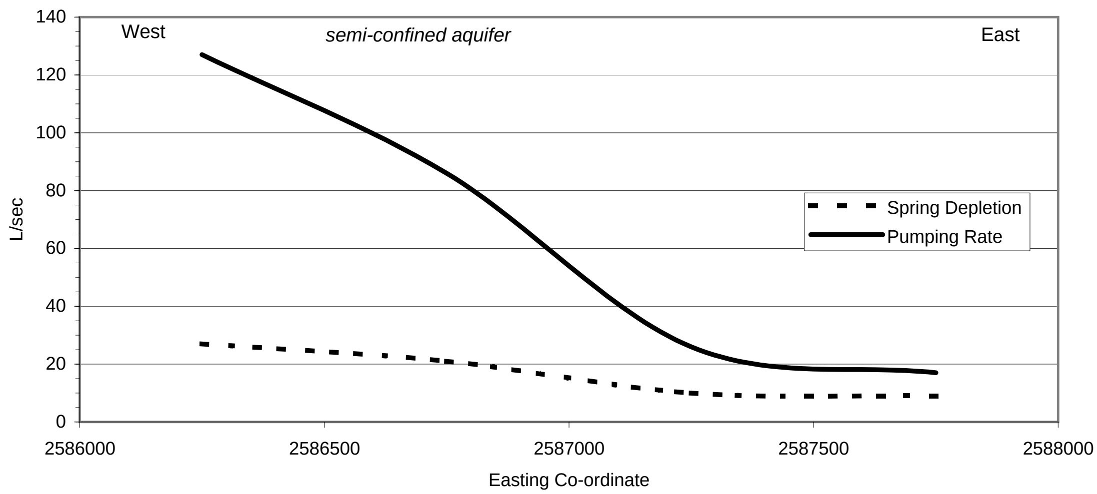


Figure 18: Modelled head output for Doctors Creek Area, Layer 2 Wairau Aquifer

A



B

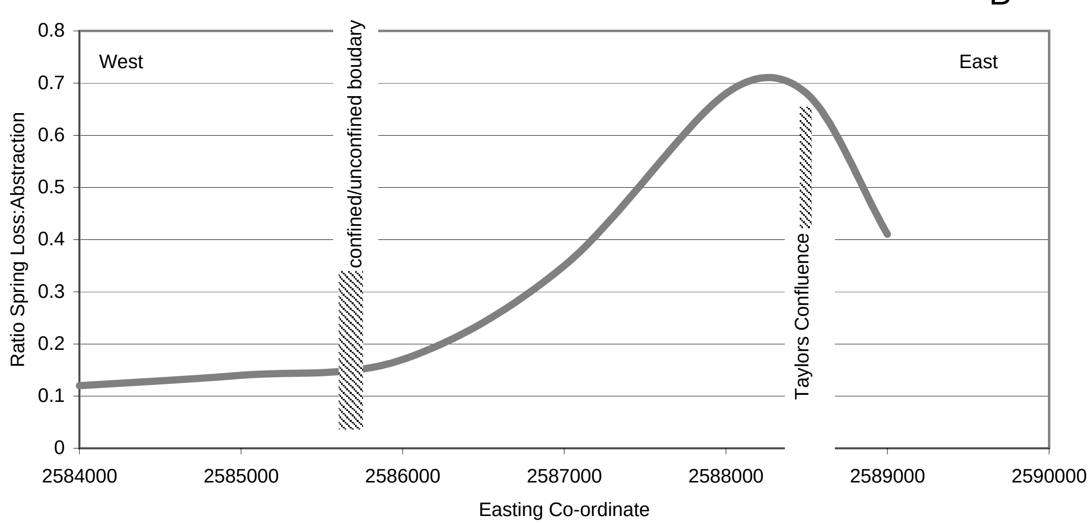


Figure 19: Model Scenario Outputs. A - Modelled spring depletion for current pumping as a function of distance (Scenario 1); B - Theoretical depletion resulting from a moving north-south array of bores (Scenarios 9 - 14)

