Edendale Groundwater Model: Conceptualisation and Model Design

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Limitations:

The report has been prepared for Environment Southland, according to their instructions, for the particular objectives described in the report. The information contained in the report should not be used by anyone else or for any other purposes.

Table of Contents

Table of Tables

Appendices

Appendix A- Figures:

1.0 Introduction

This report has been prepared to form an interim update for the Edendale Groundwater Model project. It summarises the conceptual understanding of the model area, in terms of the natural hydrogeological flow processes and any anthropogenic processes taking place that affect the natural system.

Subsequently, this report explains how the conceptual understanding is translated into a numerical groundwater flow model, designed to represent the hydrogeologic processes taking place in the model area.

As of February 2012, the model is currently being calibrated and therefore no results from the model have been included with this report. A further report, detailing the flow model calibration and the contaminant transport model results will be provided at a later date.

The Edendale Aquifer was the subject of a technical report by Environment Southland (Wilson, 2009) which discusses the hydrogeological processes that take place across the Edendale Aquifer in detail. It is not the intention of this report to repeat information already available in detail and Sections 2 and 3 simply provide a summary of the conceptual model of the area and describe the basis on which the numerical model has been developed. Section 4 discusses how the conceptual ideas are represented in the numerical model.

2.0 Topography and Geology

2.1 Topography

The Edendale area is largely confined to the Mataura River valley and altitude in the valley ranges from ~ 80 m RL in the north of the area to around 10 m RL in the south. The Mataura River flows from north to south along the eastern edge of the river valley and the river, together with its immediate floodplain forms the topographically lowest part of the area. To the west of the immediate floodplain of the Mataura River, the ground rises steeply over the terrace margin, with a vertical rise of 10 m to 20 m within 100 m laterally. Beyond the terrace margin, the ground rises gradually to the western edge of the area.

The highest regions within the overall Edendale area are formed on its western margin and by the high ground to the east of the Mataura River.

A topographical map of the Edendale area is shown in Figure 1.

2.2 Geology

The Edendale Aquifer comprises a Quaternary gravel aquifer within the Mataura River valley and as such the main focus of this section is on the unconsolidated deposits that include these Quaternary deposits. However, the solid, consolidated geology is also important, in that it provides both the lateral and vertical boundaries to the Quaternary deposits and the aquifer as a whole.

A map showing the geology of the Edendale Area is provided in Figure 2.

2.2.1 Consolidated Deposits

The Edendale solid geology comprises (oldest rocks) basement rocks, which are unconformably overlain by the Gore Lignite Measures. Basement rocks are in outcrop in the eastern margins of the area and include greywackes of the Murihiku Terrane. These units form the high ground to the east of the area (to the east of the Mataura River).

The Gore Lignite Measures underlay the majority of the area and comprise siltstones, sandstones with occasional gravels, together with relatively frequent lignite seams. The units are relatively thick (at least 100 m) and dip gently to the south east. The Lignites outcrop in higher ground to the west of the area and form the western boundary of the Mataura River valley.

Contours showing the top of the Gore Lignite Measures are provided in Figure 3. These contours are based on interpreted borelogs, where the top of the Gore Lignite Measures have been identified. The contours show that the top of the Gore Lignite Measures includes some topography, with an elevated ridge around the Ota Creek area, but generally the elevation is consistent with overlying surface topography and drops gradually to the south and east. The contours indicate the presence of an incised channel running from just west of Edendale town in the north to east of Seaward Downs in the south. This feature is discussed further below.

It should be noted that the raw borehole data producing isolated ‘bulleyes’ in the contour pattern have been identified, checked and, where necessary, removed.

2.2.2 Unconsolidated Deposits

The unconsolidated deposits in the Edendale area comprise Quaternary gravels, which overlie the Gore Lignite Measures across much of the Mataura River valley. In general the Quaternary gravels are relatively thin; borehole logs suggest that they extend to no more than 30 m depth. The gravels were deposited by braided rivers transporting glacial outwash from glaciers further north and comprise poorly sorted quartz and greywacke gravels. Since deposition, the Mataura River has reworked these deposits into a series of terraces, with the oldest terraces in the west of the area.

Based on the geological map of the area, the Quaternary Gravels are split into two different units: terrace gravels and alluvial gravels whose occurrence reflects their terminology (Figure 2). The terrace gravels are found on the terraces that lie to the west of the Mataura River, whereas the alluvial gravels occur in the immediate vicinity of the Mataura River. The thickness and occurrence of the units also reflects the topography of the area, where the boundary between the terrace gravels and alluvial gravels is identified by the abrupt change in elevation at the edge of the terrace.

Figure 4 shows a contour plot of the thickness of the gravels, based on the contours of the top of the Gore Lignite Measures (described above) and surface elevations. It shows that the aquifer generally thins towards its western and eastern edges as the gravels pinch out against the outcropping Gore Lignite Measures in the west and where the Mataura River has eroded downwards on the eastern side of the valley. There is also a noticeable change in thickness across the terrace edge, where borelogs indicate that the alluvial gravels are much thinner than the terrace gravels.

Previous studies Wilson (2011) identified the presence of a buried palaeochannel within the Quaternary terrace gravels, running roughly north south and parallel with the edge of the terrace south of the Edendale township. This feature is thought to represent an abandoned channel of the Mataura River and appears to be incised into the underlying Gore Lignite Measures, as indicated in Figure 3.

A photo illustrating the terrace edge and the terrace gravel deposits is presented in Figure 5. Note that the gravels are locally exploited by small scale quarrying operations along the terrace edge.

All the Quaternary gravels are overlain by a variable layer of loess that can be up to 5 m thick, although the thickness of these deposits varies considerably throughout the area. These deposits are also highlighted in Figure 5.

3.0 Conceptual Hydrogeological Understanding

3.1 Abstractions

Abstractions in general form a relatively small part of the overall water balance for the Edendale Area, however their spatial distribution is relevant as it provides a useful indication of areas where yields are typically high. Figure 6 presents the locations of abstractions within the Edendale Aquifer with the colour of each abstraction point reflecting its consented use. In general the abstractions are clustered towards the centre of the aquifer, which may support the presence of a more permeable palaeochannel.

The largest consented abstraction is the Fonterra Factory abstraction, close to Edendale town centre. The consent allows abstraction of up to 3 million m^3/year and 10,000 m3/day, although the returns data for this consent indicates that actual abstraction to date rarely exceeds more than 1.5 million m^3/year.

Figure 7 presents the total aquifer allocated abstraction volumes per year since 2000 (based on data provided by Environment Southland), together with total water use. It indicates that total allocation has risen from approximately 3.2 million m^3/year in 2000 to around 5.6 million m^3/year in 2009/2010, with reported water use rising from 1.4 million m^3/year in 2000 to 2.1 million m^3/year in 2009/2010. Figure 7 also shows the volume of allocated abstraction where returns data is unavailable or unknown, which has fluctuated from around 120,000 m^3/year to a maximum of approximately 720,000 m^3/year in 2006/2007.

Figure 8 presents abstractions broken down by consented use, showing the total allocation per use per year. It shows that industry is the predominant use, which reflects the large size of the Fonterra consents. However, other uses have been increasing, particularly Dairy and Irrigation consents, which now comprise 11 % and 10 % of the total allocated volume (2009 and 2010 data) compared to 0 % in 2000 and 2001. In addition, a recent (2009-2010), large, municipal consent was granted for 400,000 m^3/year.

3.2 Land Use, Irrigation and Anthropogenic Discharges

Figures 9a, 9b and 9c show the distribution of land use across the Edendale catchment for 1992, 2000 and 2005 respectively. The most salient point to emerge from the maps is the increase in dairy landuse across the area at the expense of a substantial decrease in Sheep and Beef landuse. The landuse maps also show a small increase in the area of land allocated to dairy factory wastewater, particularly between 2000 and 2005, when the Leondale and Pedrian Farms began operating using wastewater from the Fonterra Dairy Factory. Table 1 below illustrates the changing proportions of land cover for each of the six land use types across the Edendale area between 1992 and 2005.

Table 1: Land use proportions (ha)

Land use Type	1992 Area (% of total)	2000 Area (% of total)	2005 Area (% of total)
Dairy	2534 (21.6%)	2962 (25.3%)	6081 (51.9%)
Dairy Factory Wastewater	265 (2.3%)	265 (2.3%)	870 (7.4%)
Forest Nursery	95 (0.8%)	95 (0.8%)	95 (0.8%)
Industrial	54 (0.5%)	54 (0.5%)	54 (0.5%)
Residential	28 (0.2%)	28 (0.2%)	28 (0.2%)
Sheep and Beef	8741 (74.6%)	8314 (70.9%)	4590 (39.2%)

With the conversion of a number of farms to dairy, there has been an associated increase in abstraction consents for irrigation (Section 3.1). In general, irrigation takes place across some (but not all) dairy farms through summer months to enable grass growth for livestock, where water is abstracted from the underyling aquifer and distributed across pasture, with timing usually controlled by soil moisture deficits. Abstraction consents for irrigation use are therefore not completely consumptive, in that a proportion of water used for irrigation contributes to recharge going back into the aquifer.

However, whilst there has been a substantial increase in the area of land allocated to dairy farming in the Edendale area, the area of land consented for irrigation is considerably smaller and does not appear to show such a large rise. This discrepancy indicates that a majority of dairy farms within the Edendale area do not use irrigation.

3.3 Groundwater Levels and Spring flows

3.3.1 Groundwater Levels

Groundwater level records exist for the Edendale Aquifer since 1995, although there is a gap in the dataset between 1998 and 2000. Regular monitoring takes place at six different sites, five of which are monitored manually on a monthly basis and one (F46/250) is monitored using an automatic pressure transducer. The location of the six sites is shown in Figure 10 and a plot showing hydrographs for each of the sites is presented in Figure 11a. Table 2 provides details of the monitored bores.

Table 2: Long Term Monitoring Borehole Details

Bore number	Owner	Depth (m)	Diameter (mm)	Monitoring frequency
F46/0185	The Grange LTD C/- J R Hall	14.00	100	Monthly

F46/0190	ND Rayner	10.00	50	Monthly
F46/0192	M Howden	15.00	50	Monthly
F46/0193	DC (Clark) McLeod	11.80	150	Monthly
F46/0203	K & T Norman	7.70	75	Monthly
F46/0250	Environment Southland	18.00 (Screened from 17 m bgl to 17.7 m bgl)	100	Automatic

The hydrographs for the five sites can be split into two main groups, as shown in Figure 11a. The five most northerly wells comprise Group 1 and show a relatively pronounced response to recharge, with levels fluctuating by up 2 m. These hydrographs also show an overall trend superimposed on the seasonal trend (Figure 11 b), where declining levels are observed from 1995 to 2000, followed by a rise from 2000 to mid 2005 and a subsequent drop to the present day. Overall the Group 1 hydrographs show a slight declining trend, with current levels around 0.5 m below 1995 levels.

The hydrograph in Group 2 shows a much flatter response, with seasonal variations of around 0.5 m. Overall this hydrograph does not show the same slightly declining trend seen in Group 1 hydrographs and current levels are comparable to levels monitored in 1995. This hydrograph (F46/0192) is located close to the southern boundary of the aquifer on the margin of the terrace and close to the springs that discharge from the aquifer. The relatively stable levels are likely to be a reflection of this location, with spring discharge buffering groundwater levels.

Other groundwater levels have been monitored on a more *ad hoc* basis but there is sufficient data to allow construction of piezometric contours for 2007, presented in Figure 12. These contours indicates that the overall groundwater flow direction is to the south, although in the north of the area there is a notable easterly flow component, which is interpreted to represent groundwater flowing towards the Mataura River. The contours suggest that a groundwater divide may exist just north of Ota Creek, which is consistent with indications in the structure contours on the top of the Gore Lignite Measures (Figure 3) that show a raised area just north of Ota Creek. Moving further south, the contours indicate slight high just south of Edendale Town, which is likely to be an artefact of the contouring process and the several wells in the same area with water levels perhaps recorded at slightly different times. A further low is noticeable close to the southwestern boundary of the model, which is likely to represent the effects of pumping.

The contours indicates that overall flow is generally south-east within the main body of the aquifer around Edendale town, but towards the southern end of the aquifer the contours swing east, which reflects the impact of discharge from the aquifer to springs, discussed further below.

3.3.2 Spring Flows

There are two major springs in the Edendale area; Clear Creek and Ives Creek, both of which emerge at the base of the terrace at the southern end of the aquifer. Flow monitoring of these springs has taken place at intermittently since 1995, although more recently (since 2009) monitoring has been more regular, either quarterly or monthly. Monitoring locations are shown in Figure 13.

Clear Creek

A plot of flows at three points on Clear Creek is presented in Figure 14. Gauging at the most upstream location (Clear Creek at Settlement Stalker Road) indicates discharge from the aquifer varies between 10 L/s and 100 L/s, although a baseflow of around 25 L/s is more representative. The data indicate limited seasonal variation.

Clear Creek gains considerably from its perennial source to the next gauging point at Mataura Island Road (1.75 km downstream) with flows increasing to a maximum of 455 L/s and an average of ~320 L/s. Flows at this point appear to vary seasonally with the lowest flows generally observed during summer / autumn and highest flows occurring in winter. Some historical readings indicate there is relatively little difference in flows between Mataura Island Road and the confluence with the Oteramika Stream.

Ives Creek

A plot of two flow gauging points on Ives Creek is presented in Figure 15. Limited data is available at the most upstream gauging point (Ives Creek downstream of the Quarry) which indicates flows of between 150 L/s and 260 L/s.

At Mataura Island Road (2 km downstream), just upstream of the confluence with the Mataura River, flows in Ives Creek increase to an average of 280 L/s and, where concurrent data is available for Ives Creek downstream of the quarry, consistent gains of approximately 100 L/s are indicated.

Spring Flows and Groundwater Levels

Wilson (2010) carried out a regression analysis relating spring flows in Ives Creek and Clear Creek with groundwater levels at F46/0192, which is the borehole located on the terrace edge close to the springs (Figure 10). The analysis indicated that there is a reasonable correlation between spring flows and groundwater levels, most notably with flows in Ives Creek at Mataura Island Road.

As noted above, groundwater levels in F46/0192 are noticeably less variable compared to groundwater levels elsewhere in the area, which is interpreted to reflect the buffering effect of spring discharge whereby increases in groundwater level are manifested as increases in spring flow.

3.4 Aquifer parameters

A plot of transmissivity data from boreholes within the Edendale Aquifer is presented in Figure 16. Note that there is relatively limited number of pumping tests where transmissivity data has been calculated. To supplement this data, transmissivity values inferred from specific capacity data (Wilson, 2011) have also been included, based on a relationship from Driscoll (1987), which is a reduction of the Theim equation. However no data for the area north of Ota Creek are available.

These data indicate that transmissivity values range from a maximum of 9300 m^2/day (based on pumping test data) to a minimum of 4 m^2/day on the western edge of the aquifer, although the minimum value derived from pumping tests is 400 m^2/day.

Figure 16 shows that generally higher transmissivity values are found towards the centre of the aquifer south of Edendale town, which may represent the effects of the palaeochannel discussed in Section 2.2.2. Recorded transmissivities in this central area are up to 9800 m^2/day and with many other values in excess of 1000 m^2/day. Transmissivity values are generally lower towards the edges of the aquifer and also towards Ota Creek, with typical values in the order to 100 m^2/day.

Assuming an average saturated aquifer thickness of around 10 m, these transmissivity values would suggest hydraulic conductivity values ranging from 10 m/d around the edges of the aquifer to 980 m/d in the centre of the aquifer.

3.5 Aquifer Recharge

Variable recharge that contributes to groundwater level fluctuations in the Edendale Aquifer is almost wholly from rainfall, with a minor component of runoff from the higher ground to the east, where the outcrop of the Gore Lignite Measures provides the boundary to the aquifer. The Matauara River is expected to provide a more stable interaction of recharge and discharge to the alluvial gravels that are adjacent to its course.

The two closest rainfall stations to the Edendale area are Woodlands at Garvie Road and Mataura River at Tuturau. A plot of daily rainfall totals at both these stations is provided in Figure 17. Typical rainfall in the Edendale area is around 1080 mm/year, with significant seasonal variations.

Recharge to the aquifer has been estimated using a soil moisture balance approach. Soil properties have been determined based on soil technical data sheets and Profile Available Water (PAW) values provided in the Environment Southland GIS soils shape file. The distribution of soils and PAW values across the Edendale aquifer is shown in Figure 18. Potential evapotranspiration data has been taken from the Invercargill Climate Station for use in the soil moisture balance model.

Recharge Volumes

Recharge to the underlying water table can only occur when the soil moisture deficit is satisfied. A plot showing the calculated recharge time series since 1995 compared to rainfall data from Garvie Road is provided in Figure 19. It indicates that average recharge is in the order of 250 mm/y. This value is lower than previous recharge estimates (e.g. Rekker, 1995 (390 mm/y), and Evans, 2003 (453 mm/y)), however, the discrepancy is attributed to the time period for which recharge estimates are calculated and average rainfall for the period 1995 to 2011 is noticeably lower than rainfall for the periods used to calculate recharge in previous models.

As noted in Section 3.2 additional recharge can occur as a result of irrigation. Based on data provided by Environment Southland there are currently 8 irrigation consents within the Edendale area, which cover a total area of 230 ha. Irrigation under these consents has been factored into the recharge calculations, where irrigation is added to the rainfall time series when soil moisture balance falls to 50 %. Irrigation is assumed to cease when the soil moisture balance reaches 80 % and the volume added is constrained by the annual volume limit applied to each consent. In addition, irrigation is assumed to take place only between November and April.

Irrigation using wastewater from the Fonterra has also been taken into account, based on the same methodology. However, the irrigation volume from the Fonterra irrigation consent is not constrained by the annual volume limits applied to the Fonterra abstraction consents, because wastewater is also derived directly from the Fonterra factory. In addition, this wastewater irrigation is assumed to take place year round.

Timing of recharge

An examination of groundwater levels compared to calculated recharge indicates that there is a lag between the occurrence of recharge and an effect on groundwater levels (Figure 20). This lag is interpreted to reflect the depth of the water table beneath the soil and the delaying effect of the overlying loess deposits that are prevalent across parts of the Edendale area. Figure 20 indicates that this lag can be as much as 6-8 weeks depending on rainfall intensity, depth to groundwater and the thickness of the loess layer. This lag has been accounted for in the recharge calculations, based on a distributed grid of depth to groundwater and loess thicknesses recorded in borehole logs.

3.6 Summary of Conceptual Model

Figure 21 presents a summary conceptual model of processes occurring within the Edendale Aquifer. The aquifer consists of a relatively thin gravel terrace overlying relatively low permeability strata of the Gore Lignite Measures. To the west, the aquifer is bounded by the outcrop of the Gore Lignite Measures. The edge of the terrace aquifer to the east is demarcated by an abrupt change in elevation, where alluvial gravels cover the flood plain of the Mataura River, which effectively forms the eastern boundary of the aquifer system. The southern boundary of the aquifer is formed by further outcrops of the Gore Lignite Measures. The terrace pinches out to the north of the area.

Variable recharge to the aquifer is almost wholly via rainfall, and groundwater level fluctuations indicate that recharge reaches the water table with some delay depending on the depth to water and thickness of the overlying loess deposits. The aquifer discharges to a series of springs at the southern end of the aquifer, although it is likely that some groundwater flows into the adjacent alluvial gravels, which subsequently discharge into the Mataura River. Relatively flat groundwater levels close to the springs indicate that the springs act as a constant head discharge boundaries from the aquifer, with some fluctuations in spring flow depending on groundwater levels within the aquifer.

4.0 Numerical Flow Model

A numerical model of the Edendale Aquifer has been developed based on the conceptual model outlined above. The aim of the model is to simulate potential variation in groundwater quality and quantity in the Edendale Aquifer in response to potential future changes in abstraction and land use.

Simulation of contaminant transport within groundwater depends on a reliably calibrated groundwater flow model. The sections below detail the design and calibration of the flow model. The groundwater flow model has been developed using the USGS MODFLOW-2000 program, and its associated packages.

4.1 Model extents

Figure 22 shows the locations of the model boundaries. The western, northern and southern boundaries of the model are ‘No flow’ boundaries, which are consistent with the geology of the area and the surface outcrop of the low permeability basement strata for the gravel aquifer which is formed by the Gore Lignite Measures.

The eastern boundary of the model is represented by, and follows, the line of the Mataura River; whilst the alluvial gravels extend beyond the river, as noted above in Section 3.6, the Mataura River forms a flow boundary within the alluvial gravels as it is not expected that any significant groundwater flow would occur from one side of the river to the other side, However, the Mataura River is explicitly represented in the model so that groundwater within the alluvial gravels can interact with the river as required..

The model extends north to reach Mataura town. Whilst groundwater contours indicate a possible flow divide in the region of the Ota Creek, which could form a northern boundary to the model, the extent of flow that may occur across this divide is uncertain. Therefore the numerical model has been extended past the Ota Creek, so that groundwater can move across the divide if required, and the model can effectively determine the precise location of the divide. The northern extent of the model reaches the northern boundary of the terrace gravel deposits, based on data from the GNS Murihiku geological map

4.2 Model layering

Borehole data within the Edendale area does not indicate any significant layering within the terrace aquifer itself and although a loess layer is described in some boreholes, the extent of this loess layer is poorly defined. In terms of vertical movement of groundwater it is possible that some groundwater within the aquifer does drain through to the underlying Gore Lignite Measures, however, the relative difference between horizontal conductivity within the gravels and vertical conductivity within the Gore Lignite Measures is such that any vertical leakage from the base of the aquifer will form a negligible component of the water balance.

The aquifer has therefore been modelled as a single layer, with spatially variable hydrogeological properties.

4.3 Model discretization

The model has been developed on a 200 m square grid, extending from easting 2179500 to easting 2192100 and northing 5413900 to northing 5439500. The dimensions mean that the model is defined by a grid of 129 rows and 64 columns. The grid spacing is considered a reasonable balance between achieving sufficient detail within the model and representing the available data and Figure 23 shows the model grid overlaid across the model area.

Groundwater level data for the Edendale area is available from 1995, generally at monthly intervals, and abstraction data is available from around 2000. To represent known groundwater levels, the model therefore runs from 1995 through to 2011 with monthly stress periods, giving a total of 201 stress periods.

4.4 Model parameters

4.4.1 Recharge

Recharge to the model is applied using the MODFLOW recharge package but the values used within the package are calculated externally to MODFLOW. The process by which recharge values were calculated is described in section 3.5 and irrigation data is also taken into account.

4.4.2 Springs and Rivers

All streams and rivers in the model area are represented using the MODFLOW stream package, which has the advantage that it can accrete flow along the length of each reach. Four parameters are required to represent streams using the streams package namely:

- Stream stage
- Stream bed top elevation
- Stream bed bottom elevation
- Stream bed conductance

Stream stage has been set, where possible, using survey data, for example around the sources of Clear Creek and Ives Creek. Stream stage downstream from these points, or where survey data is not available, has been set as 1 m below surface elevation, whilst ensuring that stream stage decreases in elevation downstream.

The stream bed thickness (i.e. the difference between the stream bed top and bottom elevation) exerts some control on how easily water leaks from the stream to the aquifer, or *vice versa*. In the model, the stream bed top elevation has been set to 0.3 m below stage (meaning that the streams are modelled as 30 cm deep) and the stream bed bottom elevation is set to 0.1 m below the stream bed top.

MODFLOW Stream Conductance (C) represents bed characteristics and affects the rate of groundwater seepage into, or out of, the surface waterway, thereby defining the amount of baseflow to the stream under varying groundwater head conditions. The value of the streambed conductance is difficult to measure precisely and its 'best' value is perhaps best determined by achieving adequate representation of modelled groundwater heads and stream flows. The locations of the modelled streams are shown in Figure 24.

4.4.3 Abstractions

Consented abstractions in the model are represented by the MODFLOW well package. Abstraction data within the Edendale model area is not generally available on a monthly basis and in most cases only annual totals are available, meaning that the distribution of abstraction volumes through the year is uncertain. However, in the case of the Fonterra abstractions and municipal abstractions, monthly (or daily for the Fonterra abstractions) data are available.

Where data is not available on a monthly basis, it has been distributed through the year depending on the abstraction use. Irrigation consents are set to take their volume between November and April, with the volume peaking in January, while dairy shed consents are distributed evenly across the typical dairy season between August and May.

4.4.4 Hydraulic Conductivities

Figure 25 shows transmissivity values plotted on top of structure contours for the Gore Lignite Measures. They indicate that the higher transmissivities observed in the Edendale Aquifer generally correlate well with the approximate line of the palaeochannel, where it has incised into the Gore Lignite Measures. In the model the initial distribution of conductivity has followed this pattern, with higher conductivities assigned to the approximate outline of the palaeochannel, and lower values assigned outside this area.

Groundwater contours also suggest that groundwater levels north of Ota Creek rise relatively abruptly, suggesting a sharp change in hydrogeologic parameters, most likely conductivity. The initial distribution of conductivity reflects this conceptual understanding with a lower conductivity zone north of Ota Creek.

Alluvial gravels are generally highly permeable and therefore where alluvial gravels are identified on the geological map a high conductivity has been used. A high value of conductivity in the alluvial gravels also ensures that groundwater can discharge to the Mataura River.

Figure 26 shows the initial conductivity zones distribution zones across the model area.

5.0 Summary

This report has outlined the conceptual model of the area, formed from the existing information available and the numerical model that has been set up to represent these processes.

A numerical model cannot perfectly represent natural processes, due not least to the complexity of natural systems and imperfect knowledge of those systems. However, based on the conceptual understanding of processes within the aquifer, and the ability of the model to represent these processes, the numerical model of the Edendale Aquifer is expected to provide a reasonable representation of the natural processes that take place.

Some information gaps exist in the area, most notably with respect to hydraulic parameters north of the Ota Creek and therefore there are some uncertainties in this area. However, these uncertainties should be limited provided a satisfactory calibration is achieved based on a conceptual understanding of the processes involved.

The next stages of development for the model are to complete the transient flow model calibration, based around long term monitoring data of stream flows and groundwater levels. Once the flow model is satisfactorily calibrated, development of the contaminant transport model can be completed. A further report detailing the calibration of the flow model and development of the contaminant transport model will be provided once these stages are concluded.

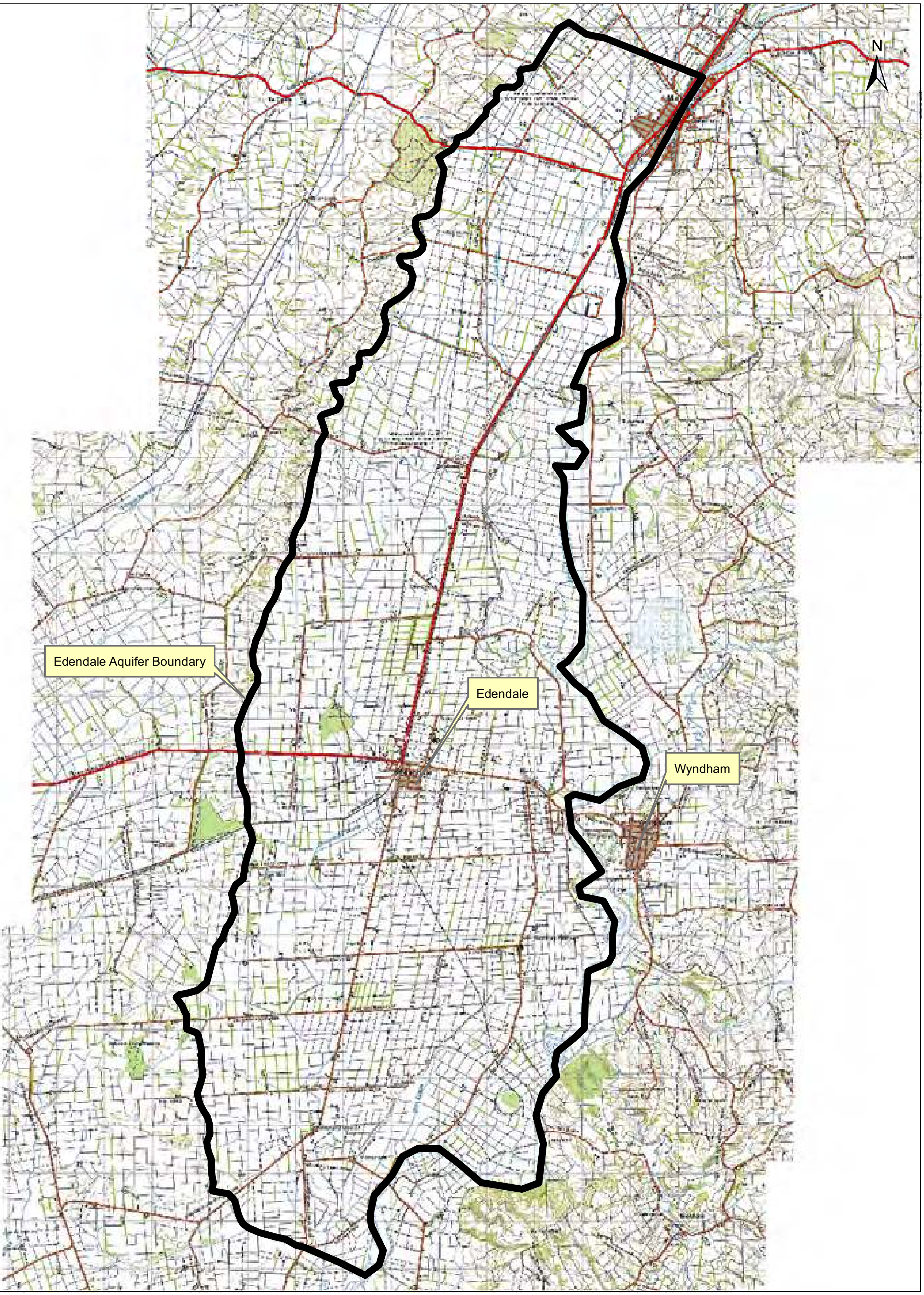

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Figure 1 : Topographical Map of the Edendale Groundwater Area

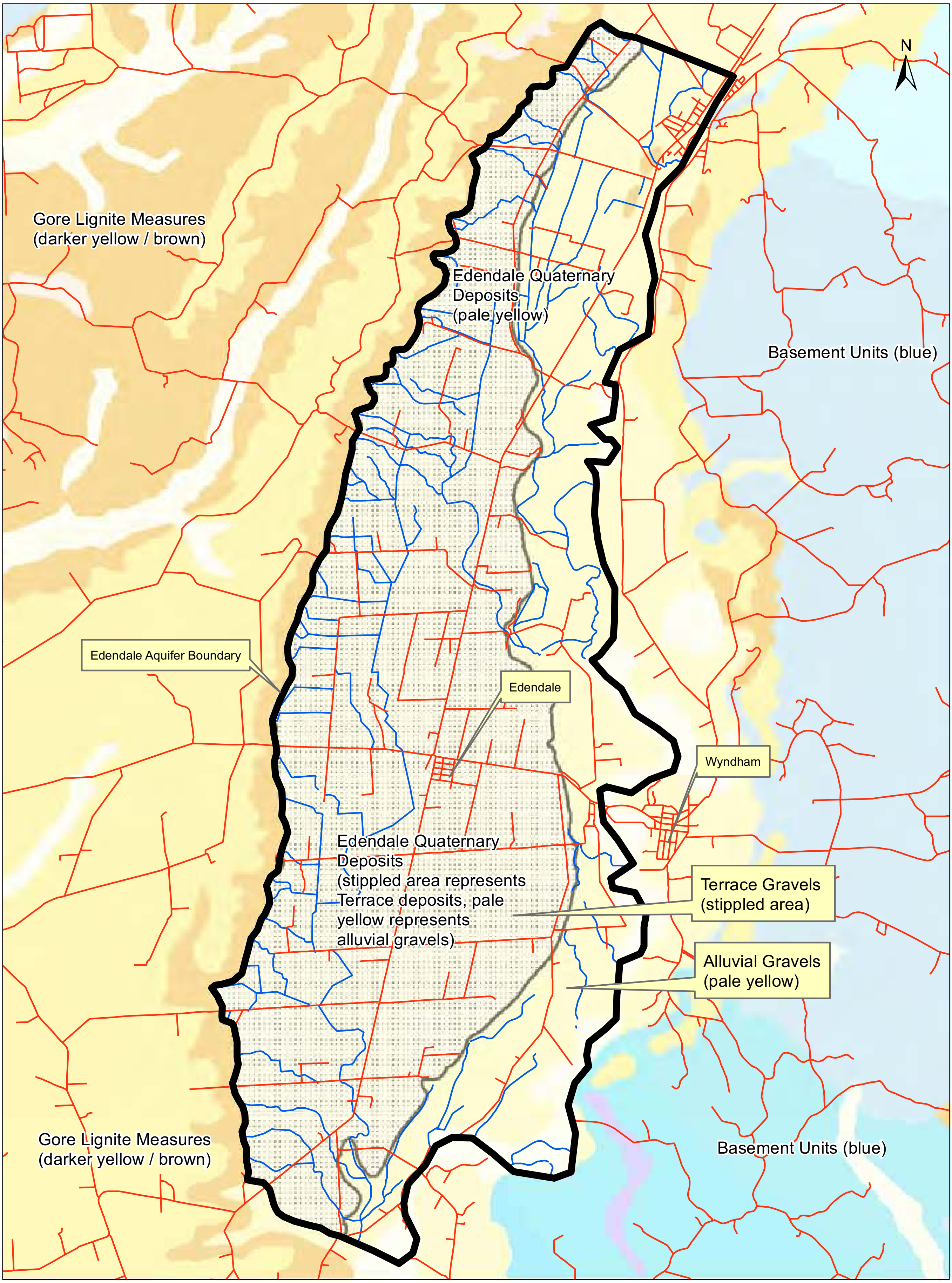

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Figure 2 : Geological Map of the Edendale Groundwater Area

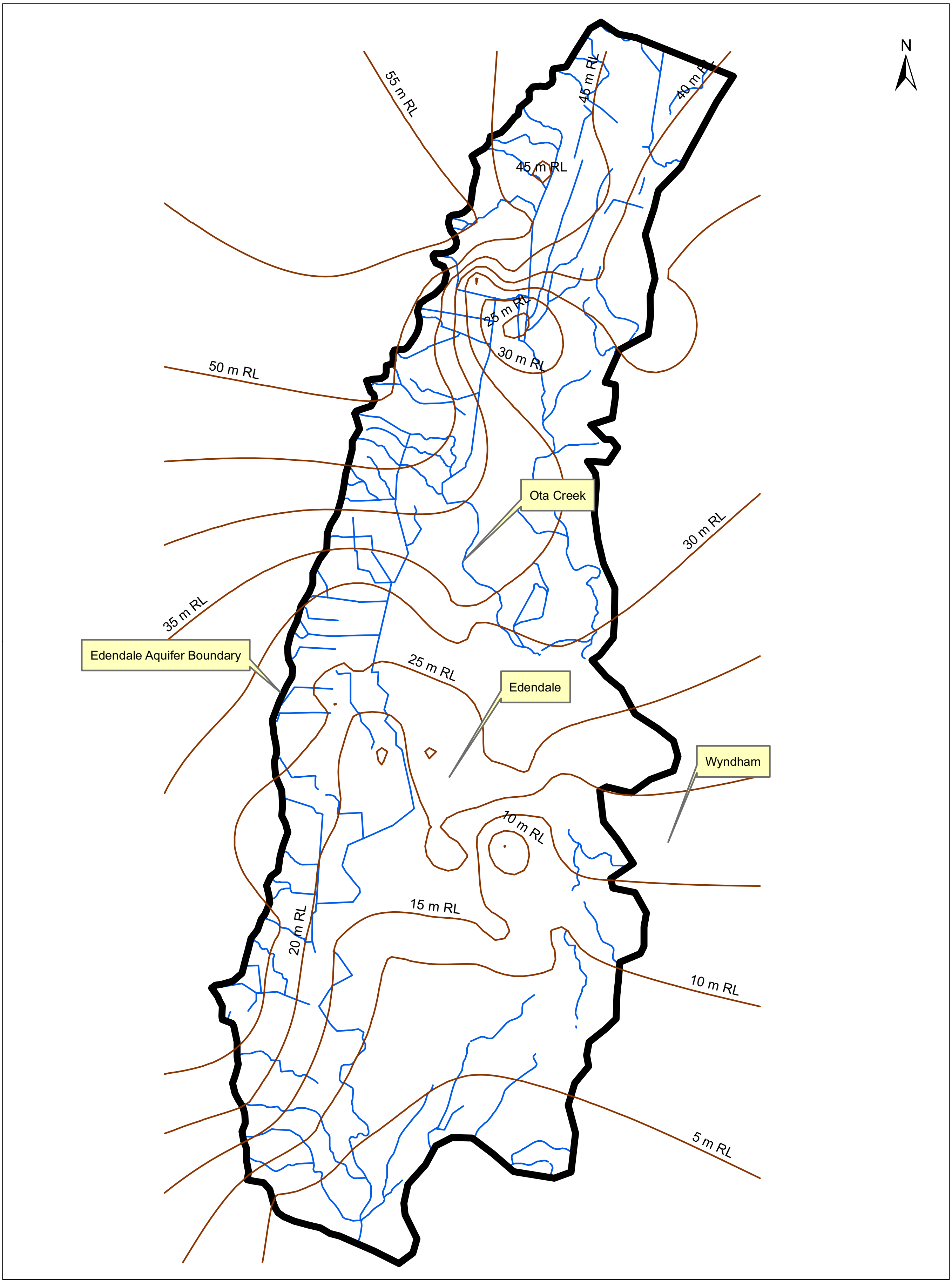

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Figure 3 : Base of Aquifer Contours (top of Gore Lignite Measures) (m RL)

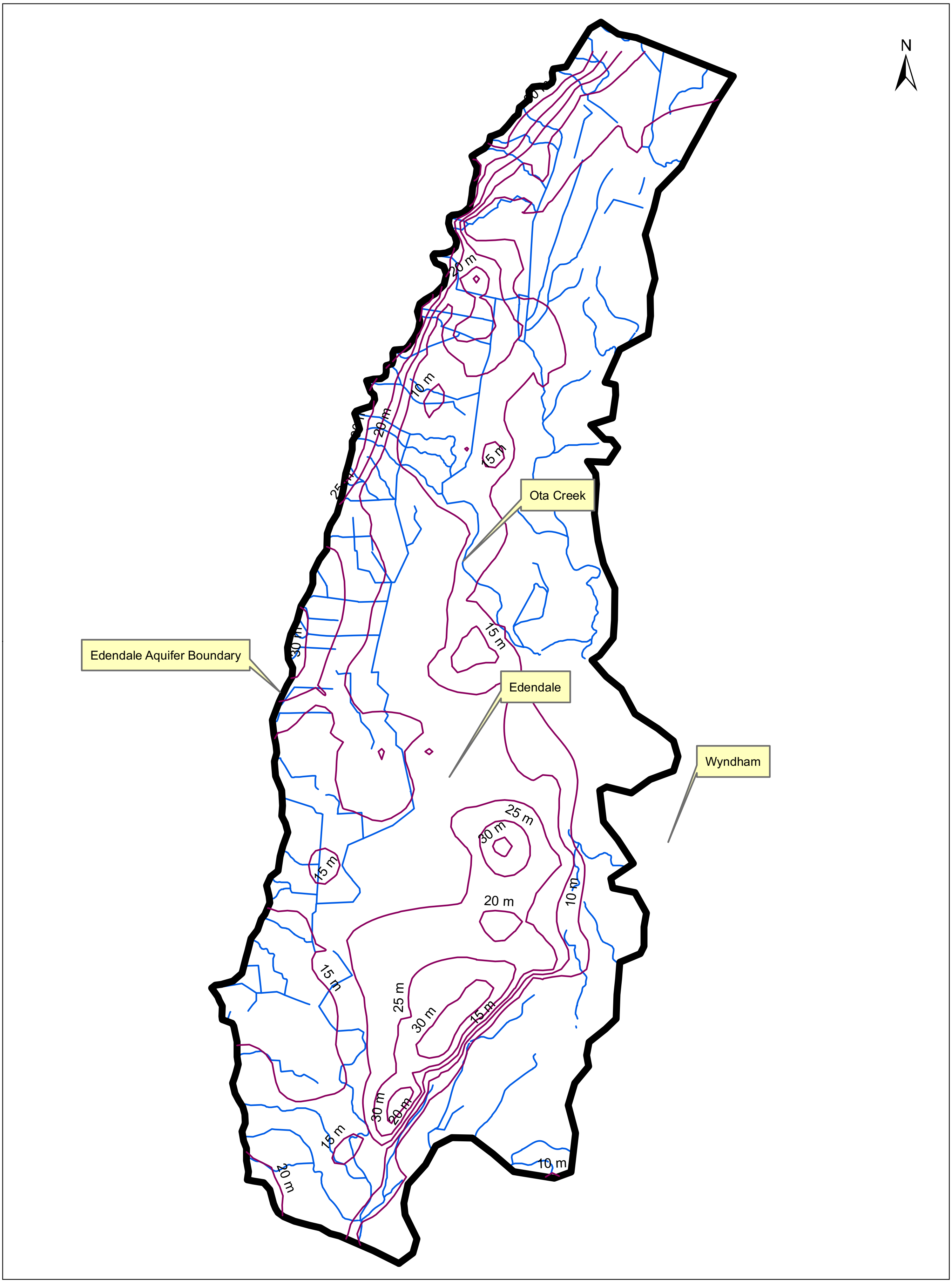

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Figure 4 : Aquifer Thickness Contours (m)

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Figure 5: Photo showing edge of the Edendale Terrace Aquifer

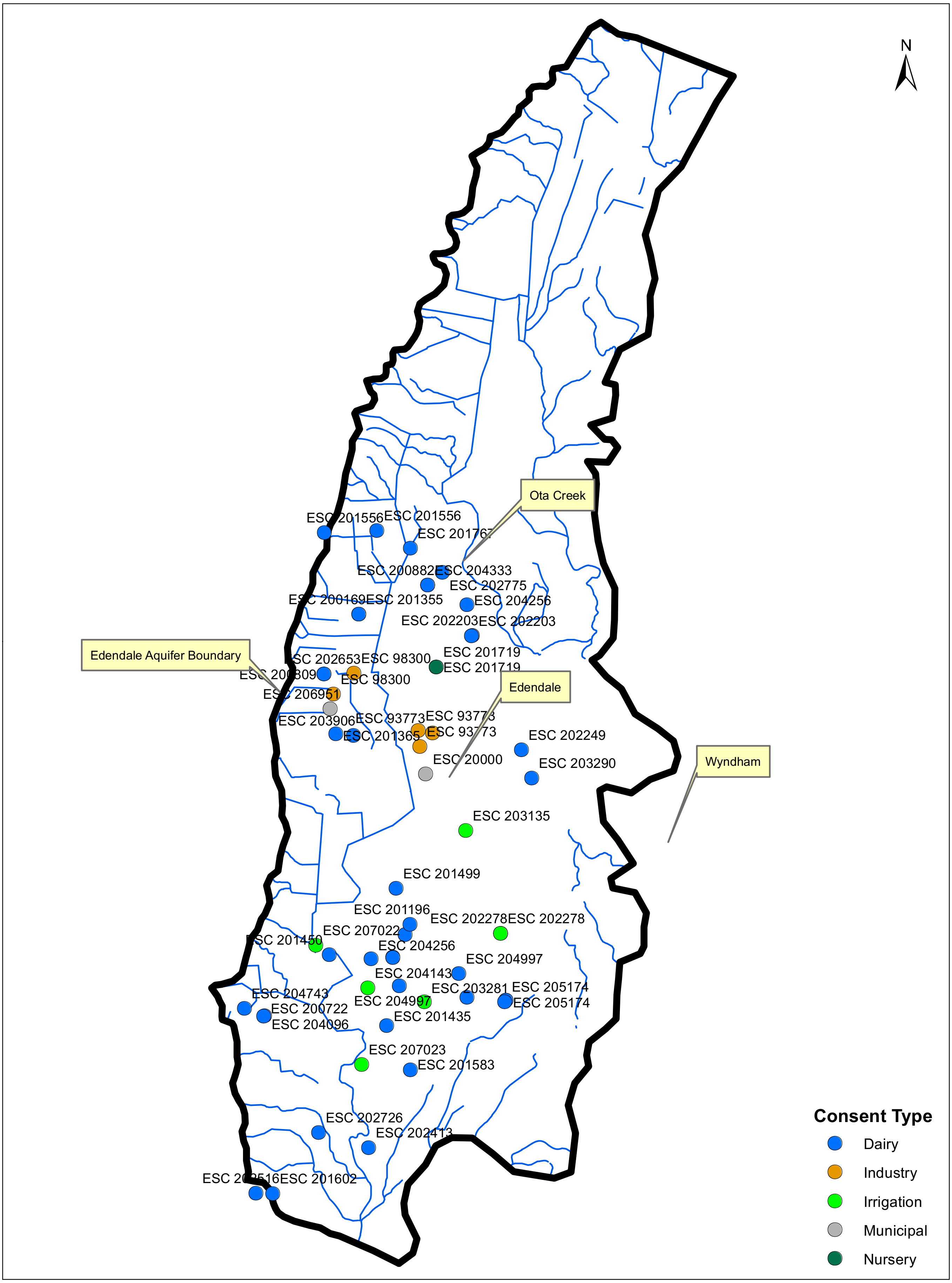

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Figure 6 : Abstraction Consent Locations and Type

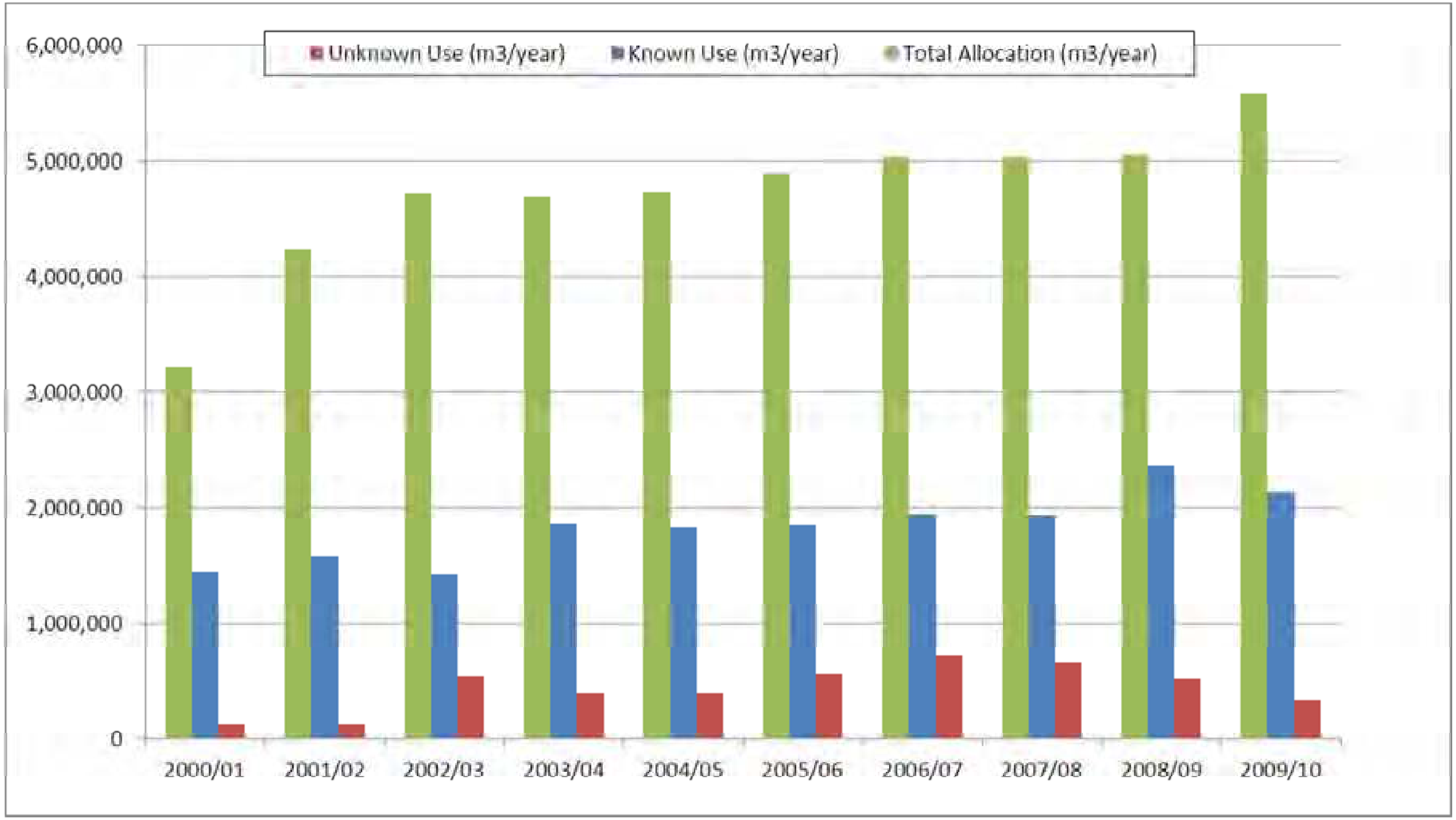


Figure 7: Abstraction Volumes

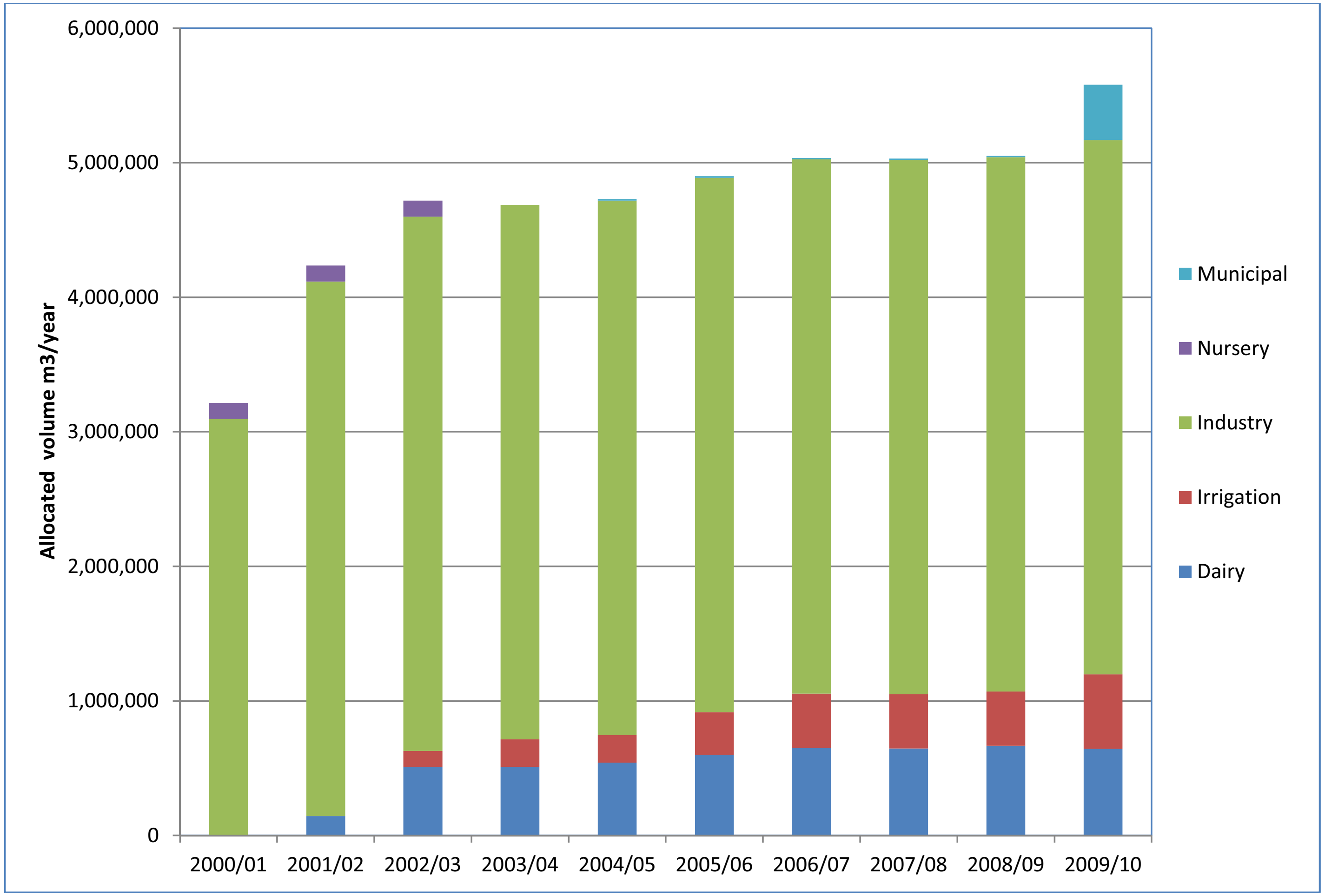
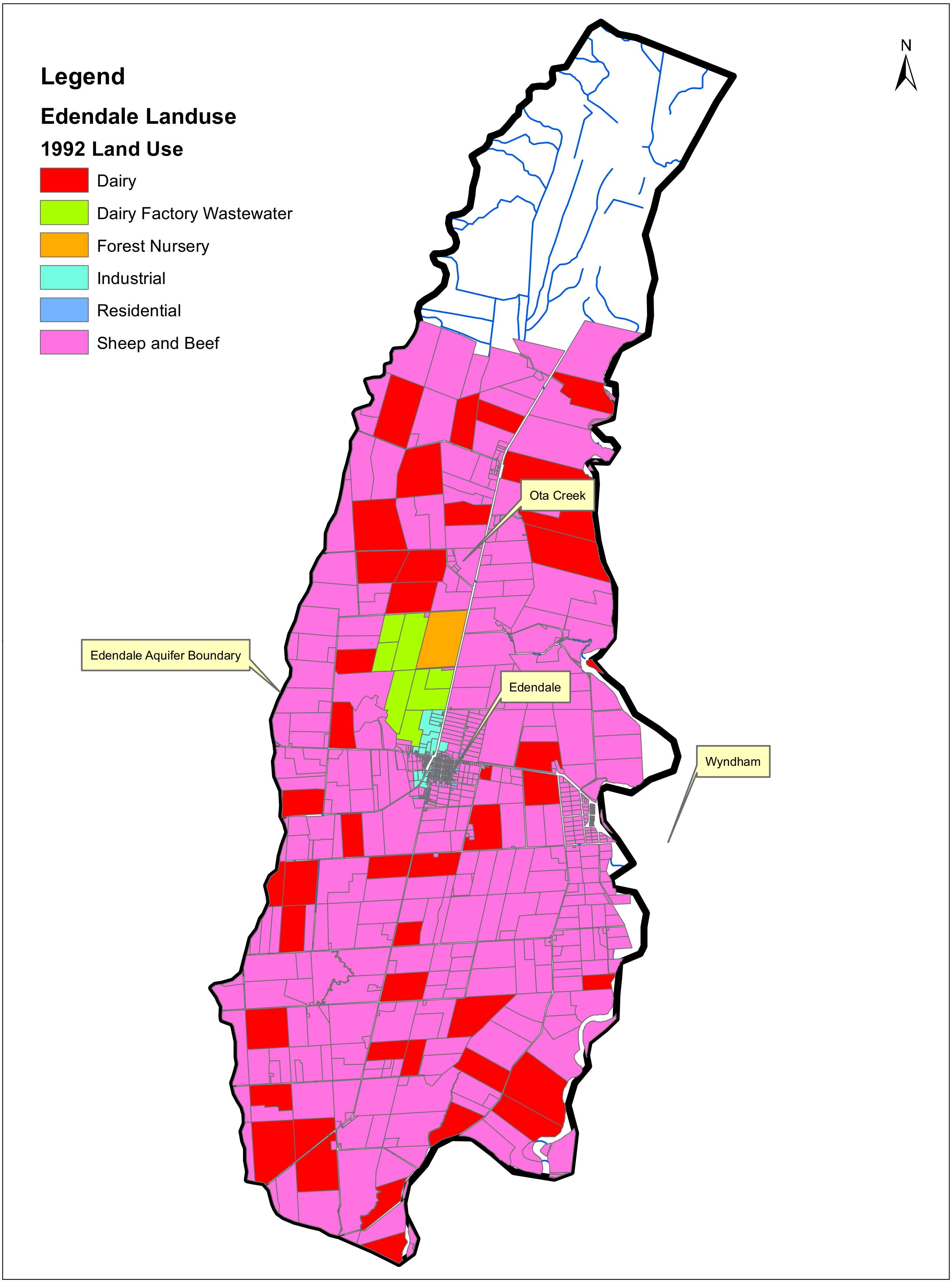


Figure 8: Abstraction Volumes by Consent type



Source :