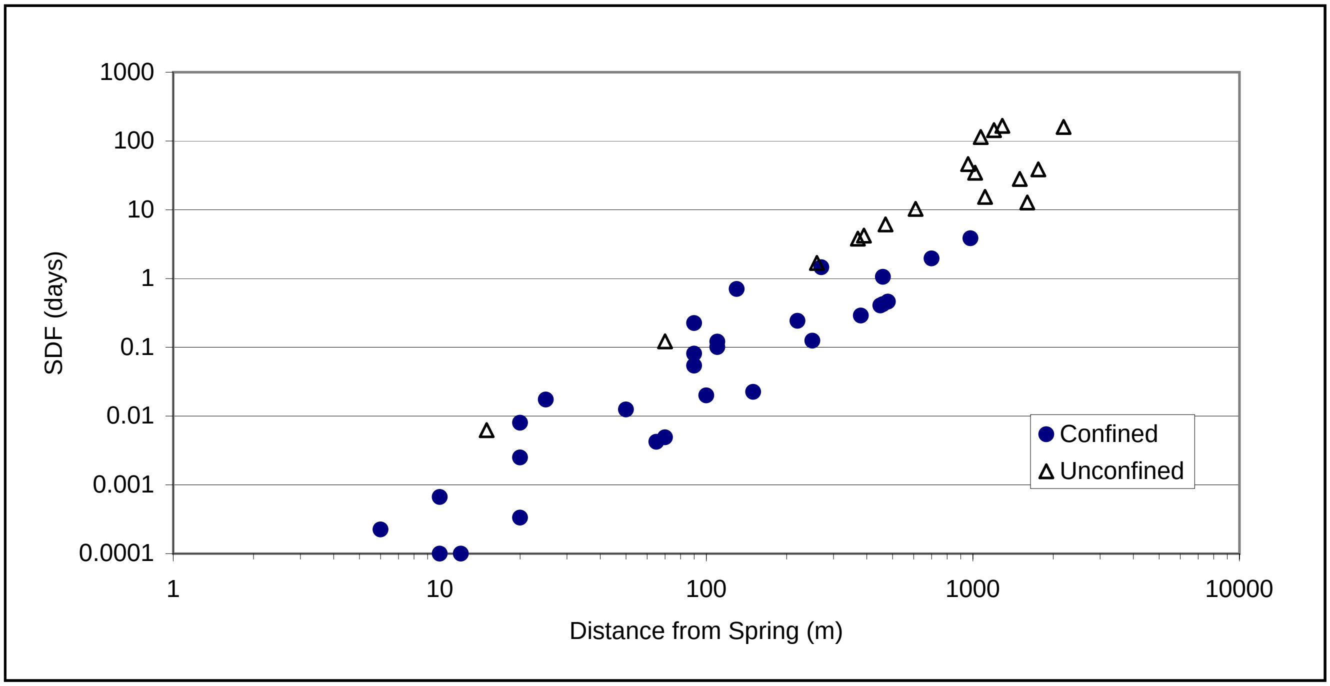


Figure 20: Stream Depletion Factor (SDF) vs Distance from Spring Source for Wells Located Around the Doctors Creek Spring System

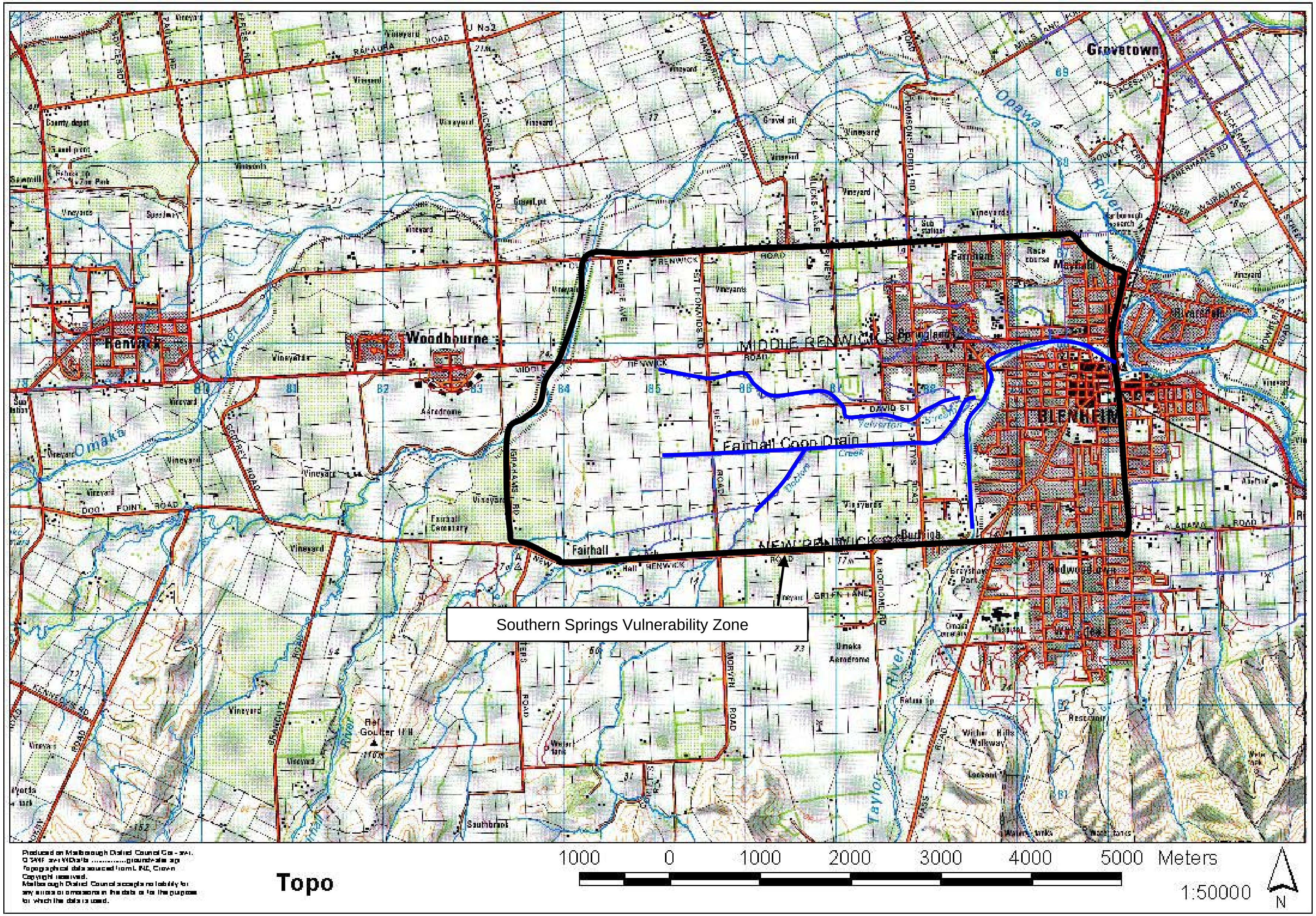


Figure 21: Proposed Southern Springs Vulnerability Zone