Figure 9a : Land Use Distribution from 1992

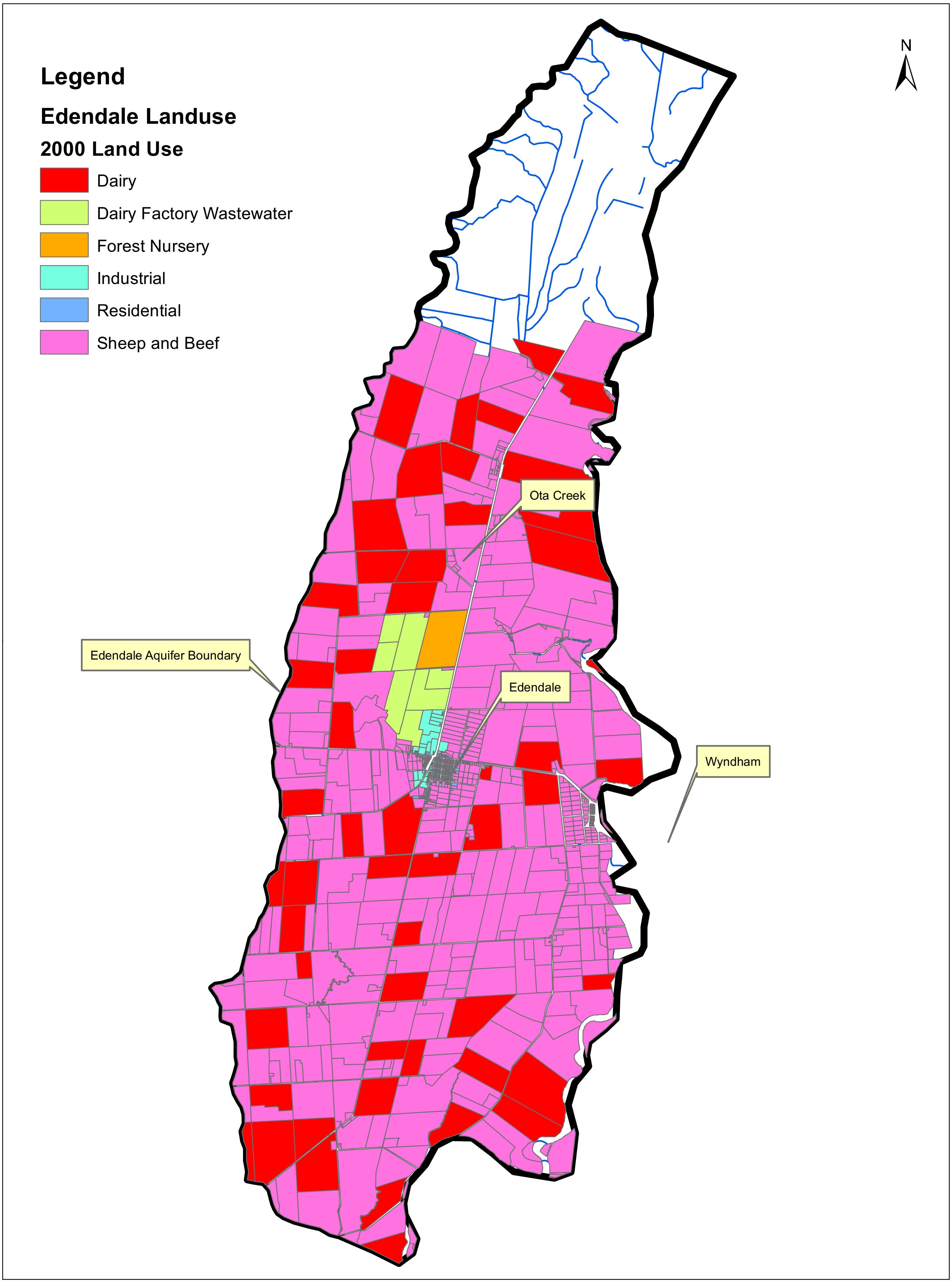


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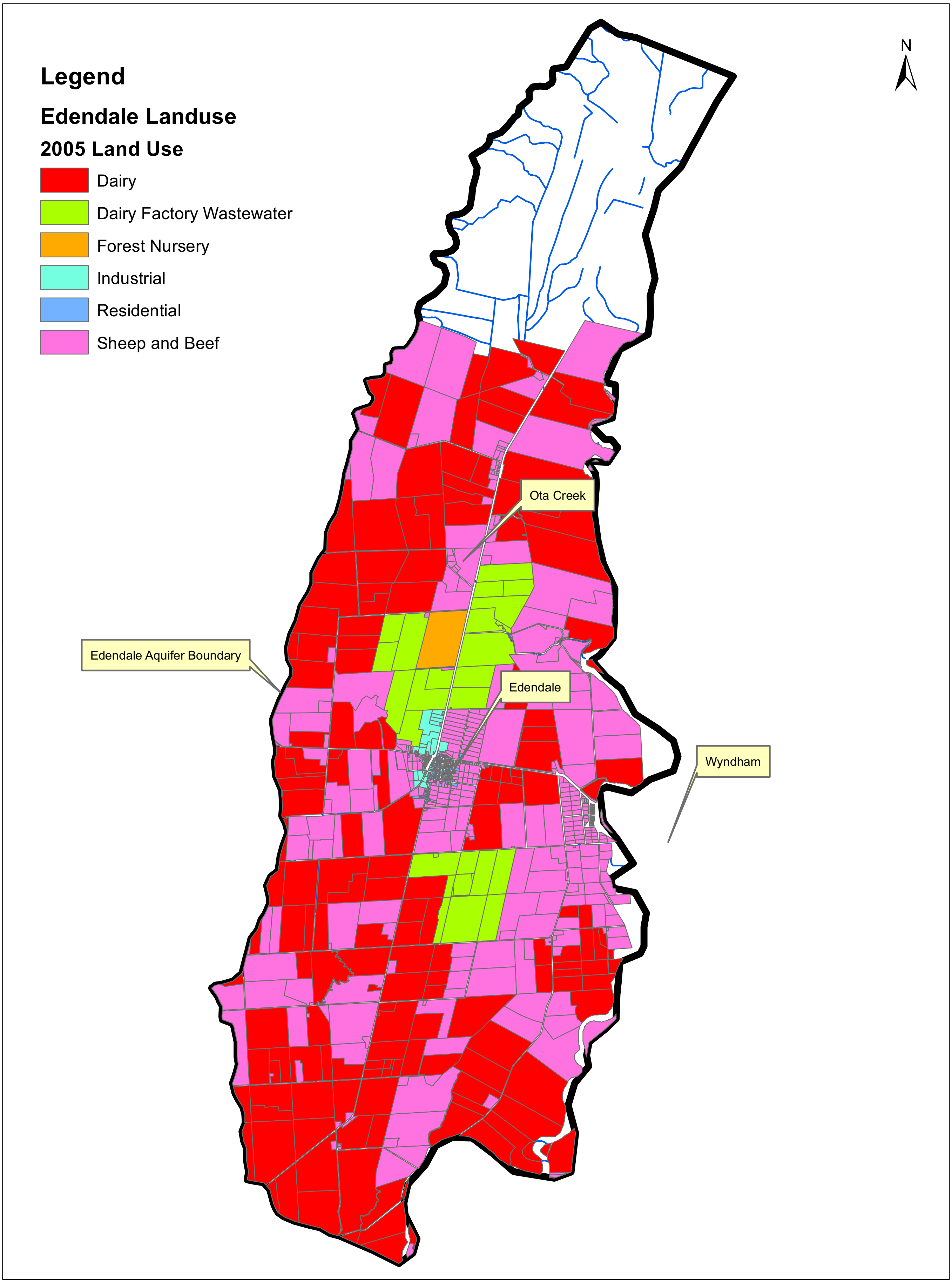
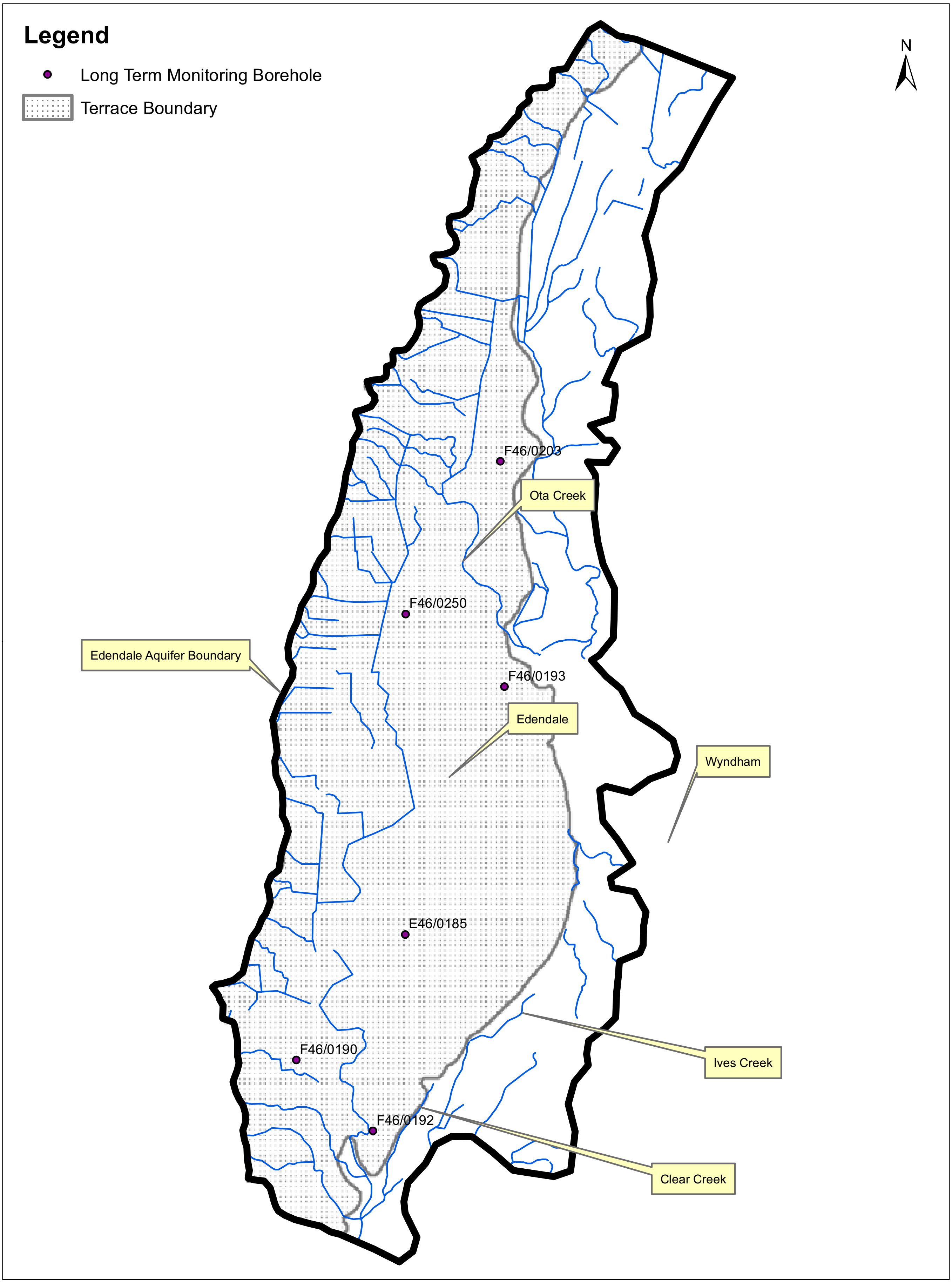
Figure 9b : Land Use Distribution from 2000



Source :

Figure 9c : Land Use Distribution from 2005



Source :

Figure 10 : Long Term Groundwater Monitoring Locations

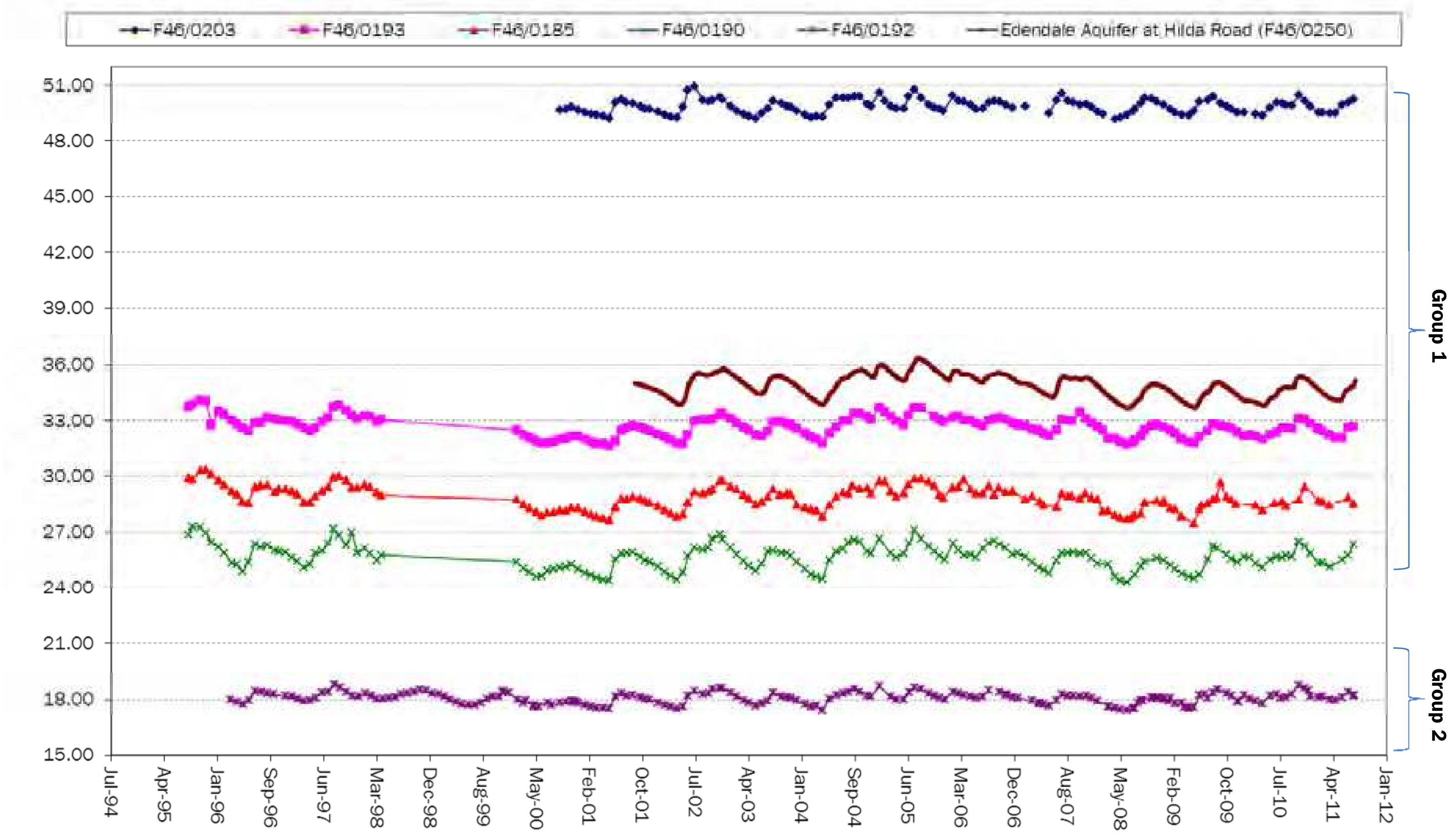


Figure 11a: Long Term Groundwater Level Hydrographs

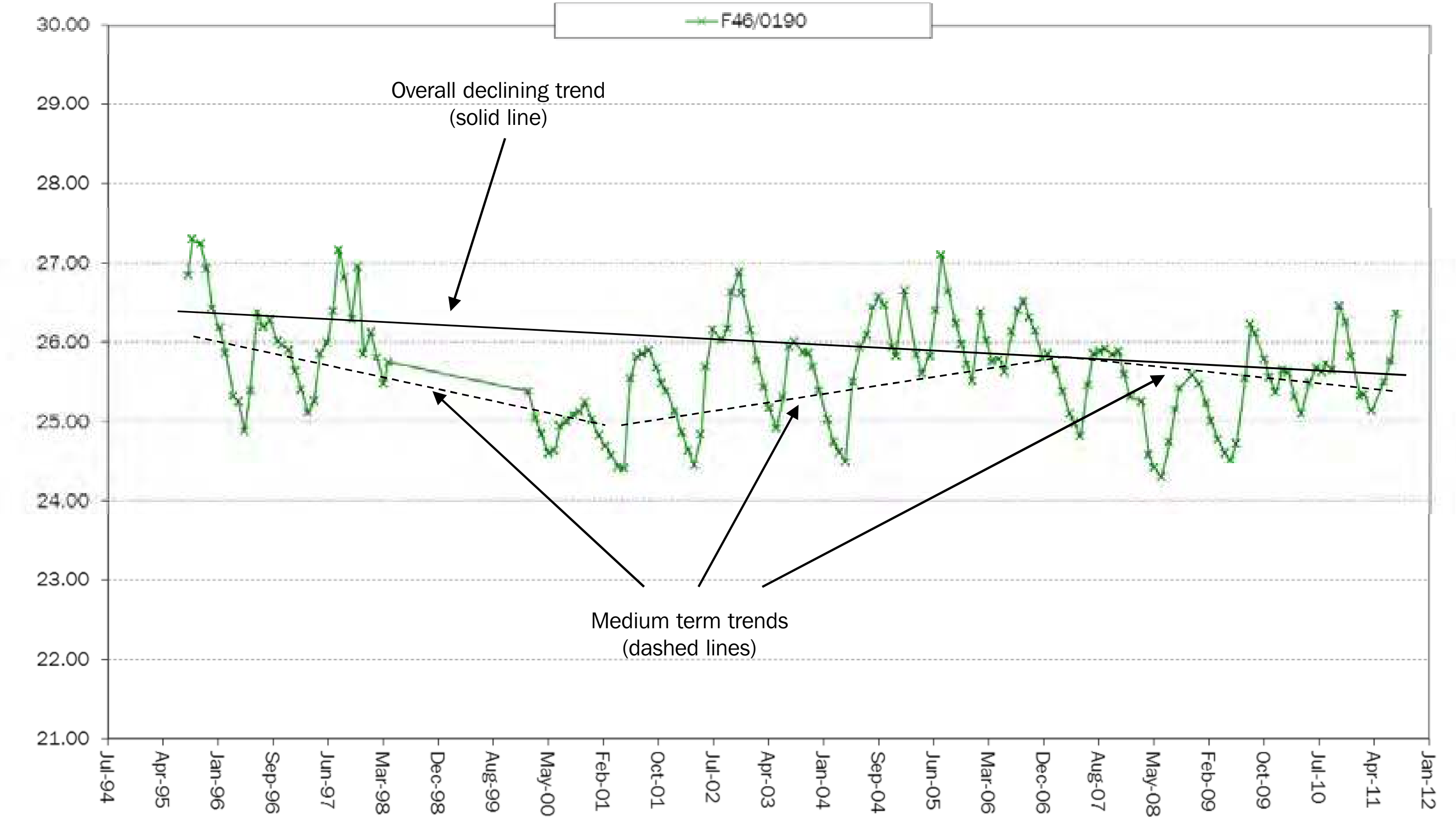


Figure 11b: Group 1 Hydrograph Trends

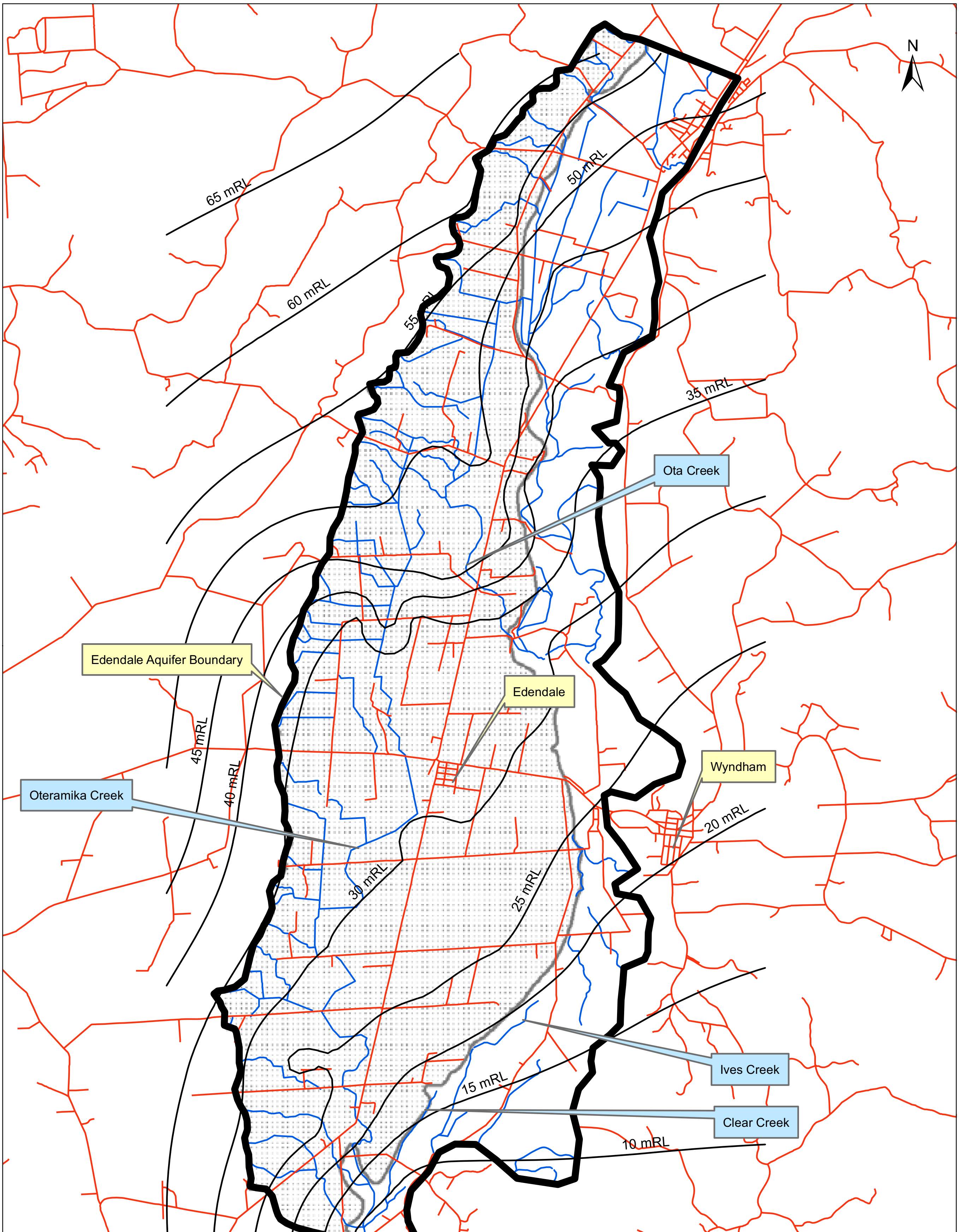


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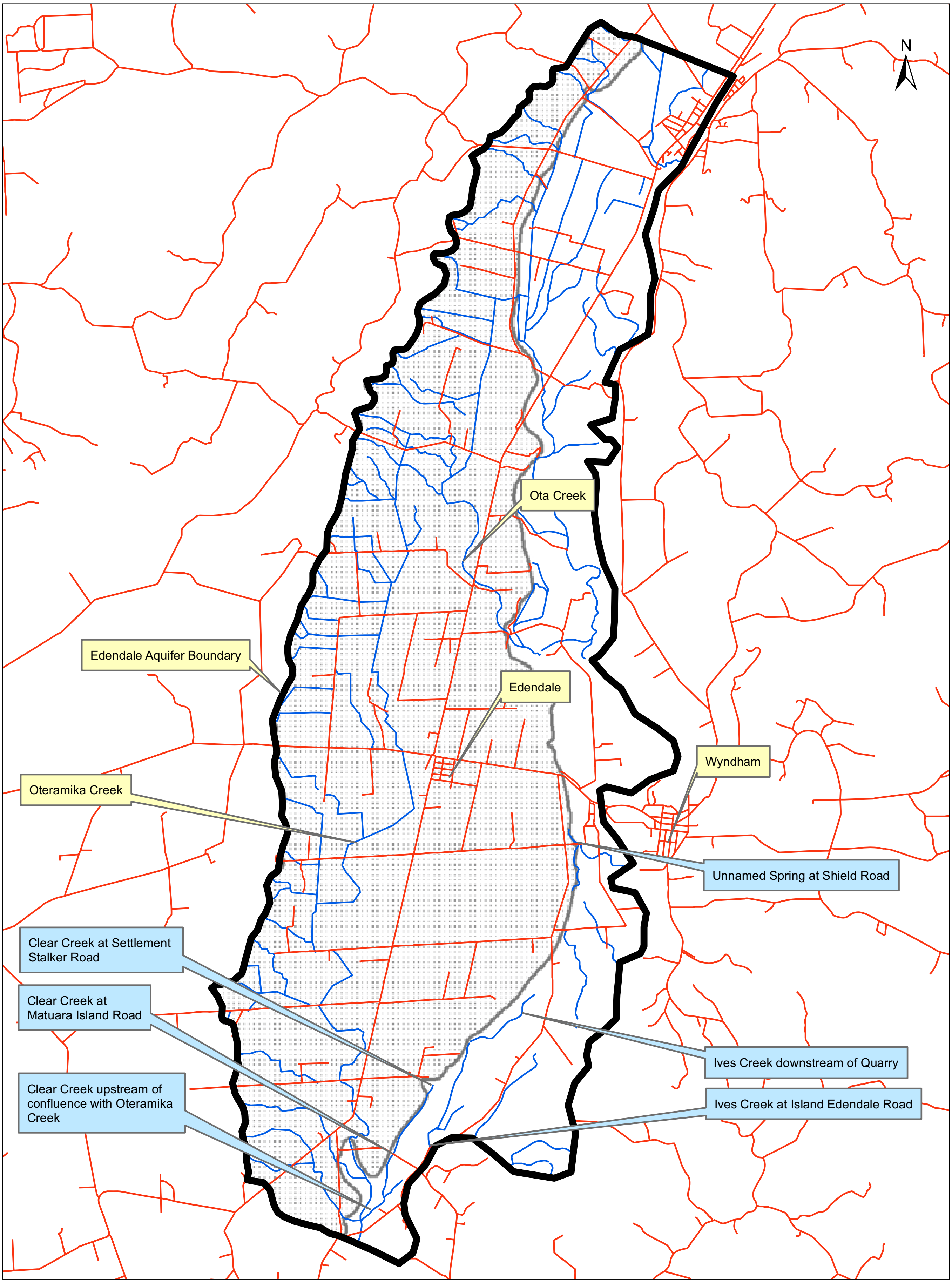
Figure 12: Groundwater Contours (2007)



Source :

Figure 13 : Spring flow monitoring locations (blue text)

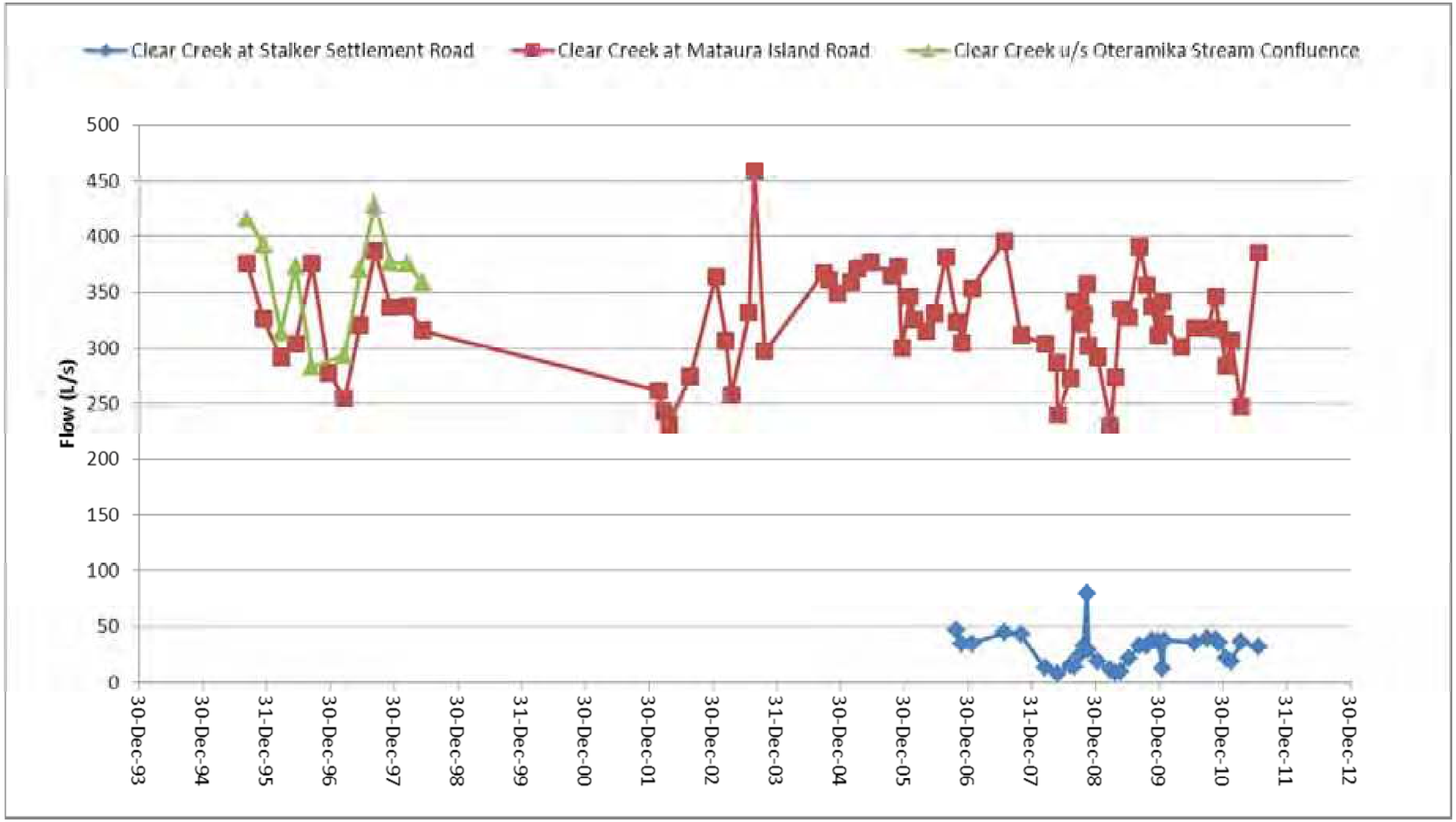


Figure 14: Clear Creek Flow Rates

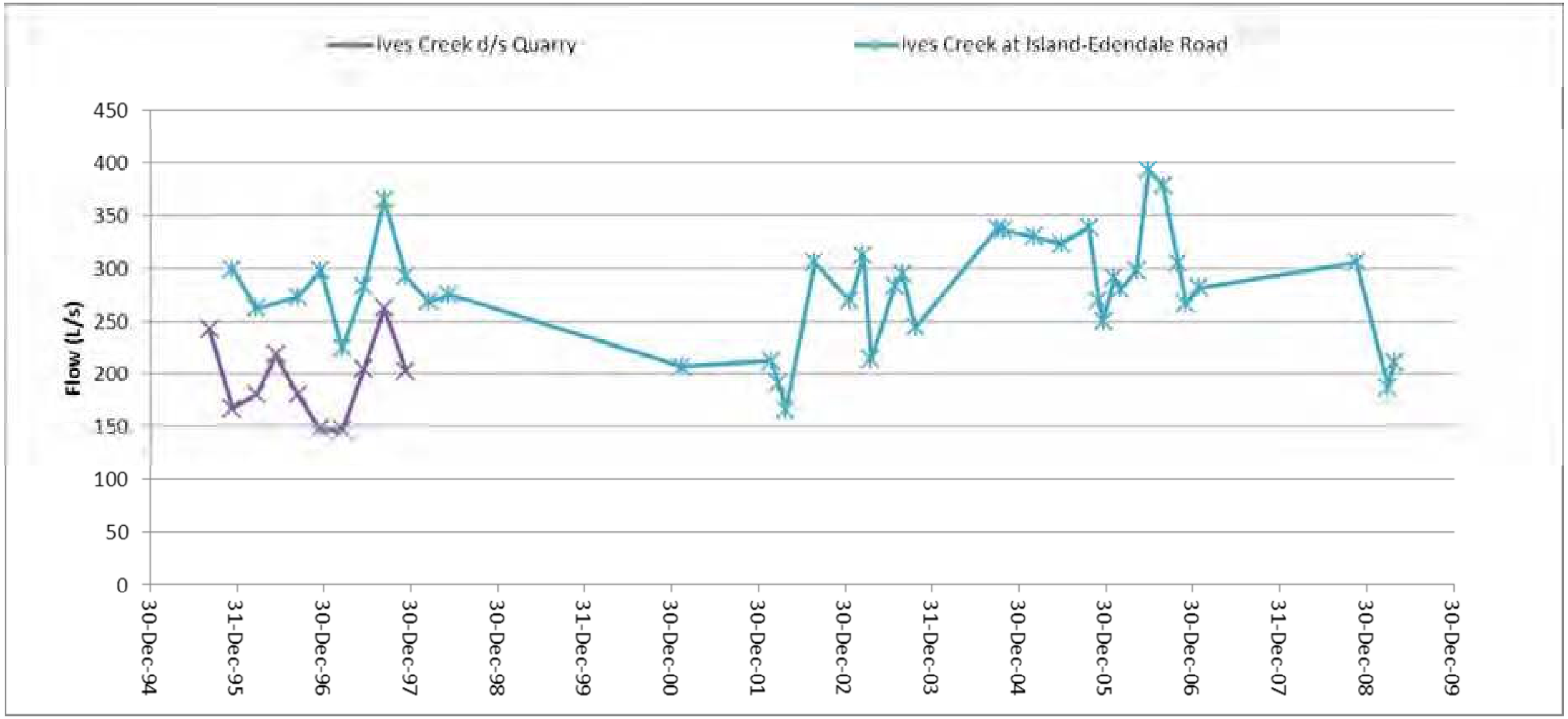


Figure 15: Ives Creek Flow Rates

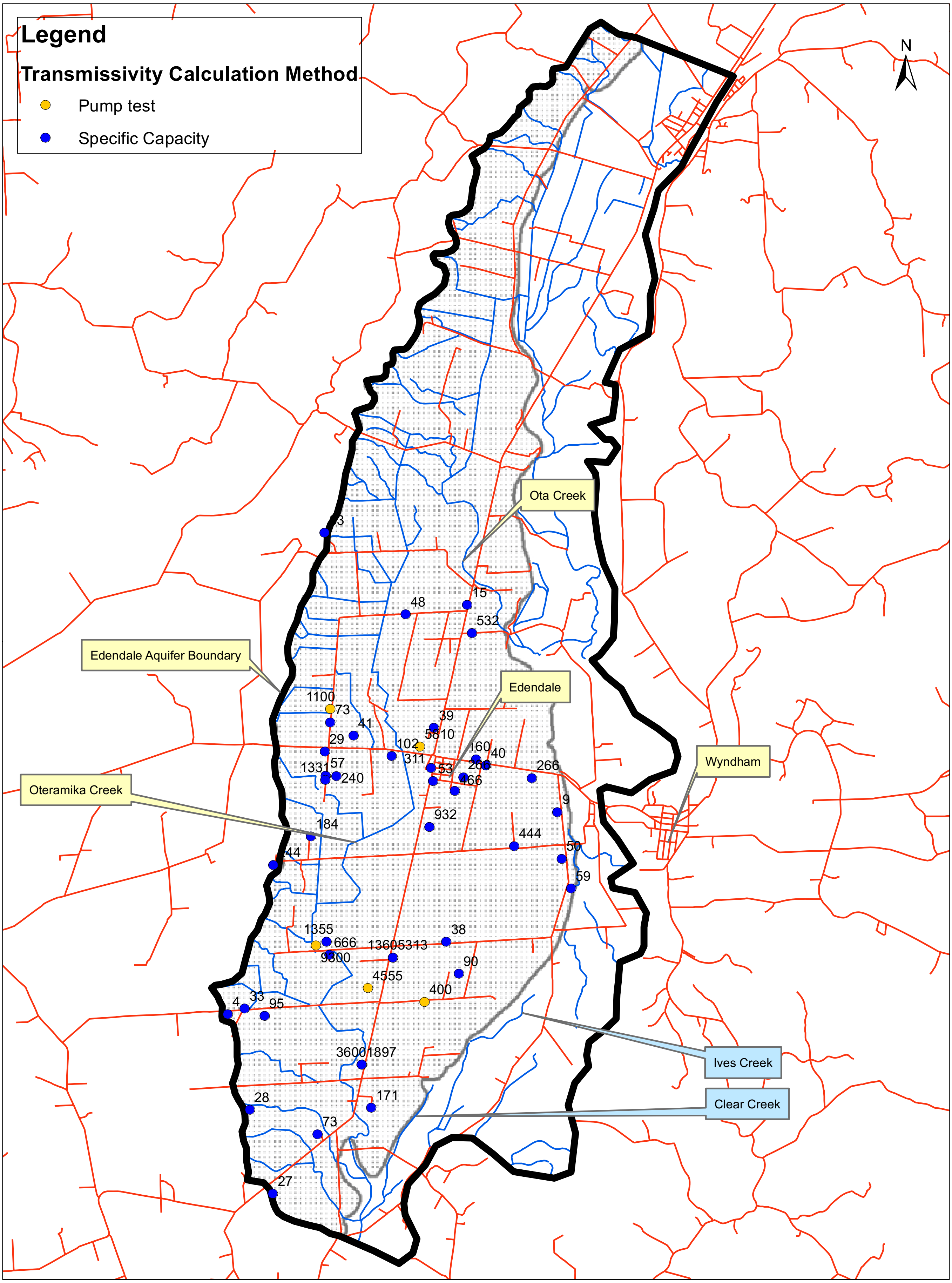


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Figure 16 : Transmissivity Data

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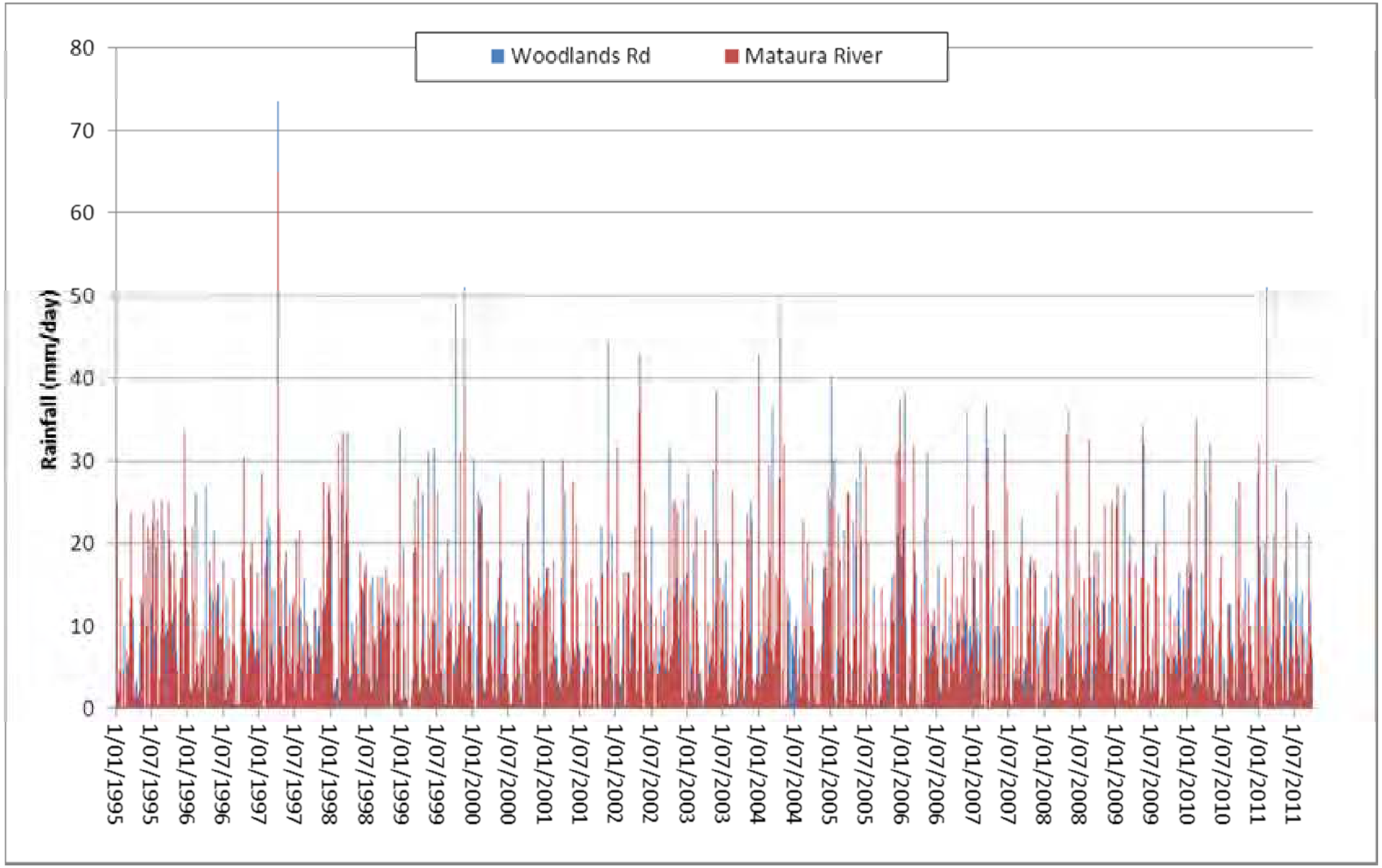

Figure 17: Daily Rainfall Rates

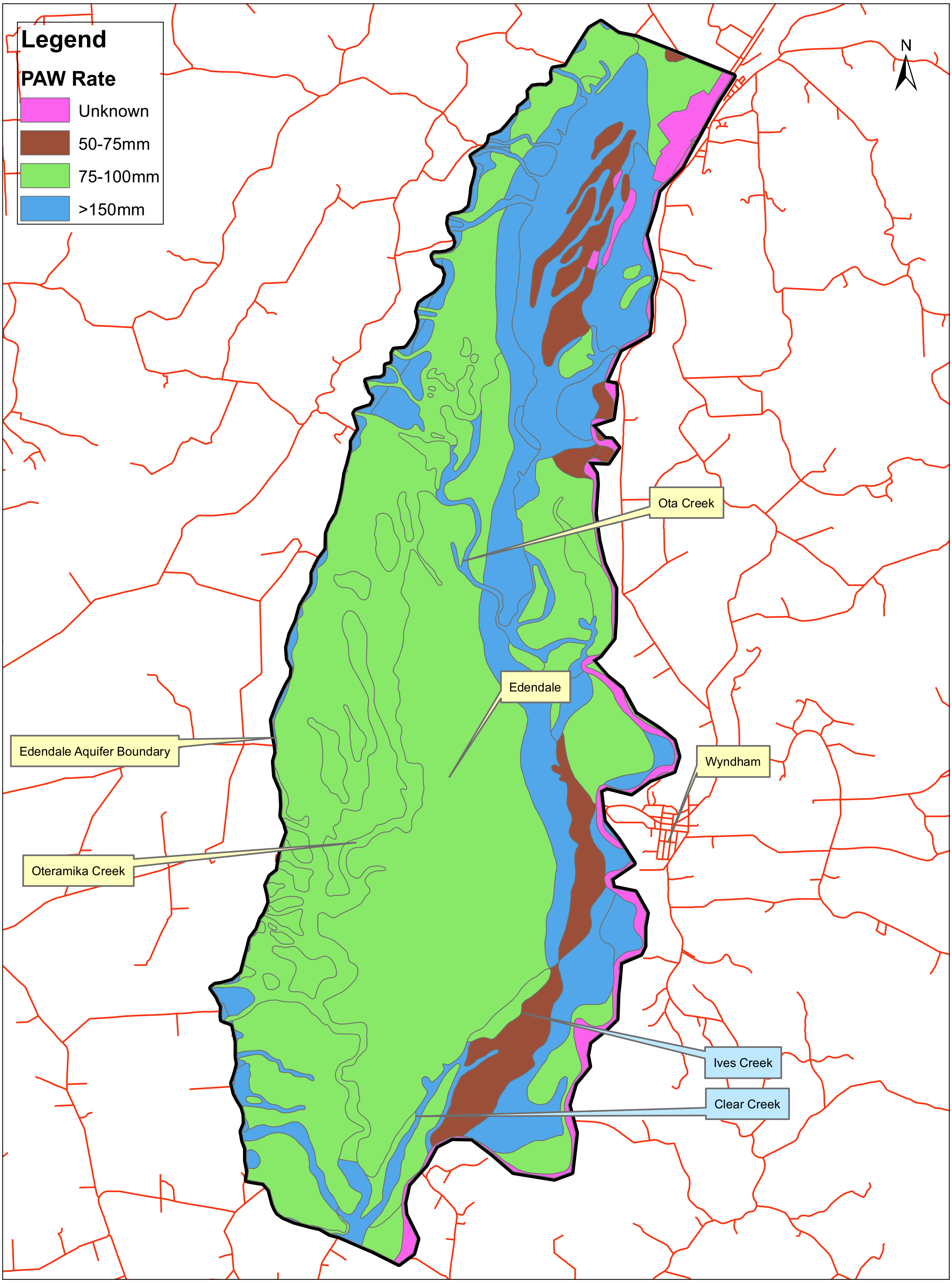

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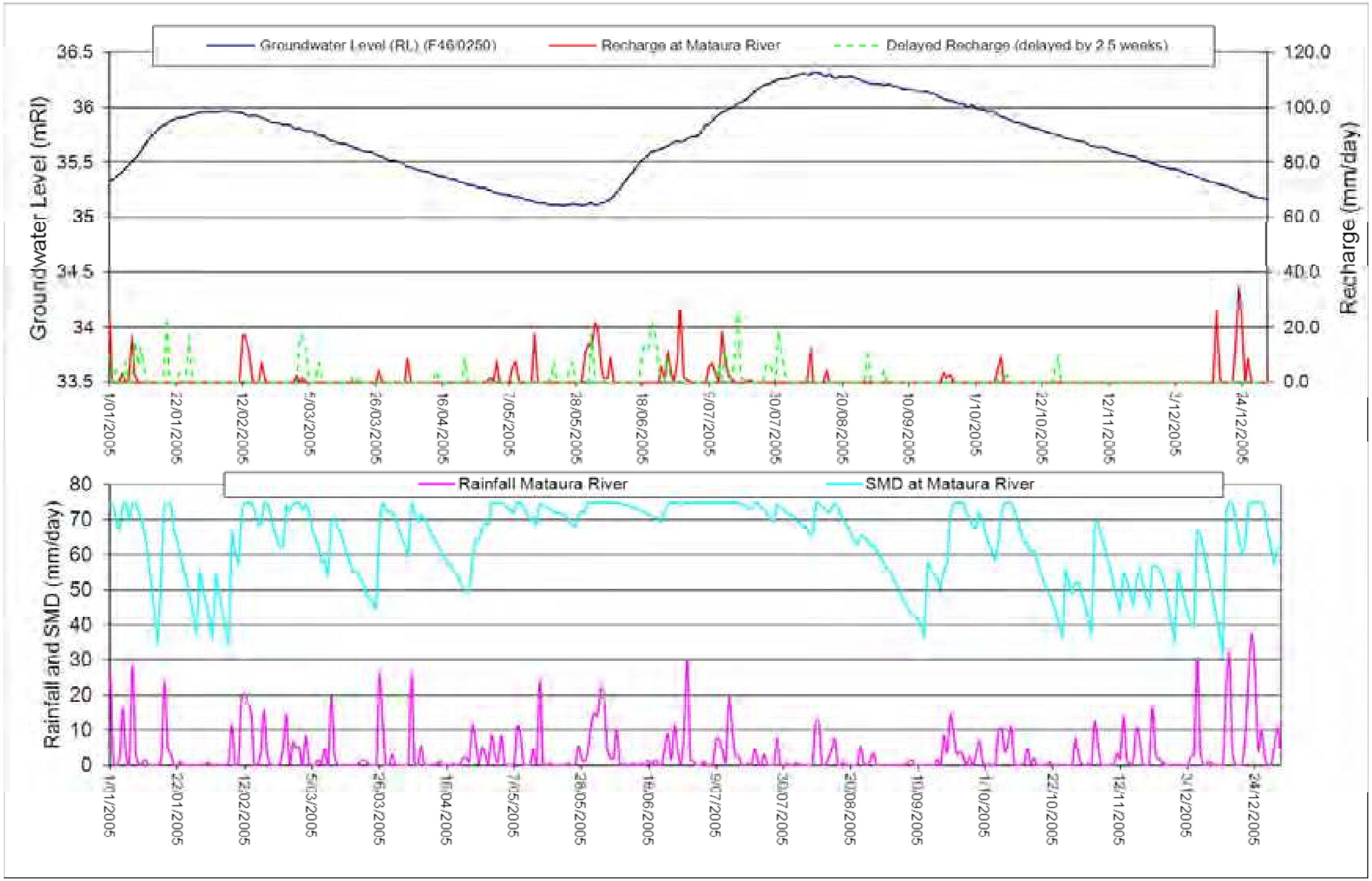
Figure 18 : Soils Data and PAW Rates



Figures 19 and 20: Rainfall / Recharge and Groundwater Level Lag

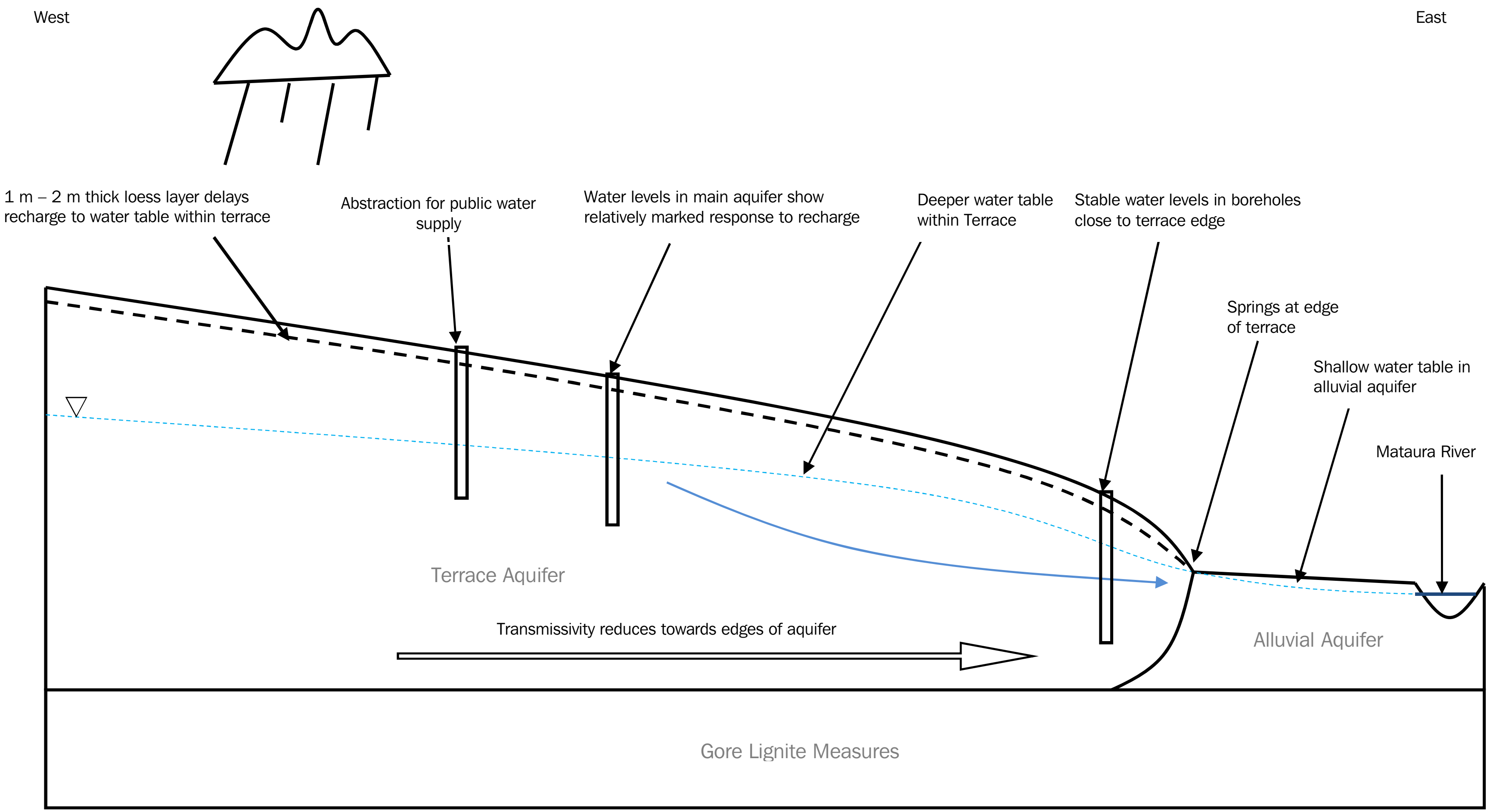


Figure 21: Conceptual Cross Section through the Edendale Aquifer

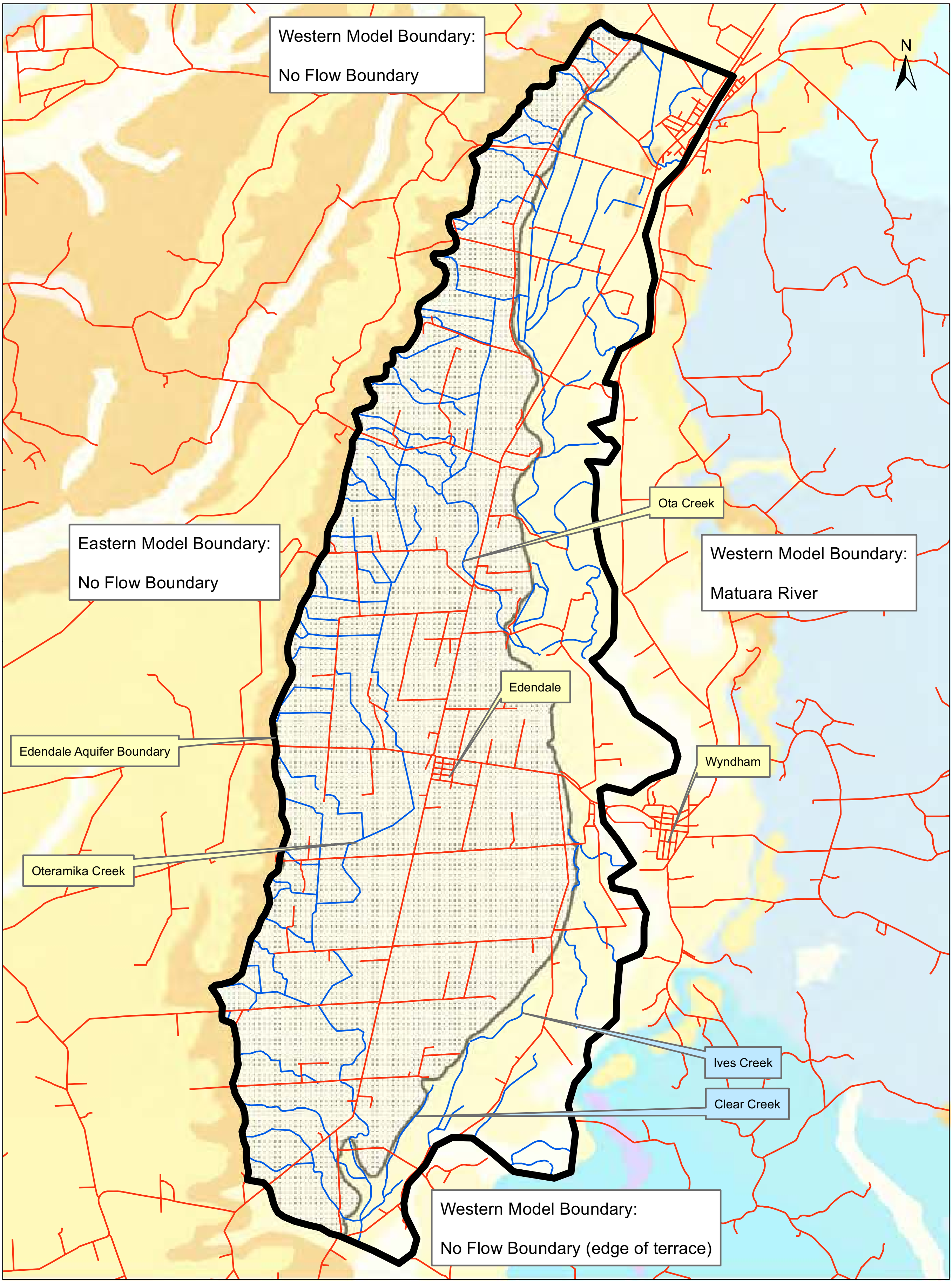


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Figure 22 : Model Boundaries

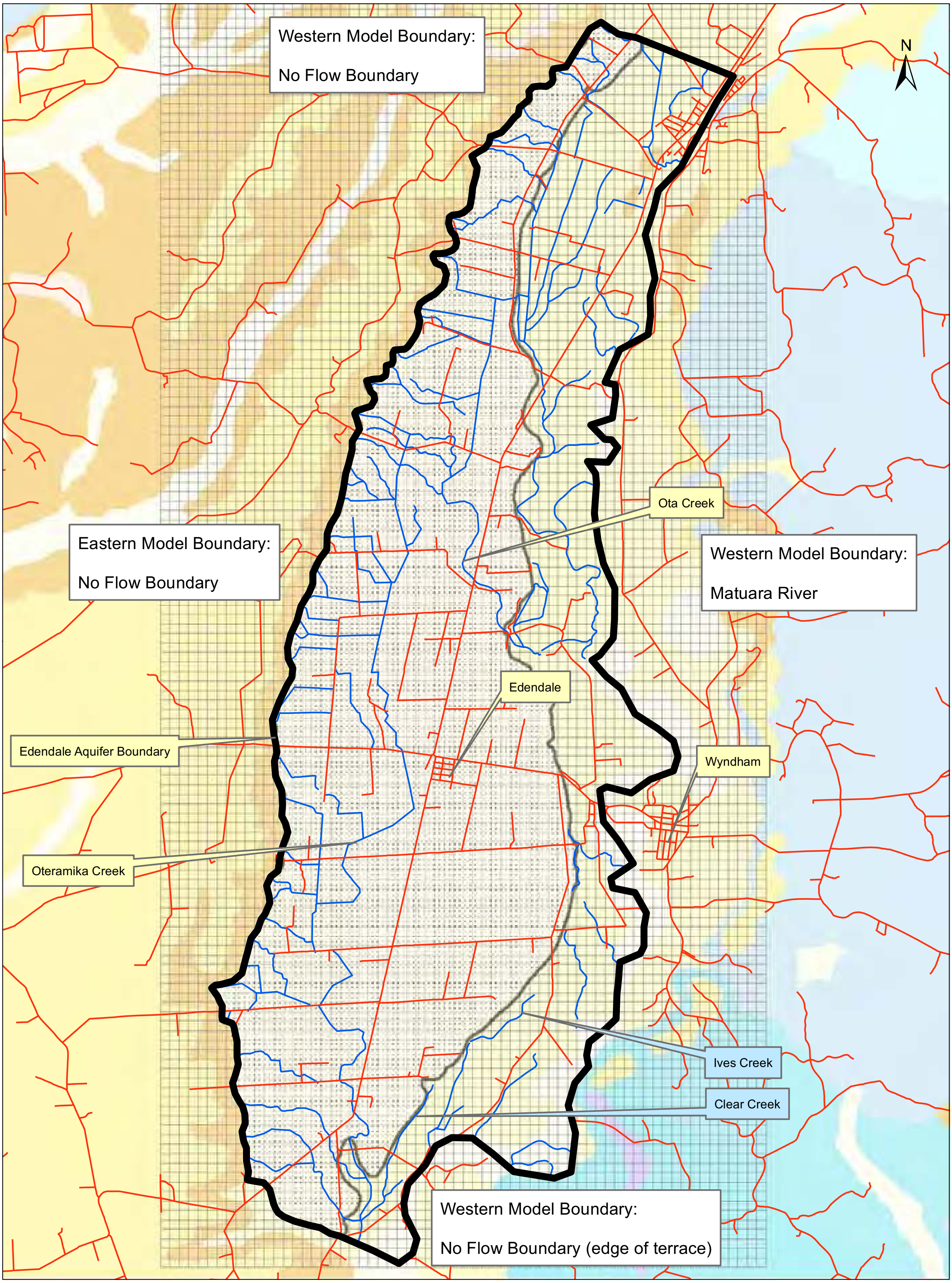

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Figure 23 : Model Grid

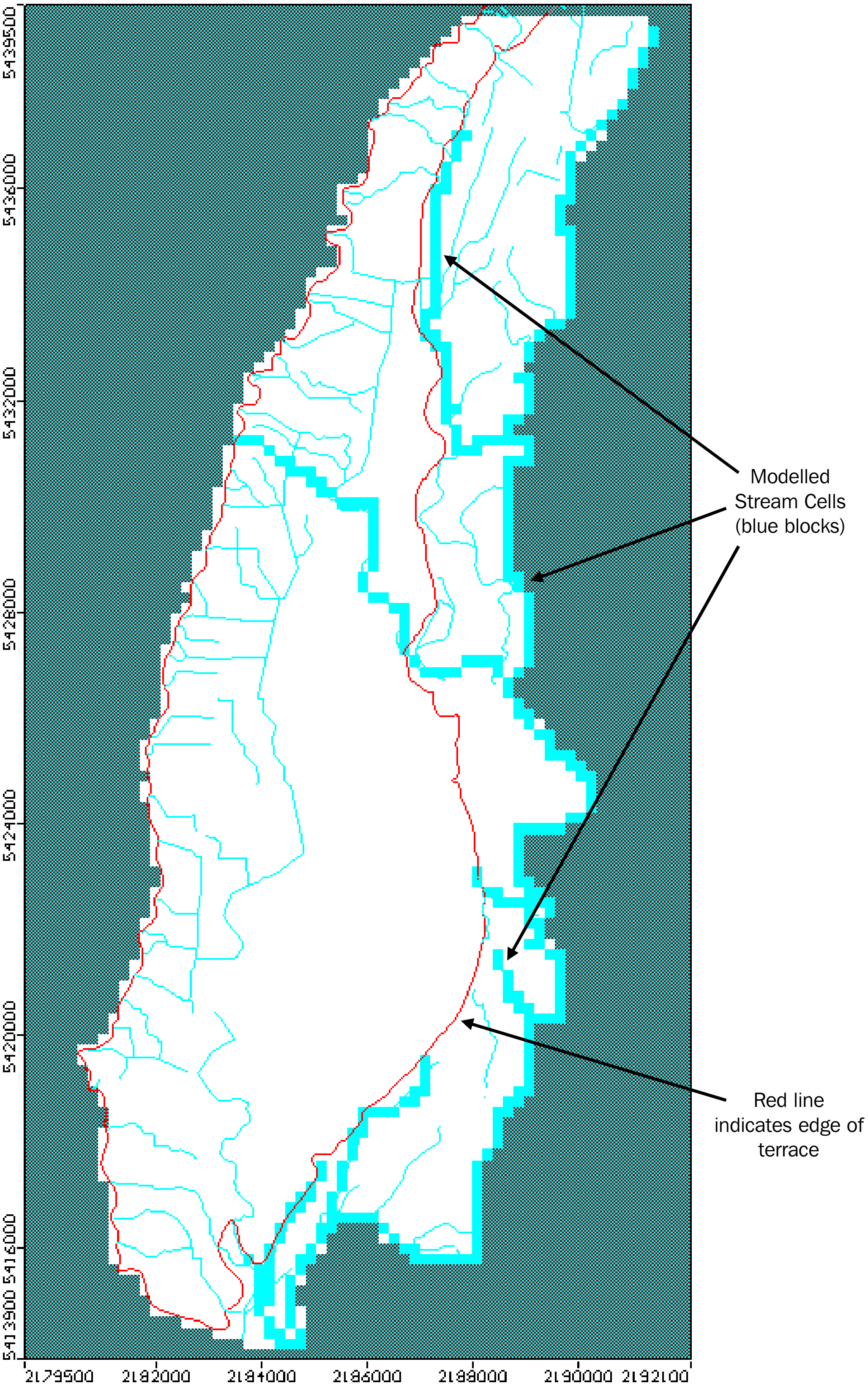

Figure 24: Modelled Stream Locations

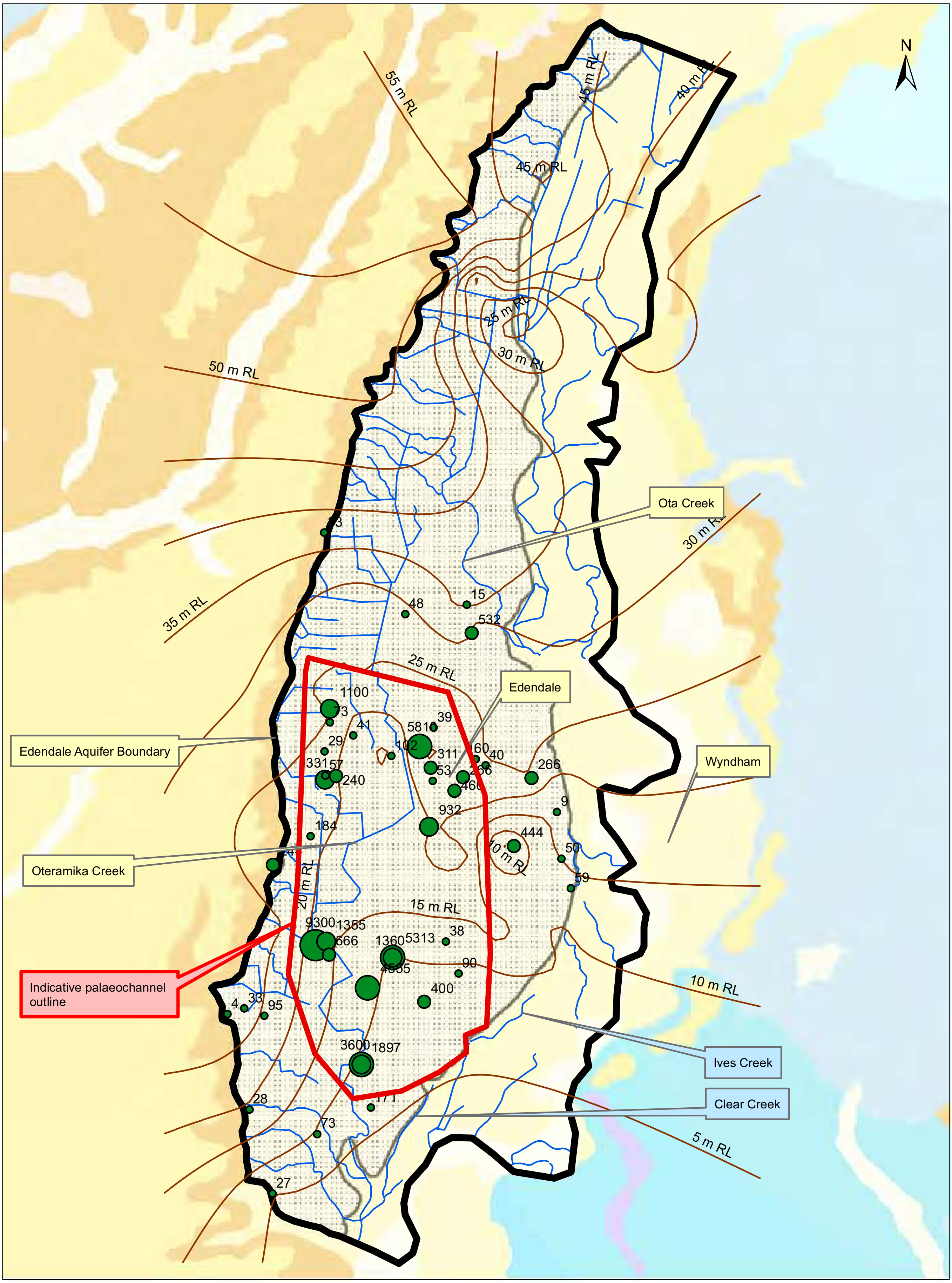

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Figure 25: Transmissivity data and base of aquifer contours

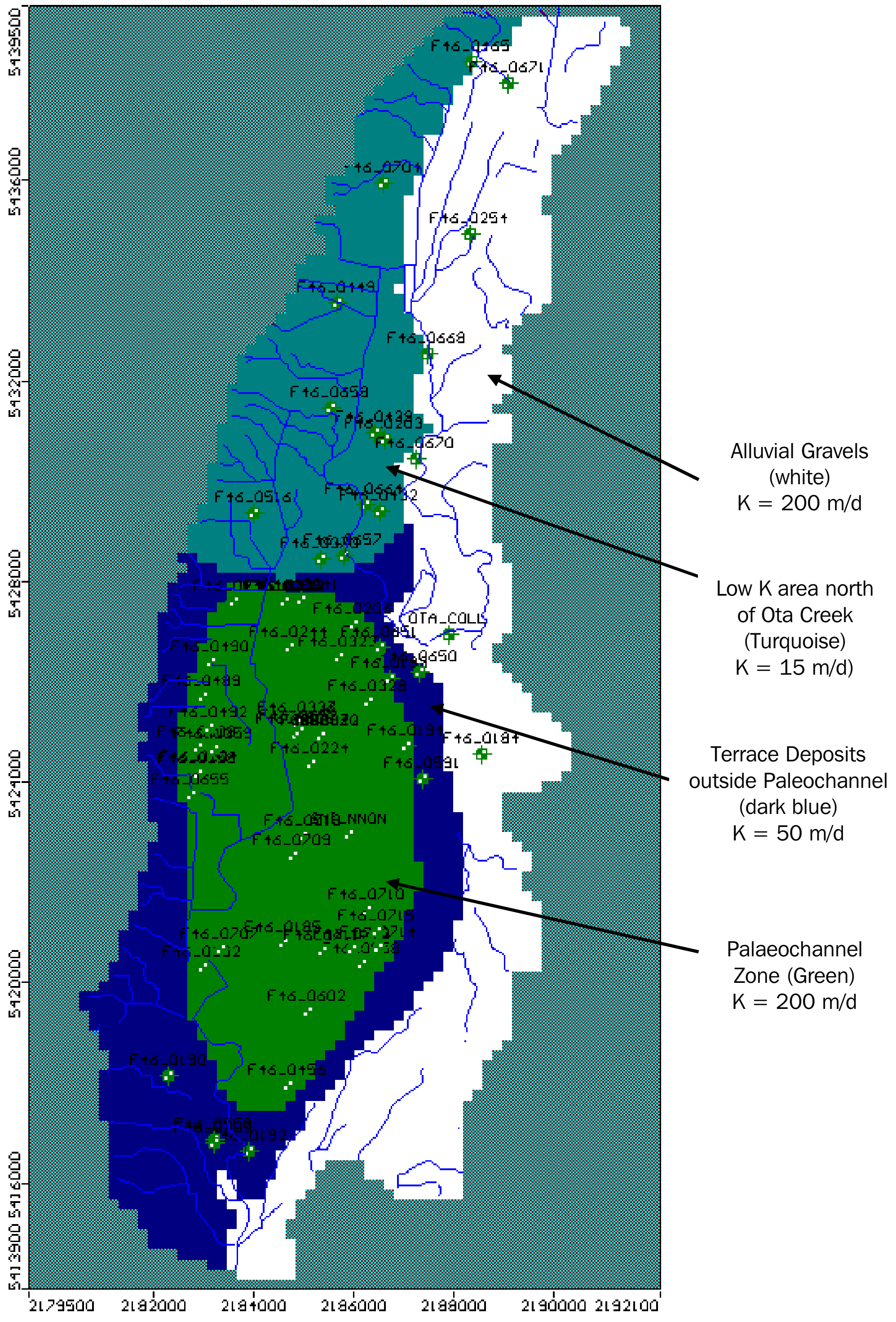

Figure 26: Initial Model Conductivity Distribution

Edendale Groundwater Model: Model Calibration and Contaminant Transport Results

Prepared for
Environment Southland

April 2012

Quality Control Sheet

TITLE	**Edendale Groundwater Model: Model Calibration and Contaminant Transport Results**
CLIENT	Environment Southland
VERSION	Draft
DATE	April 2012
JOB REFERENCE	C02535 500
SOURCE FILE(S)	C02535500_R002i1_ModelCalibration.doc

Prepared by

SIGNATURE

Neil Thomas

Directed, reviewed and approved by

SIGNATURE

Peter Callander

Limitations:

The report has been prepared for Environment Southland, according to their instructions, for the particular objectives described in the report. The information contained in the report should not be used by anyone else or for any other purposes.

Executive Summary

Pattle Delamore Partners Ltd. were engaged by Environment Southland to develop a groundwater flow and contaminant transport model for the Edendale aquifer. The Edendale aquifer is a valuable source of water for a variety of agricultural, industrial and horticultural uses across the area and as such Environment Southland and other stakeholders are keen to protect and maintain the resource. The aim of the model is therefore to provide a tool that simulates variations in water quality and quantity within the aquifer, which can then feed into discussions regarding management of the overall aquifer resource.

The conceptualisation and design of the groundwater model are detailed in a separate report and this report summarises the results of the groundwater flow and contaminant transport model. The results indicate that the model simulates processes occurring within the aquifer well, with groundwater levels and flows represented with reasonable accuracy. Across the main Edendale Terrace (south of the Ota Creek) the model water balance indicates that the majority of recharge emerges in the springs that occur at the southern edge of the model, but approximately 20 % of recharge is lost via seepage from the terrace aquifer to the riparian aquifer adjacent to the Mataura River. Abstraction accounts for approximately 12 % of recharge to the main Edendale Terrace aquifer. The model also indicates that flow from the gravels north of Ota Creek into the main Edendale Terrace provides an additional source of water equivalent to around 5 % of the total inputs to the main terrace aquifer.

A sensitivity analysis indicates that the key parameters controlling the model calibration include the conductivity of the palaeochannel that extends across the main terrace area and the conductivity of the riparian gravels adjacent to the springs in the south of the model. The conductivity of the riparian gravels in the south of the model in particular exert a strong control on spring flows, which are a key output by the which the model calibration can be judged.

Based on the calibrated flow model, a contaminant model was developed with the aim of representing observed fluxes of Chloride and Nitrate Nitrogen, which are the key contaminants of interest in the aquifer. The results of the contaminant model show a good agreement between observed and modelled concentrations. The results of the Chloride modelling suggest that the model represents transport within the aquifer reasonably accurately, and suggests that pore velocities and advective transport in the aquifer is rapid, at rates of around 2 m/d or 730 m/year.

Nitrate inputs to the model are based around landuse and landuse changes through time together with known inputs from the dairy factory wastewater disposal farms. Results from the model appear to match the steady rise in background Nitrate Nitrogen concentrations well, indicating that the approach to modelling Nitrate based on landuse reflects actual processes within the aquifer. Spatial distributions of Nitrate

concentrations across the aquifer also demonstrate the effect of the higher permeability palaeochannel in directing flow within the aquifer.

The calibrated model now provides a tool that can be used to evaluate the effects of future abstraction consents and landuse changes on water quantity and quality within the aquifer. Such information will be very useful for the consideration of future management of the water resources in this area.

Table of Contents

SECTION PAGE

Table of Tables

SECTION PAGE

Appendices

Appendix A- Figures:

1.0 Introduction

1.1 Purpose of this report

This report describes the calibration of the transient groundwater model of the Edendale aquifer, together with the design and results of contaminant modelling based on the flow model. The model conceptualisation and model design is detailed in a previous report, but is summarised briefly below.

Section 2 of this report describes the final parameters used within the model, in terms of hydraulic conductivities and boundary parameters. Section 3 presents simulated groundwater levels compared to observed groundwater levels and simulated spring flow compared to observed spring flows. Modelled water balances are also presented for both the whole model area and the main Edendale groundwater zone, south of the Ota Creek. Section 4 provides a sensitivity analysis together with an assessment of the major, associated uncertainties.

Section 5 of the report details the design and modelling approach for contaminant transport modelling, based on the calibrated flow model and Section 6 provides the results of the transport modelling. Finally, Section 7 summarises the model results and provides recommendations for scenario modelling based on the flow model and transport model.

1.2 Summary of model design

The Edendale groundwater model is designed as a single layer model, the boundaries for which are shown in Figure 1. The model represents gravel terrace deposits overlying relatively low permeability Gore Lignite Measures. The Gore Lignite Measures outcrop to the west, north and south of the model area, forming model ‘no flow’ boundaries. Basement rocks outcrop to the east of the area forming a further no flow boundary. However, the Matuara River flows south along the eastern boundary of the area and, given that there is limited groundwater flow across the river, the line of the Matuara River has been taken as the eastern boundary to the model.

Recharge to the area is calculated based on a soil moisture deficit model, using rainfall data from Woodlands at Garvie Road and PET data from Invercargill Climate Station. Recharge to the aquifer is balanced by discharge via a series of springs in the south of the area. These springs, together with the Maturara River are represented in the model as using the MODFLOW Stream Package. Other boundaries within the model are represented using the appropriate model package, including abstraction wells and recharge. The model has been built using MODFLOW 2000.

The model runs on monthly stress periods from 1995 to 2011 and is based on a 200 m square grid.

2.0 Calibrated Model Properties

2.1 Hydraulic properties and distribution

Figure 2 shows the five hydraulic conductivity zones used within the model, together with calibrated values of hydraulic conductivity. Where available, the zones are based broadly on transmissivity data for the model area, together with a conceptual understanding of processes occurring within the aquifer. The calibrated zones largely follow the zones defined within the model design report with the exception of zone 5, which is discussed below. Note that whilst approximate hydraulic conductivity values were derived manually for each zone, further calibration was achieved using PEST to derive more precise and 'best fit' values. Table 1 summarises the calibrated hydraulic properties used in each zone.

Table 1: Summary Calibrated Hydraulic Properties

Zone number	Location	Hydraulic Conductivity (m/d)	Storage
1	Terrace gravels north of Ota Creek	16	0.15
2	Alluvial Gravels adjacent to Mataura River	60	0.15
3	Palaeochannel	360	0.15
4	Terrace gravels south of Ota Creek	39	0.15
5	Mataura River floodplain	10	0.15

Zone 1 covers the area of the model to the west of the terrace edge and north of the Ota Creek. Hydraulic conductivity within this zone is set to 16 m/d with the value based the lack of wells, indicating low permeability strata, and the need to match observed groundwater levels in the area.

Zone 2 represents the alluvial gravels adjacent to the Mataura River. Alluvial gravels are typically highly permeable and the hydraulic conductivity within Zone 2 is set to 60 m/d.

Zones 3 and 4 represent the Edendale Terrace aquifer south of the Ota Creek and west of the terrace edge. Zone 3 represents the palaeochannel that is thought to run approximately north south across the terrace. The extent of the palaeochannel is based on transmissivity values across the terrace and broadly encompasses the higher transmissivity data. Hydraulic conductivity in this zone is set to 360 m/d. Zone 4 represents the rest of the terrace area, where hydraulic conductivity is set to 39 m/d.

Zone 5 occurs at the southern end of the model and represents the flood plain of the Mataura River adjacent to, and east of, the terrace and the springs that form the discharge point of the aquifer. The conductivity in this zone is set to 10 m/d and is significantly lower than the rest of the alluvial flood plain adjacent to the Mataura River.

The reason for this much lower hydraulic conductivity is based on the mechanism for spring flow along the edge of the terrace. One mechanism for the occurrence of springs would be a sudden change in groundwater elevation at the terrace edge. However groundwater contours within the aquifer indicate a relatively gentle groundwater gradient dipping southwest across the Edendale terrace and groundwater levels some distance back (i.e. west) from the terrace edge are similar to the elevations of the springs at the foot of the terrace, indicating that there is no substantial change in groundwater elevation at the terrace edge, An alternative mechanism to generate spring flow is that there is a change in hydraulic conductivity at the terrace edge and springs occur as a result of lower hydraulic conductivity at the edge of the terrace.

Spring flows resulting from a change in hydraulic conductivity is the mechanism used in the model. The Mataura River flows through a relatively narrow valley in the area of the springs, which may indicate that at times of high flow, flooding may occur which would be contained within the relatively narrow valley. Lower permeability silts would therefore build up in the area, reducing the permeability of the gravels adjacent to the river and therefore causing spring flows. This mechanism appears to fit with the available evidence and hence is used in the model, although no bore log data is available in the floodplain to provide additional support for this mechanism.

The extent of the lower permeability silts is difficult to define and the hydraulic conductivity zone representing these deposits has therefore been delineated based on the occurrence of the springs and the width of the Mataurua River flood plain.

Specific yield is uniform across the model area and is set to value of 0.15.

2.2 Boundaries

The main boundaries within the model are the streams and stream bed conductance was also varied as part of the calibration. The highest stream bed conductance (10 000 m^2/day) was set within the springs that occur at the southern boundary of the Edendale terrace, while lower stream conductances (500 m^2/day) were used for the main line of the Mataura River. Whilst 10 000 m^2/day is a high stream bed conductance for the spring fed streams, it is calculated based on the following formula and values:

$$C = \frac{K.L.W}{M}$$

Where:

C = Stream cell conductance

K = Conductivity of the stream bed material (5 m /d)

L = length of the stream reach (200 m)

W = width of the spring stream (~2 m)

M = Thickness of the stream bed material (0.2 m)

Given the very high conductivity of the aquifer and the gravely stream bed material 5 m/d was considered likely lower estimate of stream bed hydraulic conductivity. Even despite this the stream bed conductance is calculated to be a very high value of 10,000 m^2/day in the stream cells representing the springs. A lower value (500 m^2/day) was used in stream cells representing the Mataura River due to the silty nature of its bed.

3.0 Model Calibration

3.1 Groundwater flow patterns and contours

Figures 3 and 4 present contour maps of modeled and observed groundwater contours for March 2007 (Stress period 145) respectively. The maps show a generally good agreement, particularly over the key Edendale area, where the difference is generally within 1 m.

The difference between observed groundwater levels and modeled levels for March 2007 at various monitoring points is also plotted on Figure 3. Positive differences (shown as blue dots) indicate the observed levels are above modelled levels, whereas negative differences (shown as red dots) indicate the observed levels are lower than the modelled levels.

In general, the plotted differences on Figure 3 indicate that modeled groundwater levels are approximately correct or slightly too high in the area between Ota Creek and north of Edendale town. Conversely, levels are slightly too low in the area south of Edendale town, but are approximately correct close to the terrace margin in the south of the area.

Whilst the match is not perfect, it should be noted that the observed groundwater levels are representative of a particular point in time, whereas the modeled levels represent an average level for the month around the time when the observed groundwater levels were measured. In addition, the modeled levels represent the piezometric level at the center of a 200 m model cell which may not be directly comparable to observed levels at a similar location, both laterally and vertically depending on the screen elevation in the observed bore. Figure 3b (below) plots observed and modeled groundwater levels for March 2007 graphically and shows that there is generally a good match between the simulated and modeled results.

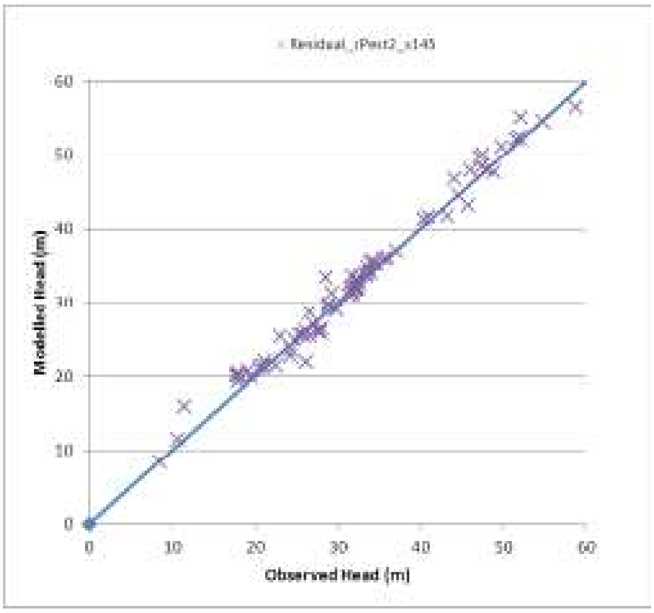

Figure 3b: Modelled versus observed groundwater levels for March 2007.

Overall the match is considered to be a reasonable representation of groundwater levels across the model area.

In the area north of Ota Creek, modeled levels are variably too high and too low, which may reflect undefined heterogeneity in this area. It should be noted that much less data exists to define transmissivity or other hydraulic properties in the area north of Ota Creek and it appears that there is less focus on this area in terms of water resources utilization. As a result, less time has been spent to effect a detailed calibration in this area.

Previous groundwater investigations (Rekker, 1995, Wilson, 2010) have indicated the presence of a groundwater divide in the vicinity of Ota Creek. The results of the model indicate that there is some movement of the groundwater divide location with seasonal changes in recharge. However, in the long term the divide remains largely in the same place, slightly south of the Ota Creek.

3.2 Groundwater level hydrographs

Figures 5a to 5f present modeled and observed groundwater hydrographs for six long term monitoring points across the model area. A map showing the locations of these monitoring points is presented in Figure 6. The hydrographs are split into three groups based on their location across the aquifer area and each group is discussed separately below. Table 2 provides borehole details for each of the monitoring points discussed.

Table 2: Long Term Monitoring Borehole Details

Bore number	Owner	Depth (m) (Screen details unknown unless stated)	Diameter (mm)	Monitoring frequency	Measured Average depth to water (m)
F46/0185 (Group 2)	The Grange LTD C/- J R Hall	14.00	100	Monthly	6.49
F46/0190 (Group 2)	ND Rayner	10.00	50	Monthly	5.80
F46/0192 (Group 3)	M Howden	15.00	50	Monthly	9.81
F46/0193 (Group 1)	DC (Clark) McLeod	11.80	150	Monthly	11.19
F46/0203 (Group 3)	K & T Norman	7.70	75	Monthly	5.69
F46/0250 (Group 1)	Environment Southland	18.00 (Screened from 17 m bgl to 17.7 m bgl)	100	Automatic	12.84

The comparison between modeled and observed groundwater levels fall into three different groups, as described below:

Group 1

Monitoring points F46/0250 and F46/0193 (Figures 5a and 5b) are both located within the main Edendale terrace, between the Ota Creek and Edendale town. As noted above, modeled groundwater levels in this area are slightly above observed levels, and this difference reflected in the hydrographs, both of which are approximately 1 m above the observed level. However, the modeled hydrograph response is a good fit to the observed magnitude of response and the model appears to reasonably simulate absolute changes in water level as a result of seasonal changes in recharge.

Group 2

Monitoring points F46/0185 and F46/0190 (Figures 5c and 5d) are located within the main body of the Edendale Terrace south of Edendale Town. Modelled water levels at F46/0185 are below the observed level by approximately 1.5 m but levels at F46/0190 are a good fit to the observed data. Similarly to the hydrographs in Group 1 above, the seasonal simulated response is a good fit to the observed response.

Group 3

Whilst the two monitoring points in group 3 (F46/0192, Figure 5e and F46/0203, Figure 5f) are spatially separated, they are grouped together here because both are located close to the edge of the terrace and exhibit a smaller range of groundwater level fluctuations compared to the hydrographs in Groups 1 and 2. The modeled levels at both these boreholes are a good fit to the observed levels, with absolute levels around 1 m above observed levels in F46/0192 but very close to observed levels in F46/0203.

The muted response in both is interpreted to be a result of the buffering effect of groundwater discharge to springs in the vicinity of both boreholes. This muted response is closely simulated in both boreholes, suggesting that the model reproduces the buffering effect reasonably well.

3.3 Stream hydrographs

Stream hydrographs for Clear Creek, Ives Creek and an unnamed spring at Shield Road are presented in Figures 7a and 7b respectively.

Observed flow measurements are available at three different points along Clear Creek, although records for the most downstream point (Oteramika Creek confluence) are only available between 1995 and 1998. Figure 7a indicates that modeled flows at the perennial source of Clear Creek are somewhat overestimated, although it should be noted that modeled flows represent stream gain across a 200 m stream reach, rather than representing flows at the source. Further downstream, modeled flows are much closer to observed flows, indicating that the simulated stream gains approximately the correct amount between its modeled source and the gauging point at Mataura Island Road.

Figure 7b indicates that simulated flows along Ives Creek are a good match to observed flows, particularly downstream at the confluence with the Mataura River, although inevitably some peak flows are underestimated in the model, because the groundwater seepage primarily only contributes to the baseflow in the stream. Similarly to Clear Creek, flows at the source of Ives Creek are somewhat overestimated. Figure 7b also shows a plot of simulated flows at the unnamed spring at Shield Road, which is located to the north of Ives Creek. The simulated flows at this point are a good match to observed flows.

3.4 Model water balance

The overall water balance for the entire model area is presented as a timeseries in Figure 8 and a steady state water balance for the entire model area is presented in Table 3.

Table 3: Steady State Water Balance for Total Model Area

Inputs (m^3/day)			
Recharge	Stream Loss	Wells	Total
94575.39	1158.0	0	95733.4
Outputs (m^3/day)			
Recharge	Stream Gain	Wells	Total
0	88720.2	7012.4	95732.6

Table 2 indicates that the water balance closes without any significant discrepancy between inputs and outputs. The majority of water applied to the model as recharge finds its way out via streams, with a minority taken as abstraction.

Figure 9 shows the estimated catchment area of the springs that drain the terrace aquifer and Figure 10 presents a water balance for this catchment zone for the length of the model run. A summary of the water balance, based on steady state rates is presented in Table 4.

Table 4: Steady State Water Balance for Edendale Terrace Aquifer area

Inputs (m3/day)				
Recharge	Stream Loss	Wells	Flow into catchment from north	Total
54,312	0	0	3,182.2	57,494
Outputs (m3/day)				
Recharge	Stream Gain[1]	Wells[2]	Flow from terrace into alluvial gravels	Total
0	39,149	7,012.4	11,333.9	57,494

Notes:
1. Stream gain excludes groundwater discharges to stream cells located on the riparian aquifer.
2. Abstraction and recharge based on 2007 average rates

Table 4 indicates that the majority of water applied to the Edendale Terrace area leaves the terrace via the springs located at its southern boundary. However approximately 20 % of recharge exits the terrace as seepage into the adjacent riparian aquifer. In addition, a small proportion (5 %) of the total inputs into the Edendale terrace aquifer occur as flow from the Ota Creek catchment to the north.

4.0 Model sensitivity analysis and uncertainty

Groundwater models suffer from the fact that a solution using parameters that provide a good fit to the observed data may not be unique, in that alternative combinations of parameters could provide an equally good fit to observed groundwater levels and spring flows. This problem of non-uniqueness is usually minimized using a variety of observation points across the model area, and transient models are less prone to this problem than steady state simulations due to their more detailed set of observations which constrain the combinations of parameters that can replicate the observed data.

One way in which the uncertainty in model parameters can be evaluated is by assessing the sensitivity of the model results to changes in particular parameters. In general, parameters to which the model is highly sensitive tend to be better constrained, provided the parameter values fall within conceptual limits. Table 5 provides a list of the key parameters used in the model, together with an indication of the model sensitivity to the value of that parameter.

Table 5: Sensitivity Analysis.

Model Parameter	Sensitivity (and effect)	Conceptual Range of values (and selected value)	Resulting Range in RMSE[1] values for Heads (RMSE for selected value)	Resulting Range of RMSE[2] values for Flows (RMSE for selected value)
Conductivity Zone 1 (Terrace gravels north of Ota Creek)	Medium (heads north of Ota Creek)	10 m/d to 25 m/d (16 m/d)	0.019 (0.185 to 0.166) (0.170)	0 (6.1 to 6.1) (6.1)
Conductivity Zone 2 (Alluvial Gravels adjacent to Mataura River)	Low	30 m/d to 70 m/d (60 m/d)	0.015 (0.178 to 0.163) (0.170)	0.3 (5.8 to 6.1) (6.1)
Conductivity Zone 3 (Palaeochannel)	High (heads and stream flows)	200 m/d to 400 m/d (360 m/d)	0.146 (0.316 to 0.17) (0.170)	4.3 (9.6 to 5.5) (6.1)
Conductivity Zone 4 (Terrace gravels south of Ota Creek)	Medium	20 m/d to 80 m/d (39 m/d)	0.005 (0.185 to 0.180) (0.170)	0.3 (5.9 to 6.2) (6.1)

Continued Overleaf

Table 5: Sensitivity Analysis.

Model Parameter	**Sensitivity (and effect)**	**Conceptual Range of values (and selected value)**	**Resulting Range in RMSE[1] values for Heads (RMSE for selected value)**	**Resulting Range of RMSE[2] values for Flows (RMSE for selected value)**
Conductivity Zone 5 (Mataura River floodplain adjacent to springs)	High (stream flows)	5 m/d to 30 m/d (10 m/d)	0.020 (0.190 to 0.17) (0.170)	3.4 (5.4 to 8.8) (6.1)
Stream bed conductance	Medium (stream flows)	400 m/d to 10 000 m/d (10 000 m/d)	0.020 (0.19 to 0.17) (0.170)	3.3 (9.4 to 6.1) (6.1)
Specific yield	Medium (groundwater level response /stream flows)	0.05 to 0.2 (0.15)	0.005 (0.199 to 0.204) (0.170)	0.9 (7 to 6.1) (6.1)

Notes:

1: RMSE represents the Root Mean Squared Error comparing modelled groundwater levels to observed groundwater levels recorded around March 2007. A smaller number indicates closer agreement between modelled and observed groundwater levels.

2: Whilst the RMSE value for stream flows is comparatively large compared to the RMSE for heads, this is due to the difficulty of matching peak flows, which skew the results towards a larger RMSE.

3: The final RMSE value in the model was 0.17 for heads and 6.1 for flows.

Table 5 indicates that the two key parameters to which the model is most sensitive are the conductivity of the palaeochannel and the conductivity of zone five, which represents the Mataura River floodplain where it is adjacent to the springs. Streambed conductance is also a sensitive parameter affecting the modeled stream flows. In general the values selected for the calibrated model are those that resulted in a lower RMSE while remaining within conceptual limits.

However, whilst the sensitivity analysis is an effective way of illustrating the effect of different parameters on the model calibration, it should be noted the overall calibration depends on the effect of an optimum combination of all parameters. In some cases a change to parameters can result in an improvement in one area, but a worse result in others which is an effect that may not be captured in a single number representing the 'fit' of the model.

Therefore, whereas increasing the hydraulic conductivity beyond 400 m/day in the palaeochannel may improve the overall RMSE, modeled groundwater levels tend to increase towards the north of the main terrace area whilst reducing further towards the centre of the aquifer. In addition, the very high values required are not justified by pumping test data and also results in groundwater contours that are strongly influenced by the shape of the palaeochannel, which is not apparent in contours based on observed data.

Limited data is available to help constrain the value of conductivity in the riparian gravels close to the springs at the southern end of the aquifer. Given the strong influence of the value of conductivity in this zone, the conductivity of zone 5 is one of the key uncertainties in the model where further information may be valuable.

5.0 Contaminant Modelling

This section of the report aims to summarise the conceptual understanding of contaminant transport within the Edendale Aquifer, focussing primarily on Chloride and Nitrate as the two contaminant species of concern within the aquifer and the results of contaminant modelling of those species. The conceptual understanding of contaminant transport revolves around the history of contamination, in terms of initial concentrations of contaminants and the location of contaminant loading within the aquifer.

Contaminant transport is to a large extent also dependent on the flow regime which is described above. Note that Environment Southland (Wilson, 2010) produced a detailed technical report for the Edendale Aquifer, which includes information on the history of contamination within the aquifer and the summary below draws on this report.

Sections 5.2 and 5.3 of this report detail the pattern of contamination for Chloride and Nitrate, together with a description of the modelling approach used to represent the patterns of contamination.

Section 6 presents the results of Chloride and Nitrate modelling together with conclusions based on the modelled patterns of contamination seen in the aquifer.

5.1 Selection of Modelling Code

Various modelling codes are available to represent the movement of contaminants through an aquifer, however, given that the flow model was developed using MODFLOW 2000, an appropriate choice would be a modelling code that is compatible with that flow model. Two main codes are available, ranging from the relatively simplistic particle tracking program MODPATH, to the more sophisticated MT3DMS, which allows consideration of dispersivity, retardation and sorbtion, and contaminant decay processes.

Both Chloride and Nitrate N are conservative species, in that neither undergo significant retardation within the aquifer matrix and therefore the main process by which the concentration of both the contaminants reduces is dispersion. Given that MT3DMS simulates dispersion and that reasonably good data is available for contaminant concentrations through time, allowing dispersion values to be calibrated and refined, the most appropriate code is therefore considered to be MT3DMS.

5.2 Chloride

5.2.1 Pattern of Chloride Concentrations

Chloride is a relatively conservative contaminant, in that it undergoes limited decay and retardation within an aquifer. The main process by which Chloride moves through an aquifer is therefore advective transport and dispersion. Natural sources of Chloride include rainwater and mineralisation from rock and water interaction; however, high Chloride concentrations tend to be from anthropogenic activities, including wastewater and effluent discharges. As such Chloride is often used as an indicator of overall water quality.

Figure 11 shows the maximum concentration of Chloride at different sites across the Edendale area. In general the highest concentrations are seen around Edendale Town, with a maximum concentration of 296 mg/L at F46/0246. Concentrations south and east of the town generally decrease, with the lowest concentrations seen in boreholes close to the southern end of the aquifer. Long term monitoring for Chloride at borehole F46/0336 is presented in Figure 12a, together with other relevant boreholes (F46/0246 and F46/0344, Figure 12b and 12c) and indicates a clear 'breakthrough' curve, with a steady increase in Chloride concentration from 1997 to 2002, followed by a steady decrease from 2002 to the present. Breakthrough curves typically indicate the passage of a plume of contaminant moving through an aquifer. The timing of the breakthrough curve suggests that the source of contamination occurred before 2002. Interestingly the maximum concentration at F46/0336 occurs in 2001, after the maximum concentration at F46/0246, which occurs in 2000, despite F46/0246 being located downgradient of F46/0336, suggesting the presence of aquifer heterogeneities in this area.

Further downgradient of the farm, Chloride concentrations in borehole F46/0709 (Figure 3d) indicate the passage of a relatively dispersed plume, with concentrations at this borehole showing a broad peak of around 110 mg/L from 2001 to 2003, before steadily declining to the present levels of around 50 mg/L.

The pattern of Chloride concentrations both spatially and temporally is consistent with the known history of Chloride contamination within the aquifer. Mararua Farm, located some 2 km north west of Edendale Town is used for dairy effluent disposal and during the 1990's some problems were experienced with regard to nutrient leaching at the site with elevated concentration of Chloride, Nitrate and Sodium detected in groundwater.

Partly to overcome these issues an additional site for wastewater disposal was purchased at Inglemere Farm, located some 2km south of Edendale town. In addition, land management practices were also refined at the disposal farms and the dairy factory wastewater also underwent additional treatment resulting in lower concentrations of leached Chloride. This pattern of Chloride leaching to a relatively high concentration for a number of years, followed by a subsequent reduction is reflected in the borehole concentration patterns, and suggests the passage of a slow moving plume.

Data from borehole F46/0335, located up gradient of the Mararua Farm, indicates that background concentrations in groundwater are around 30 mg/L to 45 mg/L. Concentrations in boreholes located downstream of the Mararua Farm have reduced to similar levels, suggesting that the plume of Chloride has passed through and that limited Chloride contamination is taking place at the farm.

5.2.2 Modelling Approach

The conceptual understanding above can be represented in the model as a constant concentration source of Chloride applied to the aquifer at the location of the Mararua Farm. Based on the available evidence, it seems likely that this source was present at least from 1995 (which is the start date of the flow model) until around 2000, when Inglemere Farm began to be used for effluent disposal.

No data regarding the timing of wastewater application between 1995 and 2000 is available, however, wastewater production from the dairy factory would be relatively constant through the year, and therefore wastewater disposal is considered to be relatively constant through the year.

Concentrations within the modelled source are therefore set to peak between around 2000. Beyond 2000 the concentration at the source is modelled as gradually reducing until 2004 to represent the effect of Chloride within the unsaturated zone flushing through the aquifer and the impact of reductions in Chloride concentrations in dairy effluent begin to take effect. In conjunction with dispersivity parameters, the source concentration of Chloride was altered until a best fit was achieved to the observed data. Independent information of the source concentration of Chloride applied to the dairy factory wastewater disposal farms was not available.

5.3 Nitrate Nitrogen

5.3.1 Pattern of Nitrate Nitrogen Concentrations

Similarly to Chloride, Nitrate N is also a relatively conservative contaminant after it passes beyond the soil root zone, in that it undergoes limited transformation within an aquifer and experiences relatively limited retardation. The main process by which concentrations will reduce with distance from a source and time is therefore via dispersion.

Nitrate N is required to support plant growth, but where Nitrate N is in excess of plant requirements it can leach from the soil profile into the underlying groundwater. Some leaching can occur naturally, but in cases where fertiliser is applied to fields, or Nitrate N rich water from irrigation is applied, leaching rates can increase.

Figures 13a, 13b and 13c show maximum Nitrate N concentrations for samples within the Edendale aquifer in 1996, 2000 and 2005 respectively, with the land use distribution for the same year also shown on the same plot. The plots illustrate the change of landuse from sheep and beef to dairy and suggest a steady rise in Nitrate N concentrations, implying a possible link between Nitrate N concentrations and landuse. However it should be noted that the change is not consistent across the whole model area; in some areas a significant conversion to dairy landuse appears to have had no immediate effect on measured Nitrate N concentrations, particularly in the west of the area.

The plots also illustrate a cluster of higher Nitrate N concentrations to the south of Mararua wastewater disposal farm, which may reflect a Nitrate N plume emerging from the farm. However, it is notable that similar plumes do not appear to be present around Leondale Farm or Inglemere Farm, suggesting that farm management is effective at mitigating Nitrate N leaching. It is also notable that the cluster of high values around the south of the Mararua Farm seems relatively static, with little change between 1996 and 2005, which could imply that either contamination from the site is continuing, or Nitrate Ns are long lived within the aquifer matrix.

Given the history of landuse change within the catchment and the complicating factor of wastewater disposal from the dairy factory at several sites around the area, Nitrate N pollution within the Edendale Aquifer is inevitably complex and difficult to constrain on a spatial basis, particularly in terms of Nitrate N loading rates through time.

A plot showing the locations of long term monitoring boreholes across Edendale is shown in Figure 14. Figures 15a, 15b, 15c and 15d show Nitrate N concentrations measured in groundwater from bores around the the Edendale area located away from the dairy effluent disposal farms which indicates that these bores show a steady rise in Nitrate concentrations (F46/0335, F46/0709 and F46/0185) with an increase from an average of 6 mg/L in 2000 to an average of 8 mg/L in 2010. All these three boreholes are located largely away from the dairy factory wastewater disposal farms and are considered to show background concentrations. The steady rise in concentrations may be related to the steady increase in dairy farm landuse across the model area, as dairy farms typically result in relatively higher Nitrate N loading compared to other landuses such as sheep and beef, which has decreased at the expense of dairy farming.

Figures 16a, 16b, 16c and 16d show Nitrate N concentrations in four boreholes located close to the southern end of Maraura Dairy Effluent Farm (F46/0335, F46/0246 and F46/0344). All three boreholes show similar patterns of Nitrate N concentrations, rising from around 7 mg/L in 1997 to 11 mg/L in 2006 / 2007. Since 2006 / 2007 Nitrate N concentrations in all three boreholes appear to have stabilised or reduced to around 9 mg/L, perhaps indicating that concentrations in the source of upgradient Nitrate N have also reduced or stabilised.

Figure 17 shows a plot of maximum measured nitrate concentrations for 2009 for boreholes across the Edendale aquifer. It shows that the highest concentrations appear to be around the Edendale township with an overall progressive reduction in concentrations towards the southern end of the aquifer, albeit with higher values around the Inglemere dairy factory wastewater disposal farm. This distribution of concentrations seems to reflect conceptual expectations of the occurrence of nitrate in the aquifer, with higher values appearing around the wastewater disposal farms

Nitrate leaching rates and concentrations are well documented for the effluent disposal farms (Mararua, Inglemere, Leondale and Pedrian) at least since 2001 and data has been made available for average Nitrate N concentrations and leaching rates (based on concentration data) across each farm between 2001 and 2010 on a monthly basis. A summary of leaching rates are presented Figure 18a, which shows that leaching rates are seasonal, with higher leaching rates in winter. Notably higher leaching rates are observed at Inglemere Farm compared to the other farms, where leaching rates appear to have peaked at 123 kg N / ha / month. Concentrations of Nitrate within leachate are shown in Figure 18b, which indicate that Nitrate concentrations within leachate vary, although peaks in concentration do not appear to correspond to peaks in the loading rate. In general, concentrations of nitrate in leachate appear to show a gradual decline from 2004 to 2010.

Nitrate loading rate for other areas of the model area based on landuse. Table 6 provides typical Nitrate N concentrations in leachate for different types of landuse across the model area. Concentrations are based on values used by Rekker (1998), together with more recent data in Monoghan (2010).

Table 6: Average Nitrate Concentration per landuse

Landuse	Concentrations (mg/L N)	Source
Sheep and Beef	2.6	Rekker (1998)
Dairy[1]	13.7	Monaghan (2010, Rekker (1998)
Dairy Factory Effuent[2]	25.2	Rekker (1998)
Forestry Nursery	2.8	Rekker (1998)
Residential	16.3	Rekker (1998)
Industrial	0	Rekker (1998)

Notes:

1. 13.7 mg/L is an average to high rate for dairy landuse. More detailed information regarding dairy farm intensity is not available to distinguish between higher or lower concentrations.

2. Values used from 1995 to 2001 prior to measured data available from 2001

5.3.2 Modelling Approach

The conceptual understanding of Nitrate concentrations indicates that Nitrate N does not move into groundwater via discrete locations, originating instead from diffuse areas, albeit with some locations contributing more than others, for example dairy factory wastewater disposal farms. Diffuse sources of contaminants can be represented in the model as concentrations within the recharge applied to the model.

There is limited evidence to indicate that Nitrate N concentrations vary seasonally within leachate and therefore concentrations applied to the model are modelled as being constant (apart from dairy factory effluent, where monthly measured concentrations are available). However, the data indicate that changing landuse is likely to have an impact and this change is taken into account in the model. Landuse data is available in five year blocks and the landuse distribution is modelled as remaining constant within the time period of each block. Data for four blocks are available:

- 1995 to 2000 (based on landuse data from 1992, Figure 13a);
- 2000 to 2005 (based on landuse data from 2000, Figure 13b);
- 2005 to 2010 (based on landuse data from 2005, Figure 13c); and
- 2010 to 2011 (based on landuse data from 2010). Note that the model run ends in 2011.

6.0 Contaminant Modelling Results

In general the results of the contaminant transport modelling indicate that the model represents processes within the aquifer relatively well, with good agreement between modelled concentrations and observed concentrations for both Chloride and Nitrate. Some discrepancies are notable, for example within the relatively dense network of monitoring boreholes to the south of the Mararua dairy factory wastewater disposal farm, suggesting that there may be local scale heterogeneities which are difficult to represent within the model.

6.1 Chloride

The results of Chloride modelling are presented in Figures 19a to 19d.

Figures 19a, 19b and 19c shows Chloride concentrations for boreholes immediately downgradient of Mararua Farm. The observed concentrations for these bores are a good match to the observed concentrations, with the breakthrough curve and subsequent tail reasonably represented in bores F46/0246 and F46/0344 although the breakthrough curve in bore F46/0336 is less accurately represented. The difficulty in representing the breakthrough curve in bore F46/0336 may be a result of aquifer heterogeneities noted above in Section 5.2.1; bore F46/0336 is located upgradient of F46/0344 (where the breakthrough curve is well represented) and F46/0246, where the breakthrough curve is also closely modelled. Yet the peak of the breakthrough curve at bore F46/0336 appears to be later than the downgradient bores, suggesting that relatively small scale changes within the aquifer in this area may be responsible and may slow movement of contaminants around this borehole.

Further downgradient of Mararua Farm observed Chloride concentrations in borehole F46/0709 indicate the passage of a relatively dispersed plume, where concentrations appear to peak in 2001-2001 and subsequently reduce. The model shows relatively good agreement with concentrations within this borehole (Figure 19d), with a peak in concentrations around 2001 and a subsequent decline, although the rate of decline in the model is faster compared to observed concentrations.

Note that no background concentration of Chloride within groundwater is represented in the model. Concentrations in a borehole (F46/0335) upgradient of Mararua, where the effects of the dairy factory wastewater disposal are limited, indicate a background concentration of around 35 mg/L to 45 mg/L Chloride and to mimic the effect of background levels of Chloride, 45 mg/L has been added to the modelled concentrations.

Figure 20 shows a series of plots indicating the spatial extent of the Chloride plume in the aquifer at different model stress periods, together with the location of the modelled Chloride source. The plot indicates the plume extent after 5 years (i.e. January 2000, representing the final period of Chloride contamination as a result of dairy effluent at Mararua Farm), 10 years (January 2005) and 15 years (August 2010) and shows that the plume migrates relatively rapidly through the aquifer, with some effects from the plume reaching the springs discharging the aquifer within 5 years. After 10 years concentrations of Chloride within the aquifer are significantly reduced and after 15 years the model indicates that concentrations of Chloride as a result of the plume are all but gone. The model indicates that the majority of Chloride would eventually exit the aquifer via spring discharge, which is in keeping with the conceptual model of the aquifer.

Modelled concentrations of Chloride in groundwater discharging to the spring flows for Ives Creek and Clear Creek are presented in Figure 21. The figure indicates that the model predicts that concentrations of Chloride would be higher at Ives Creek (12 mg/L) compared to Clear Creek (8 mg/L), suggesting that the plume of Chloride originating from Mararua Farm would discharge principally via Ives Creek. There is limited observed data to compare against modelled predictions of Chloride concentrations at the springs; Rekker (1995) provides concentrations of around 25 mg/L at both Ives Creek and Clear Creek, which is somewhat higher than predicted by the model. However, the modelled results do not account for background concentrations of Chloride, which would result in lower modelled concentrations.

6.2 Nitrate Nitrogen

The results of Nitrate N modelling are presented in Figures 22a to Figure 22h and Figure 23 shows the spatial distribution of concentrations across the model area for 2009.

The timeseries plots in Figures 22a to 22d for boreholes that are located some distance from the dairy farms (F46/0185, F46/0194, F46/0355 and F46/0709) and are considered to represent background concentrations within the aquifer, are a good fit to the observed data, suggesting that the modelled representation of landuse changes, and accompanying increases in Nitrate N leaching, is consistent with observed changes. Note that the results for borehole F46/0335 are likely affected by numerical dispersion issues; in the model, it is possible for contaminants to disperse upgradient as a result of the way the transport equations are solved and to maintain mass balances (Zheng, 1999).

The timeseries plots for boreholes that are located close to and downgradient, of Mararua Dairy Effluent Farm (F46/246, F46/0249, F46/336 and F46/344, Figures 22e to 22h) show the effects of Nitrate N that likely originates from the Dairy Effluent Farm, with observed concentrations showing a steady rise from 1996 until 2000-2001 before appearing to subsequently reduce slightly or stabilise. Modelled concentrations also show a steady rise until 2000, but in contrast to the observed concentrations, subsequently show a gradual decline. The decrease in modelled Nitrate N concentration is a reflection of steadily decreasing concentrations seen in leachate from Mararua Farm, which is likely to be the primary source of Nitrate seen in these boreholes. That these decreases are not seen in the observed data suggests that an additional source of Nitrate may be present or enhanced recharge is occurring across the Mararua Farm (which would result in a higher Nitrate flux into the model), which is not represented in the model. Note that effluent disposal volumes for the dairy factory wastewater disposal farms have not been provided and are currently estimated based on abstraction volumes.

Figure 23 shows the spatial distribution of Nitrate N for 2009. The plot indicates that there are some inconsistencies between the observed and modelled spatial distribution.

However, in general the pattern of modelled Nitrate N concentrations mirrors landuse distributions across the model and also reflects the conductivity used across the model area. Areas of higher modelled Nitrate N concentrations occur predominantly under dairy farms, for example north of the Ota Creek and in the south-western corner of the model. Concentrations are particularly high in the south-eastern corner of the model, which in part may be due to the long term use of this area as a dairy farm, but may also reflect the passage of some contaminants from the terrace aquifer into the riparian aquifer, which would in effect increase the loading in this area, resulting in higher concentrations.

The model also indicates that the higher conductivity zones, particularly the palaeochannel, exert relatively strong controls on the pattern of contamination within the aquifer. Contamination that occurs upgradient of the palaeochannel tends to be focussed into the palaeochannel, where concentrations slowly increase. Contamination is then discharged into the springs, which is consistent with the conceptual model of processes within the aquifer.

Concentrations of Nitrate in Clear Creek and Ives Creek are presented in Figure 24, together with calculated loading rates based on flows at the springs at their downstream confluences (with Oteramika Creek and the Matuara River respectively). Concentrations of nitrate are broadly similar to concentrations seen in boreholes within the aquifer measuring background concentrations of Nitrate and follow the same gradually rising pattern.

Whilst no long term data is available for nitrate concentrations in the springs, spot measurements made in 2006 are similar to the modelled values. Nitrate in Ives Creek at the Island Edendale Road site was measured at 8.3 g/m^3 in 2006 and 7.6 g/m^3 in Clear Creek, agreeing well with a modelled concentration of nitrate in groundwater discharging to the springs of approximately 7 g/m^3. Total loading rates are similar in both springs, rising to around 200 kg N / day by the end of the model run in 2011.

7.0 Conclusions and recommended scenario runs

Modelled groundwater levels are generally a good match to observed groundwater levels throughout the model. In addition, the results of the contaminant model show a reasonably close agreement between modelled concentrations and observed levels. Taken together, these results indicate that the model represents the hydrogeological processes that occur in the aquifer well, particularly in the main Edendale area. Nonetheless, some areas of the model, particularly in the north of the model have limited observed data with which the model can be compared, and the calibration in these areas is consequently less certain.

Given the confidence of the model results in representing historical observations, the model can therefore subsequently be used to predict how the aquifer may behave under different stresses. Typically, scenario runs for water management assessments on groundwater levels and spring flows include the following:

- **Fully consented**: i.e. all abstractions operating at their fully consented rate;

- **Naturalised**: i.e. abstraction rates set to zero;
- **Recent Actual**: Model run using historic recharge rates, together with abstraction rates based on the last few years of data, so that impact of current (or new) abstractions can be evaluated against a variety of recharge rates; and
- Impacts of climate change on recharge volumes- i.e. changes in rainfall patterns and potential evaporation.

The model can also be used to assess impacts on water quality within the aquifer under a variety of different scenarios for example;

- Landuse changes- predicted impacts as a result of continued conversion of sheep and beef landuse to dairy farming; and
- Impacts of different management practises on reducing the overall contaminant loading to the aquifer, particularly with regard to dairy farming practises and nitrate loading.

8.0 References

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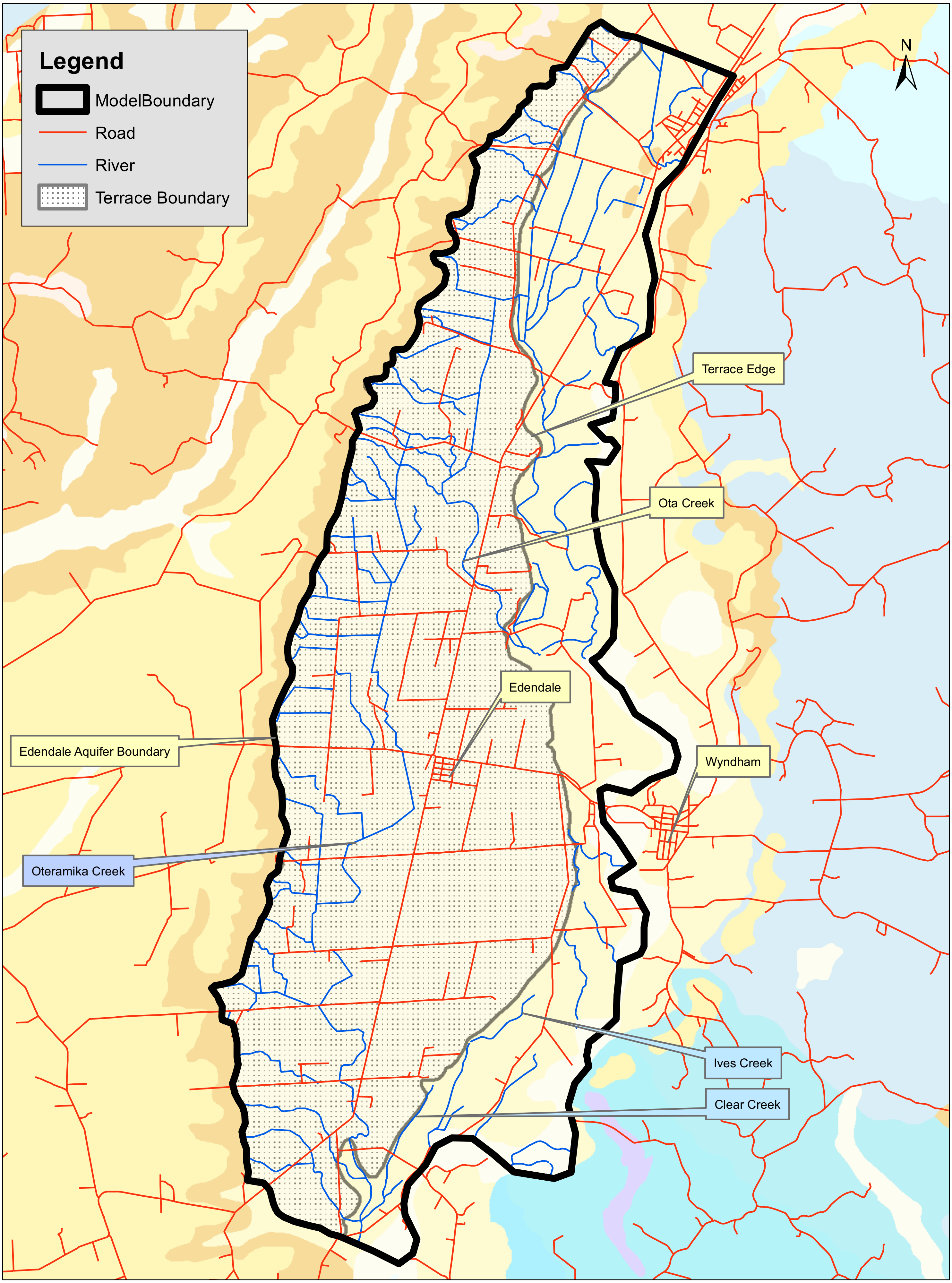
Monaghan, R., M., et al. 2009. Landuse and land management risks to water quality in Southland. Report prepared for Environment Southland. March 2009.



Source :

Figure 1: Edendale model area and boundaries

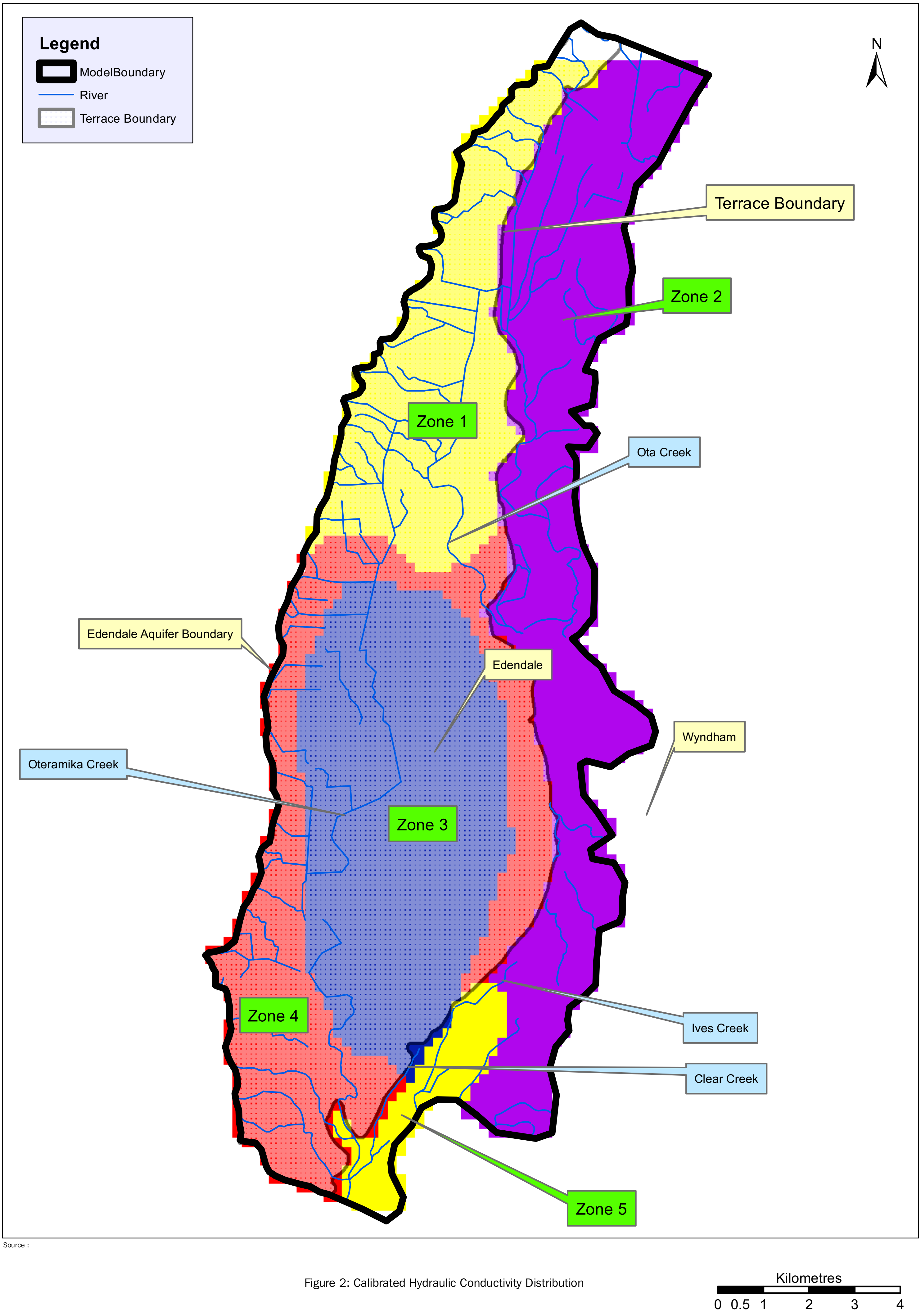


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Figure 2: Calibrated Hydraulic Conductivity Distribution

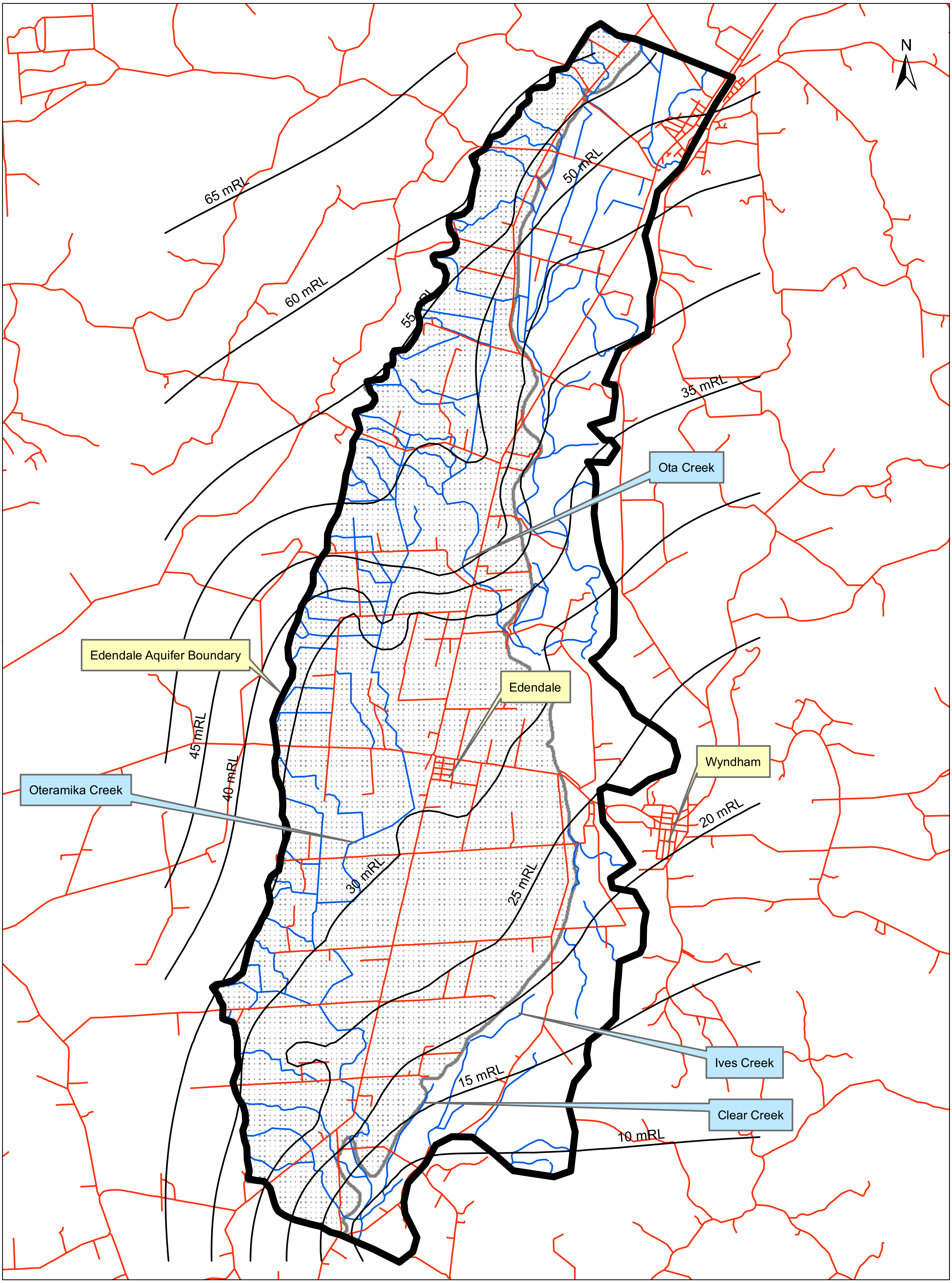

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Figure 3: Observed Groundwater Contours (Autumn (March / April) 2007)

Kilometres
0 0.5 1 2 3 4

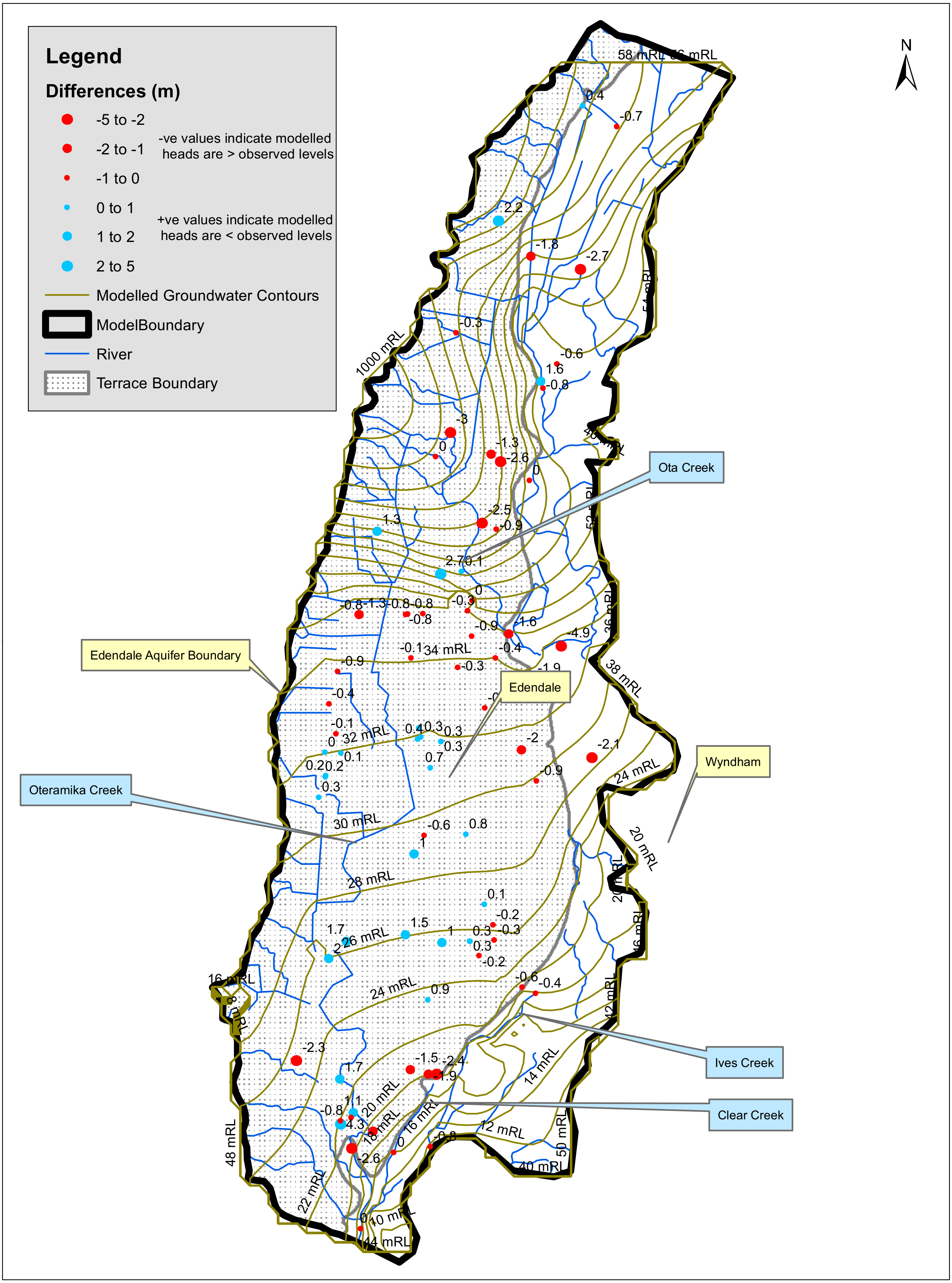

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Figure 4: Modelled Groundwater Contours and Differences between Observed Levels (March 2007, stress period 145)

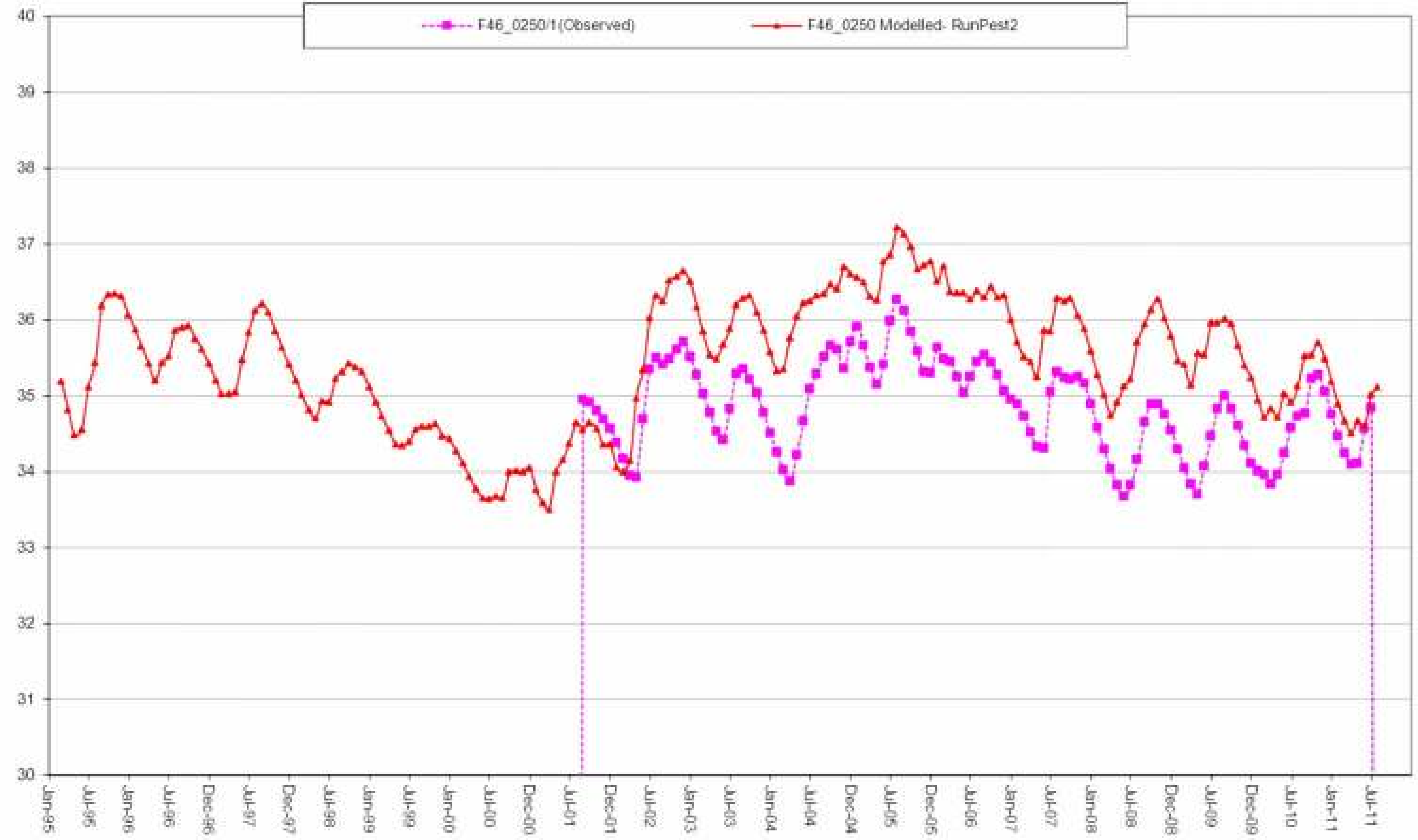

Figure 5a: Modelled and Observed Groundwater Hydrograph for F46/0250

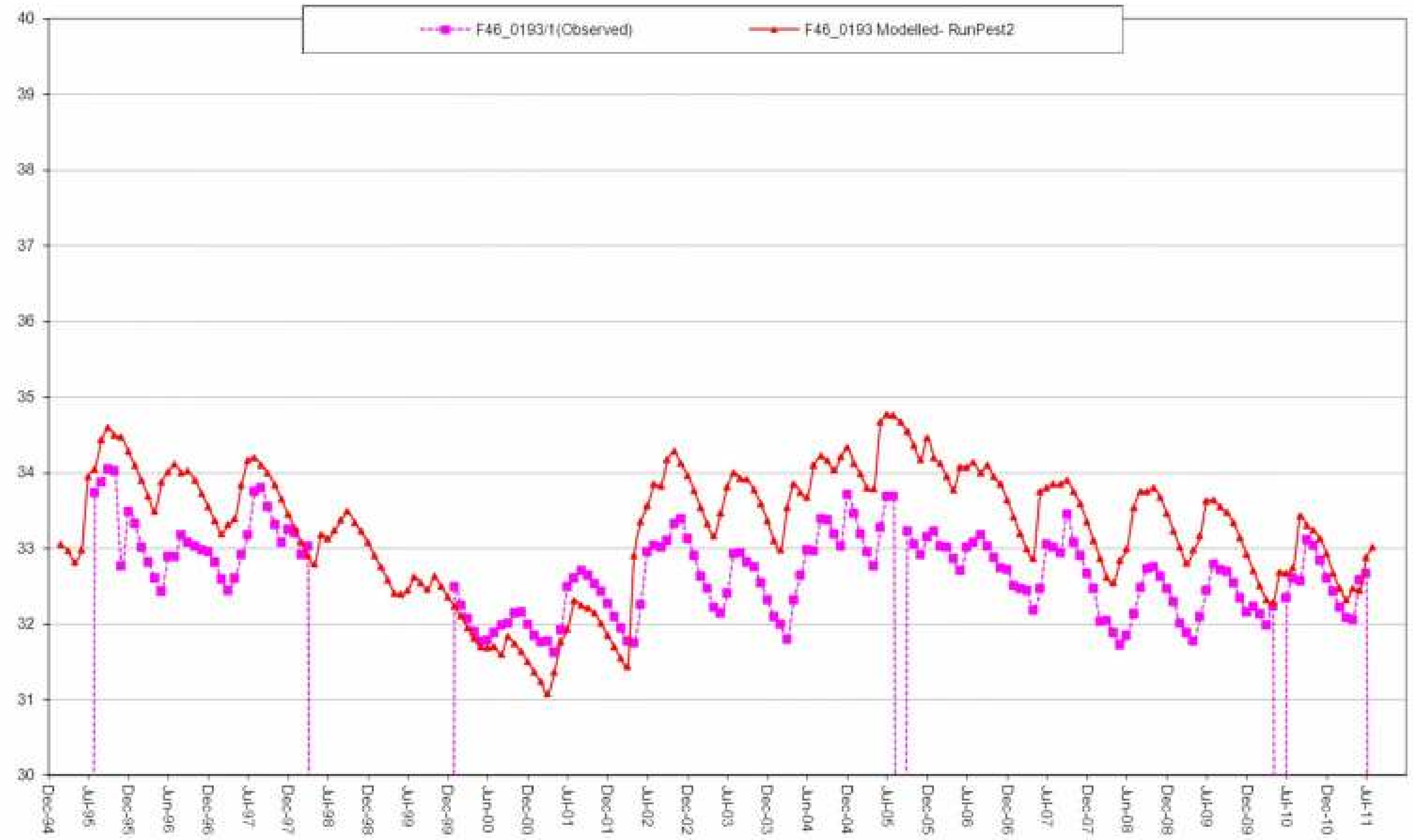

Figure 5b: Modelled and Observed Groundwater Hydrograph for F46/0193

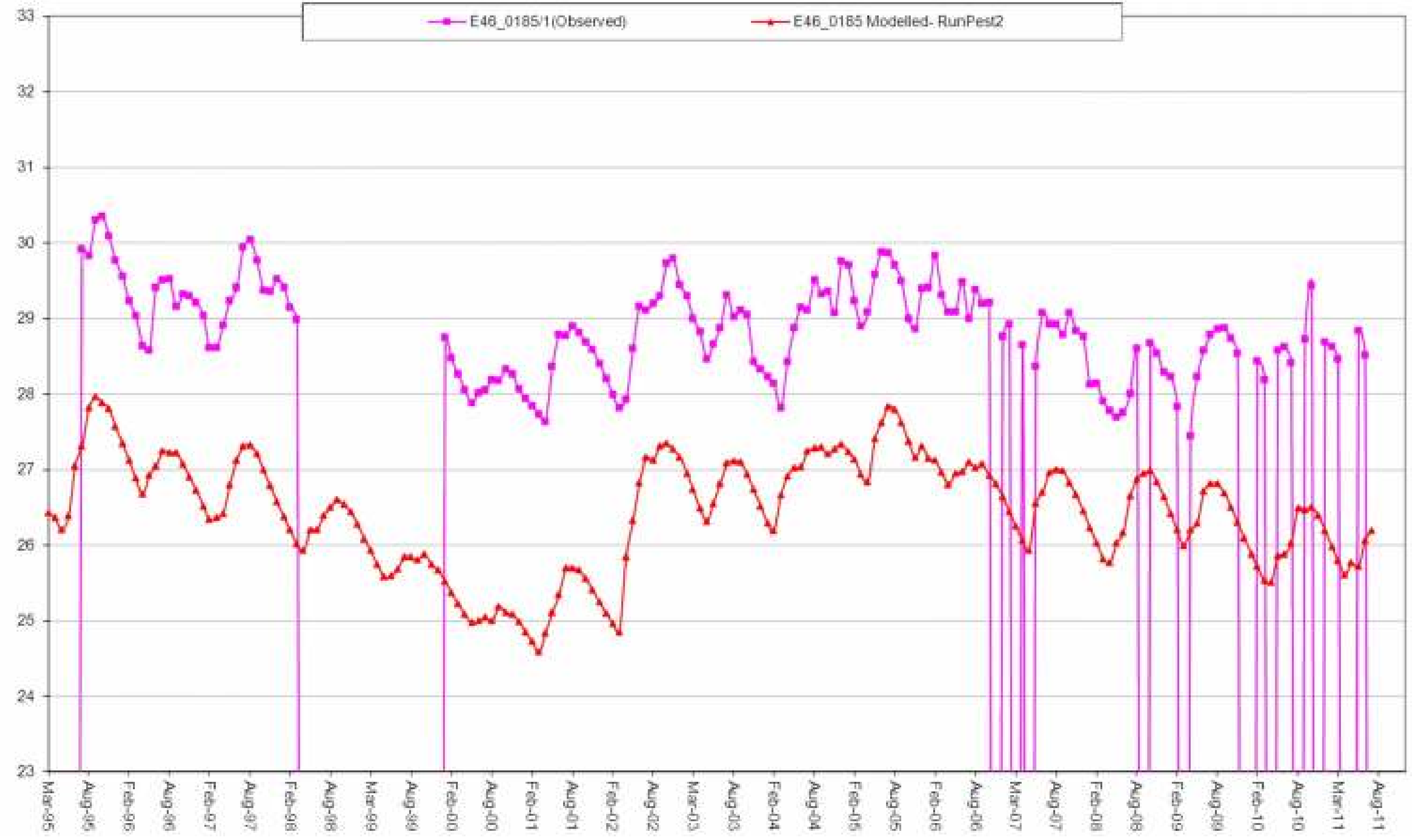

Figure 5c: Modelled and Observed Groundwater Hydrograph for F46/0185

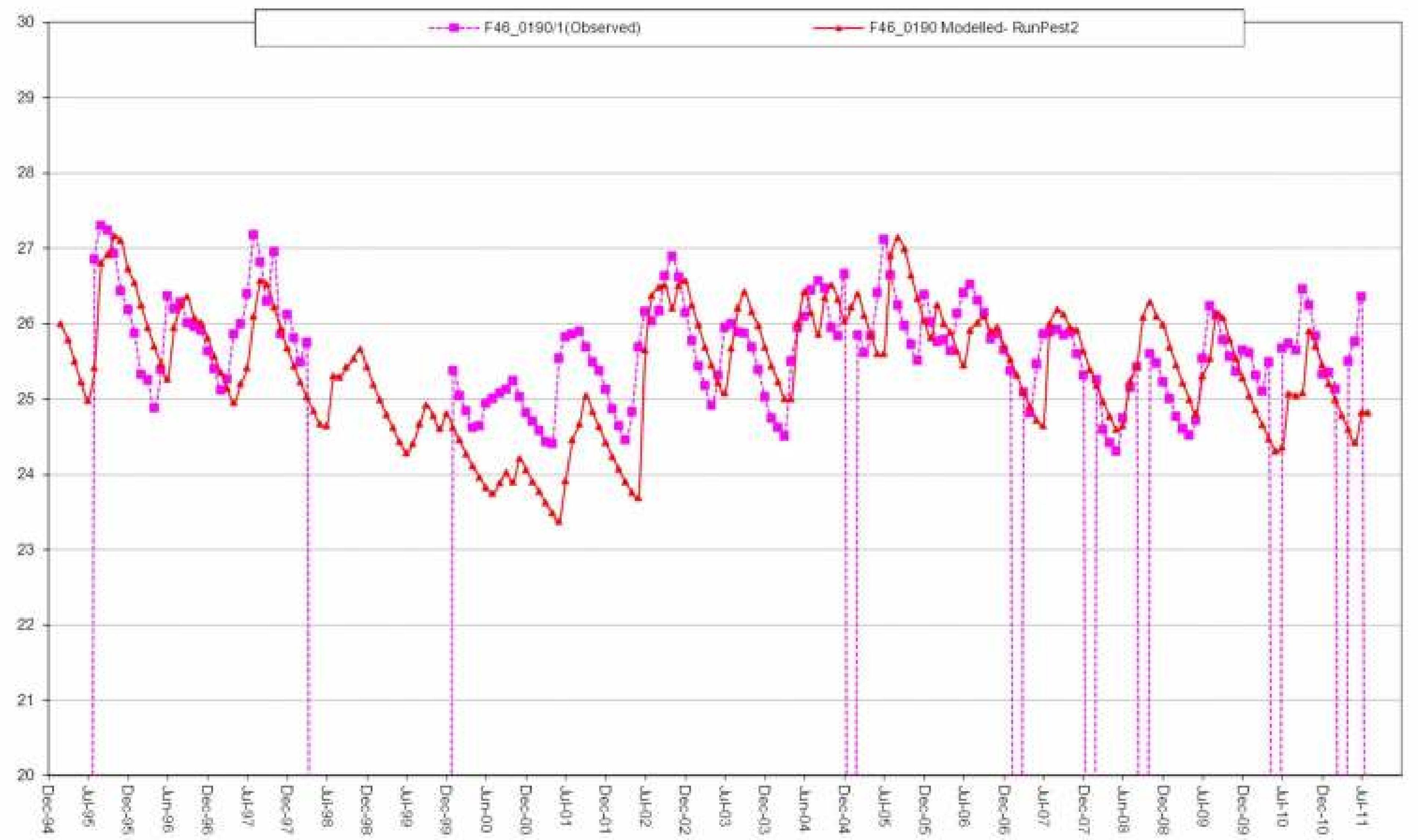

Figure 5d: Modelled and Observed Groundwater Hydrograph for F46/0190

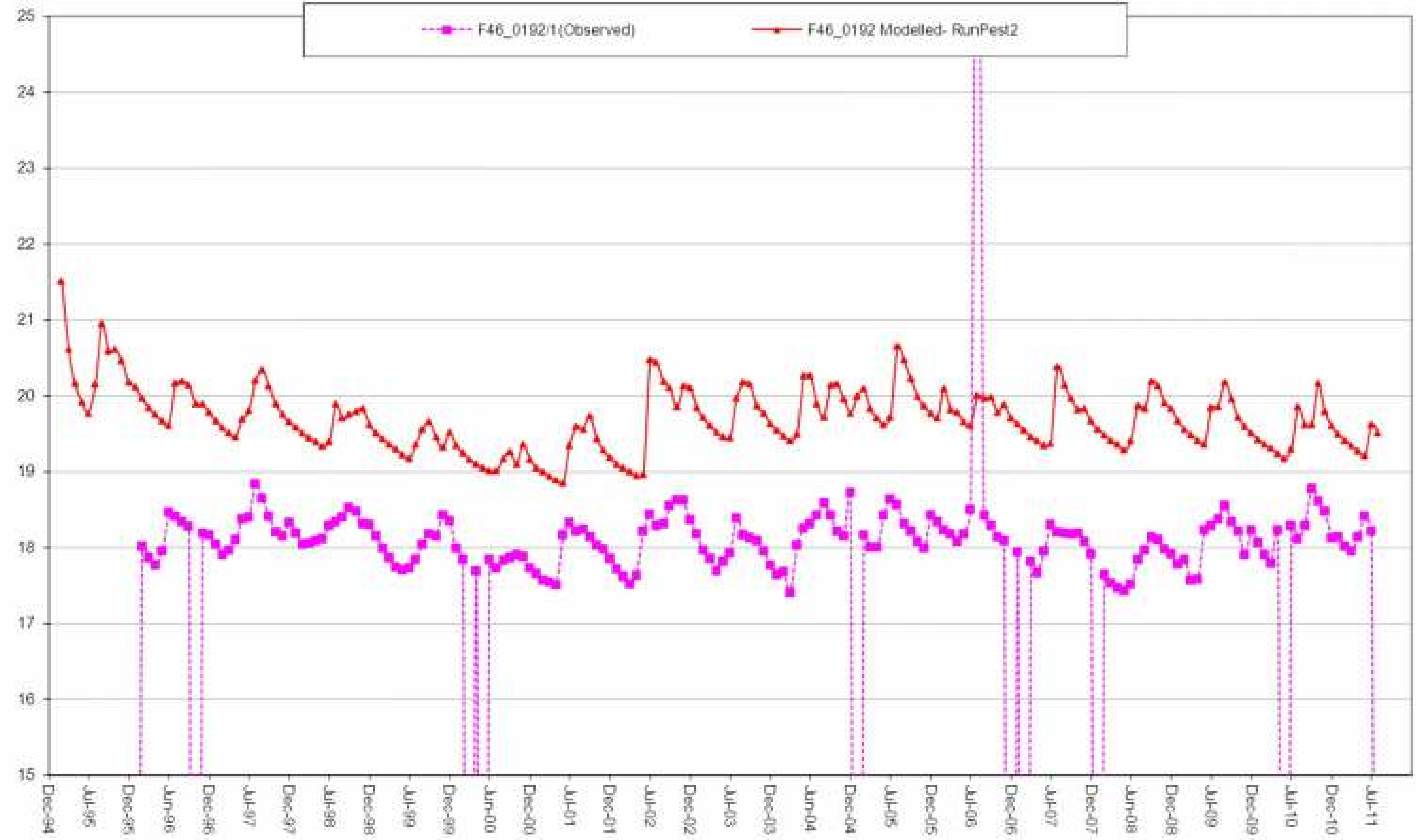

Figure 5e: Modelled and Observed Groundwater Hydrograph for F46/0192

Figure 5f: Modelled and Observed Groundwater Hydrograph for F46/0203

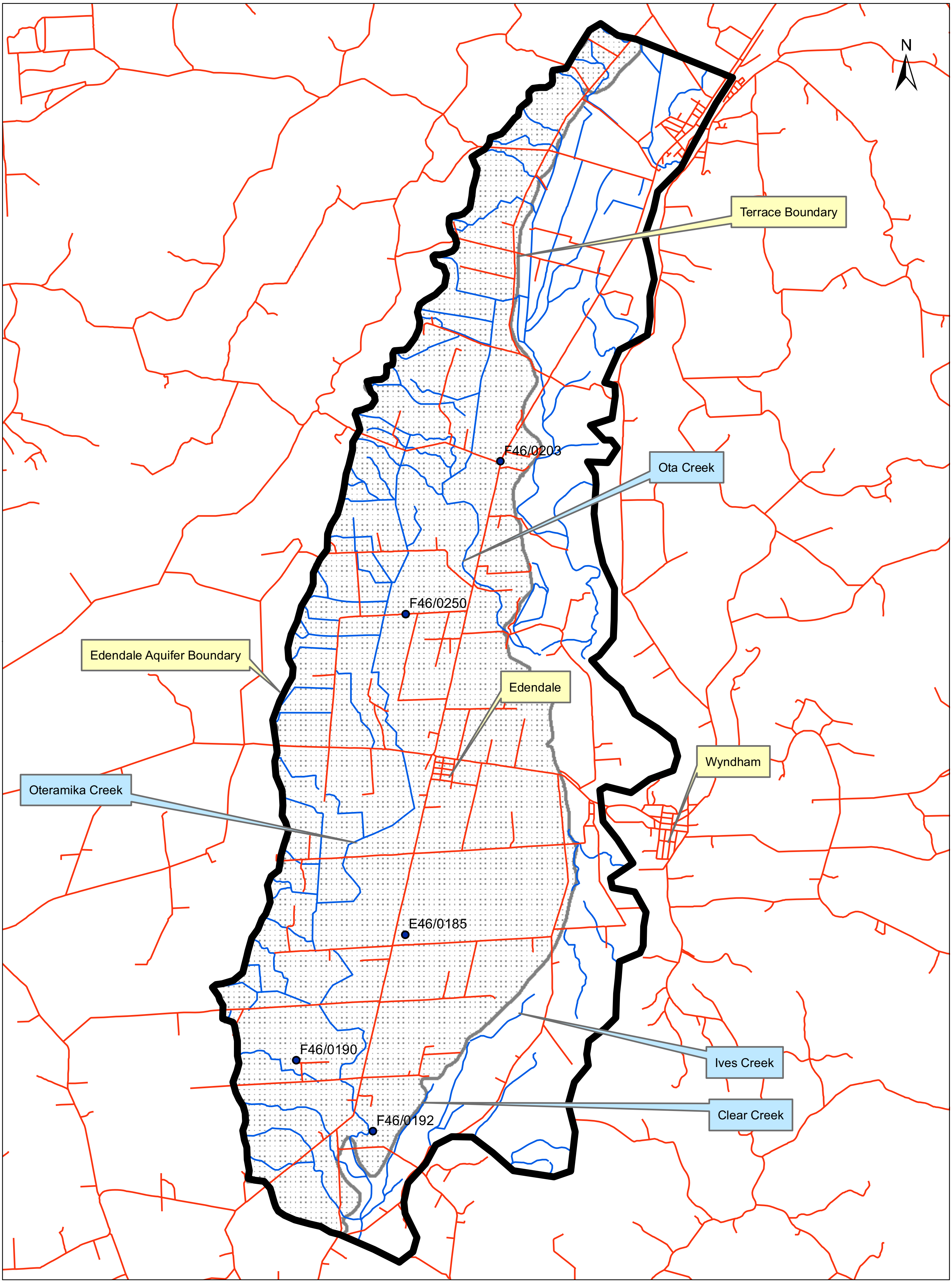

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Figure 6: Location of Long Term Monitoring Boreholes

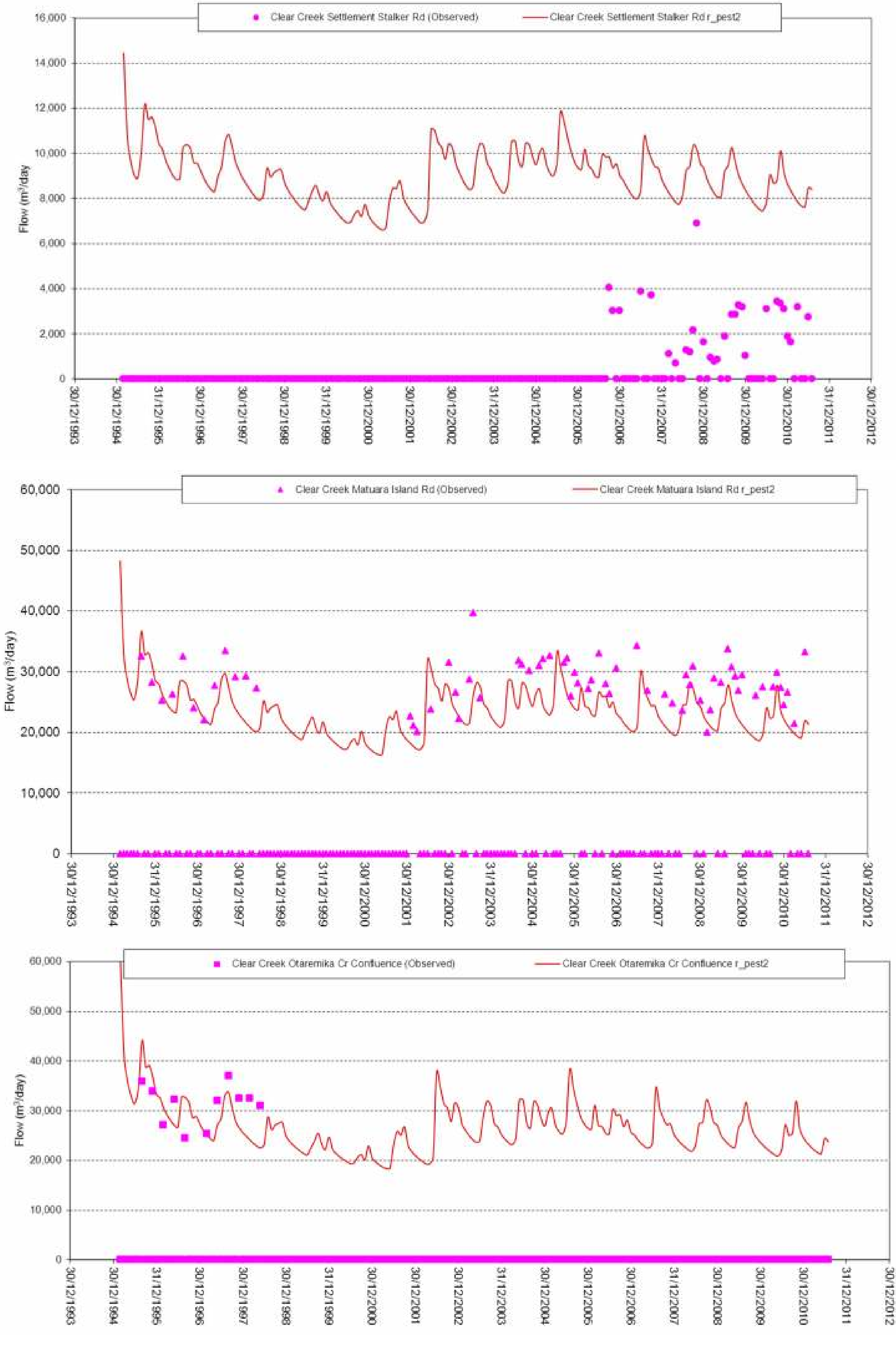

Figure 7a: Modelled and Observed Hydrographs for Clear Creek

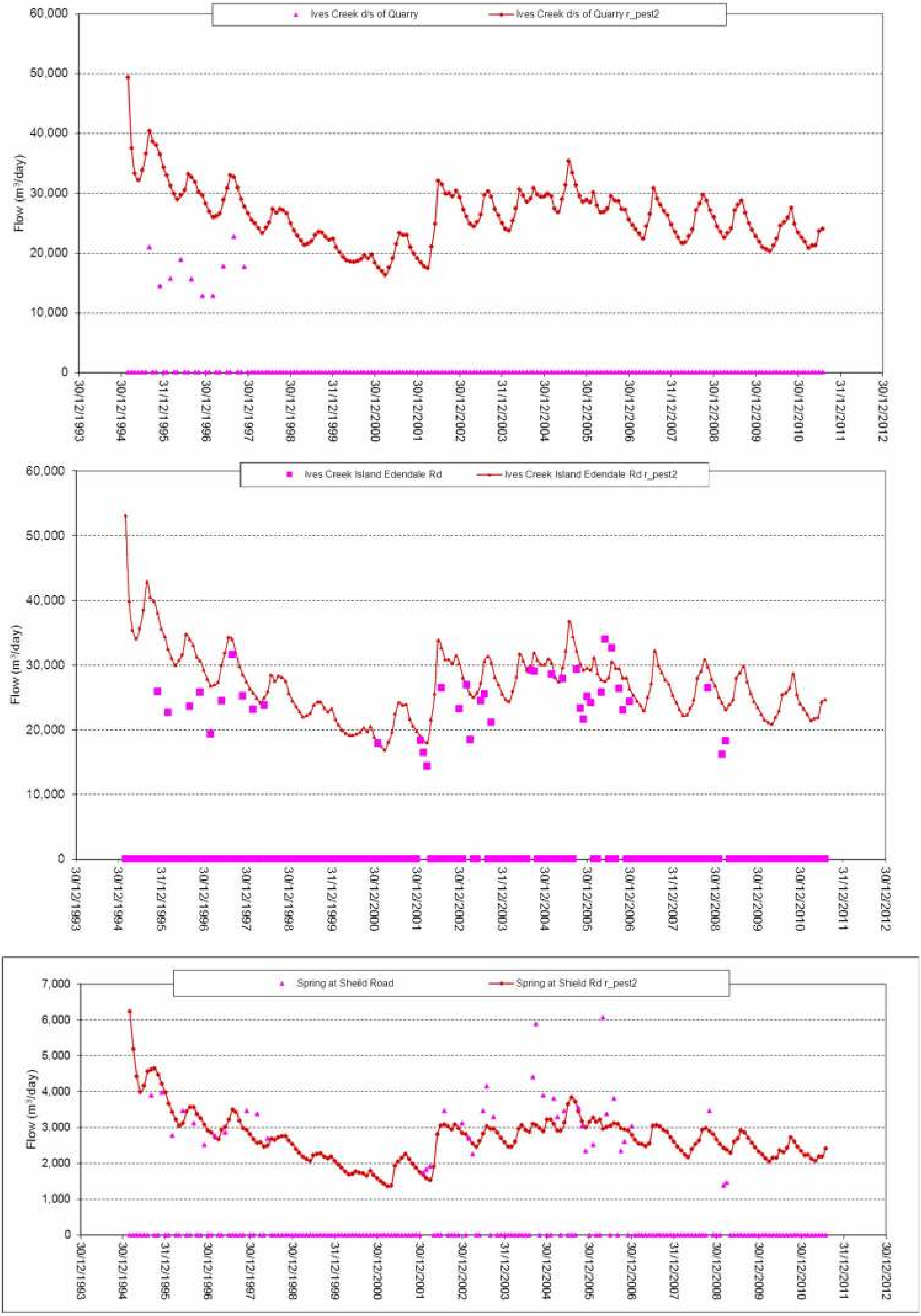

Figure 7b: Modelled and Observed Hydrographs for Ives Creek and Spring at Shield Road

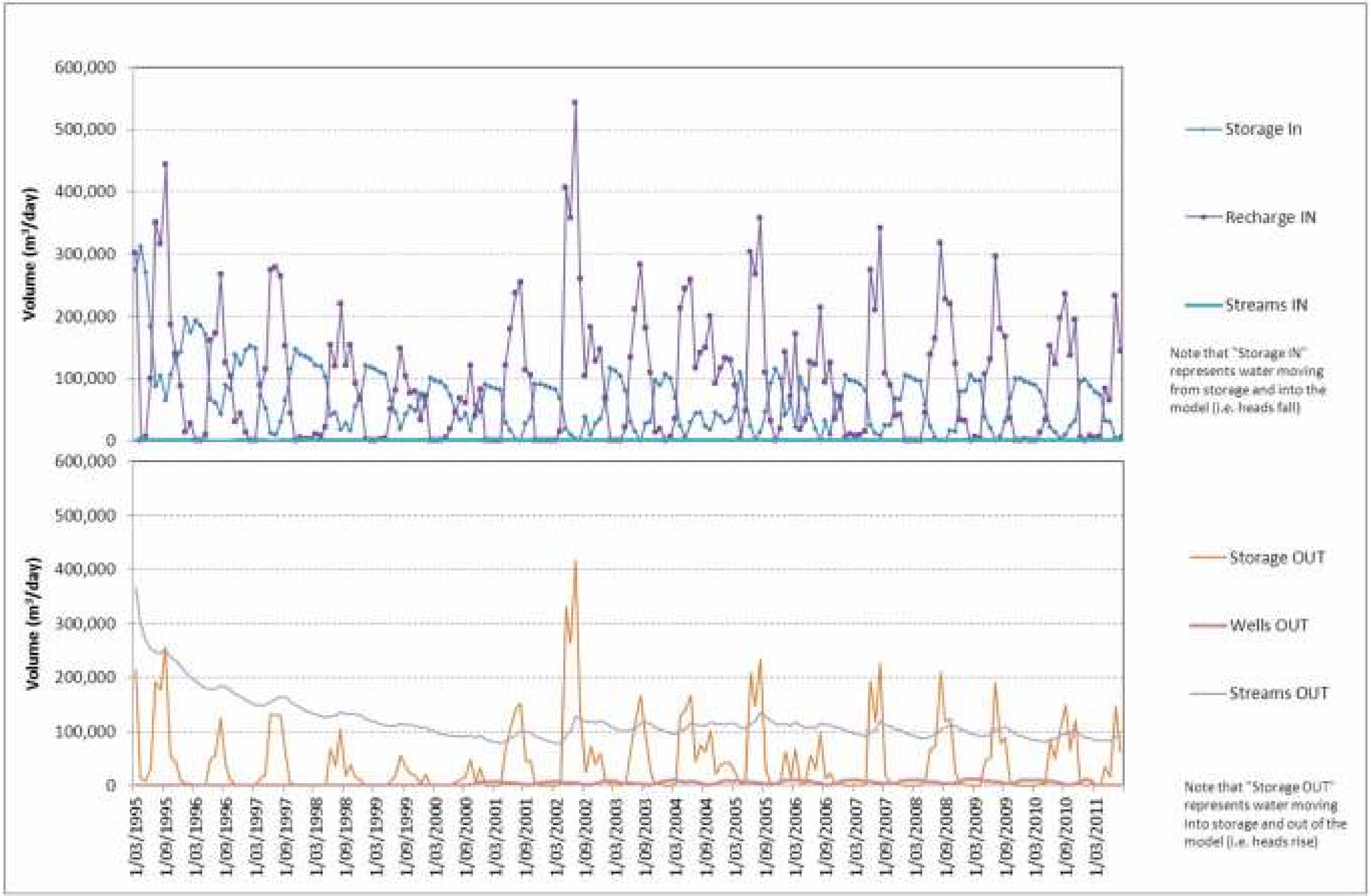

Figure 8: Modelled Water Balance timeseries (whole model area)

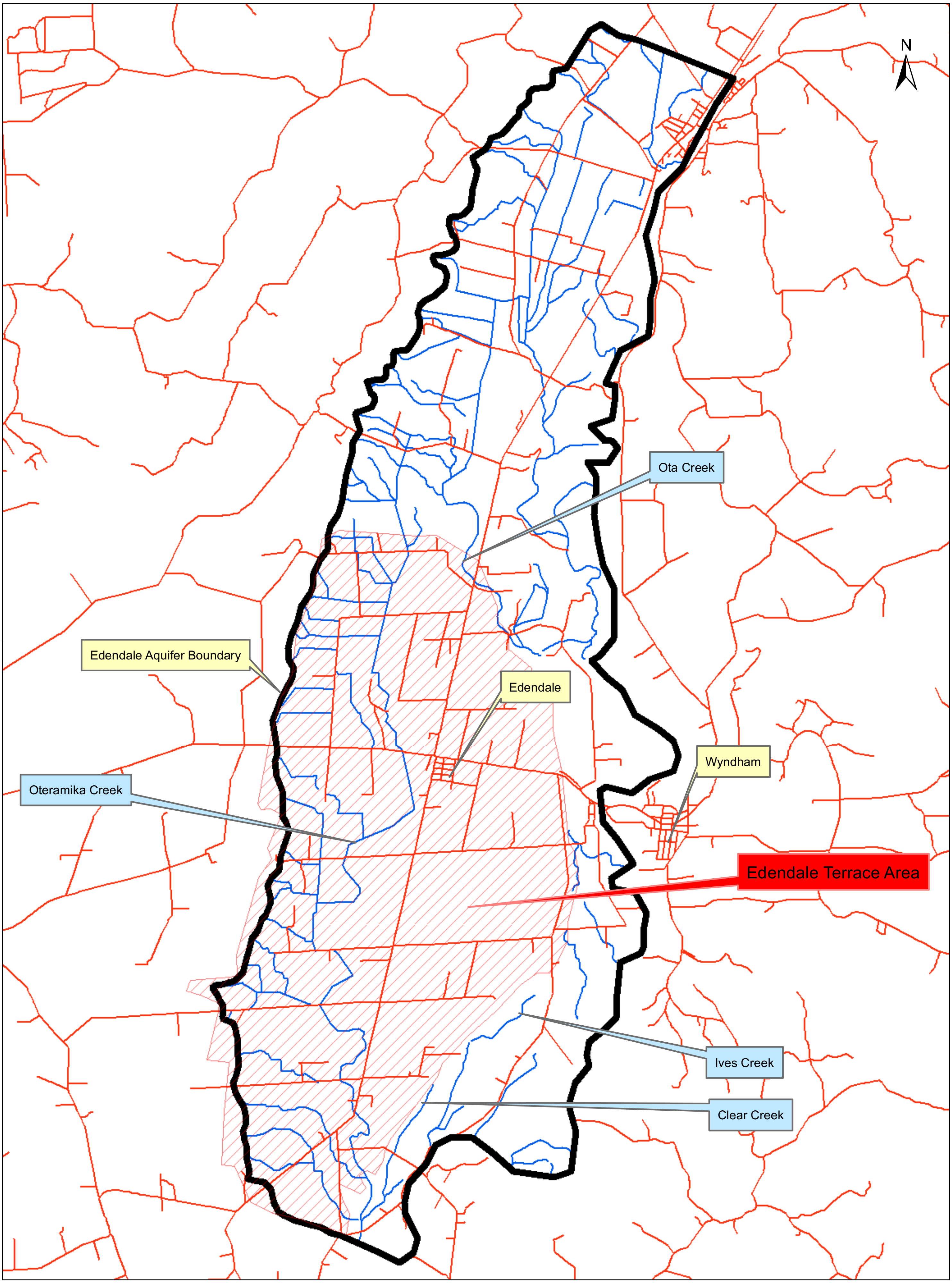

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Figure 9: Location of Edendale Terrace Area (hached area)

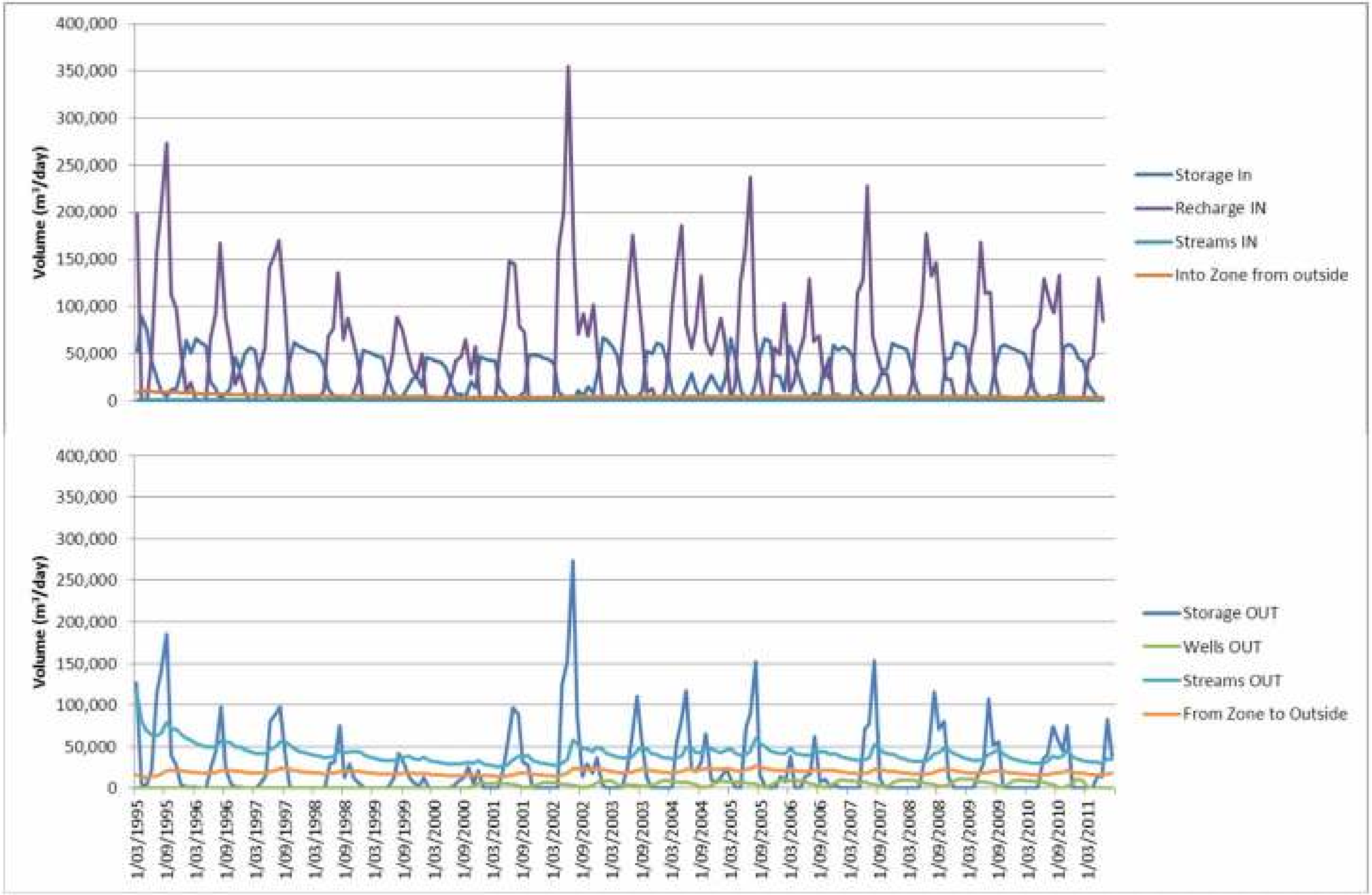
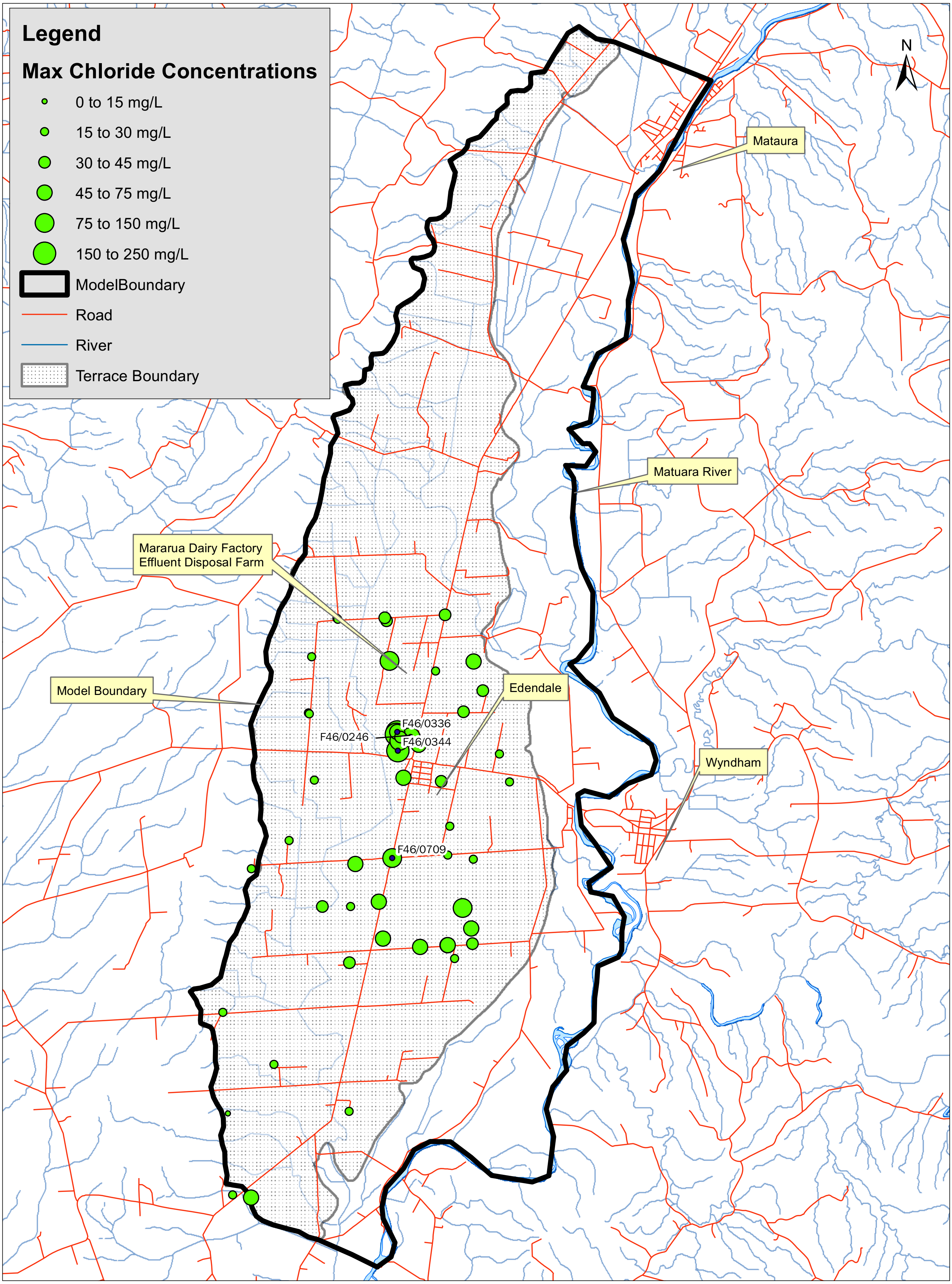


Figure 10: Modelled Water Balance timeseries (Edendale Terrace area)



Source :

Figure 11 : Spatial Distribution of Maximum Chloride Concentrations and Location of Long term Monitoring Bores

Kilometres
0 0.5 1 2 3 4

Figure 12a: Chloride Concentrations in F46/0336

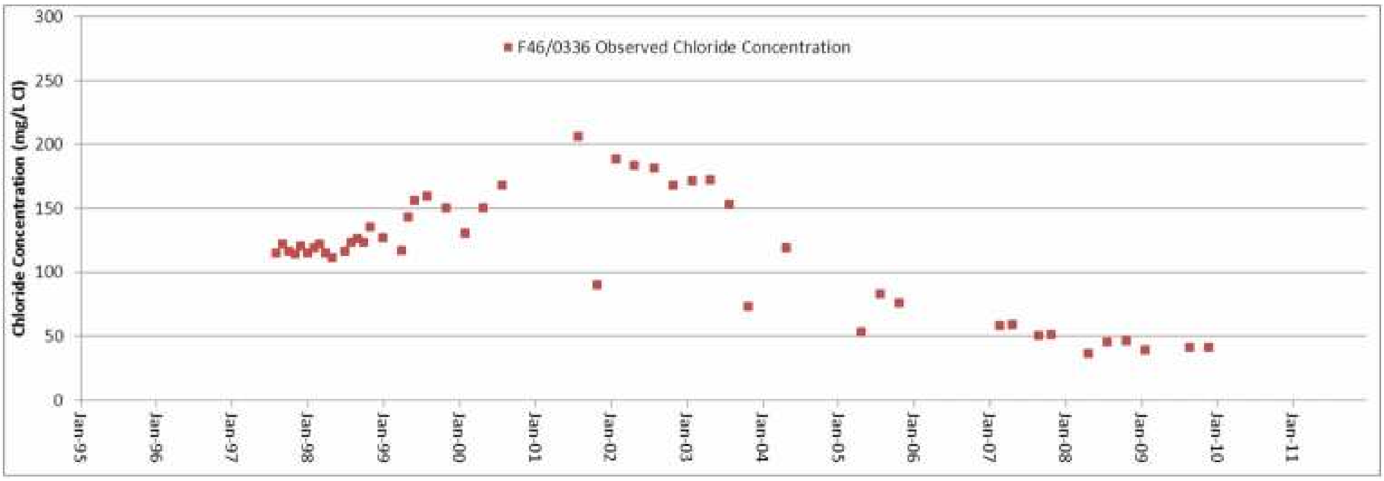


Figure 12b: Chloride Concentrations in F46/0246

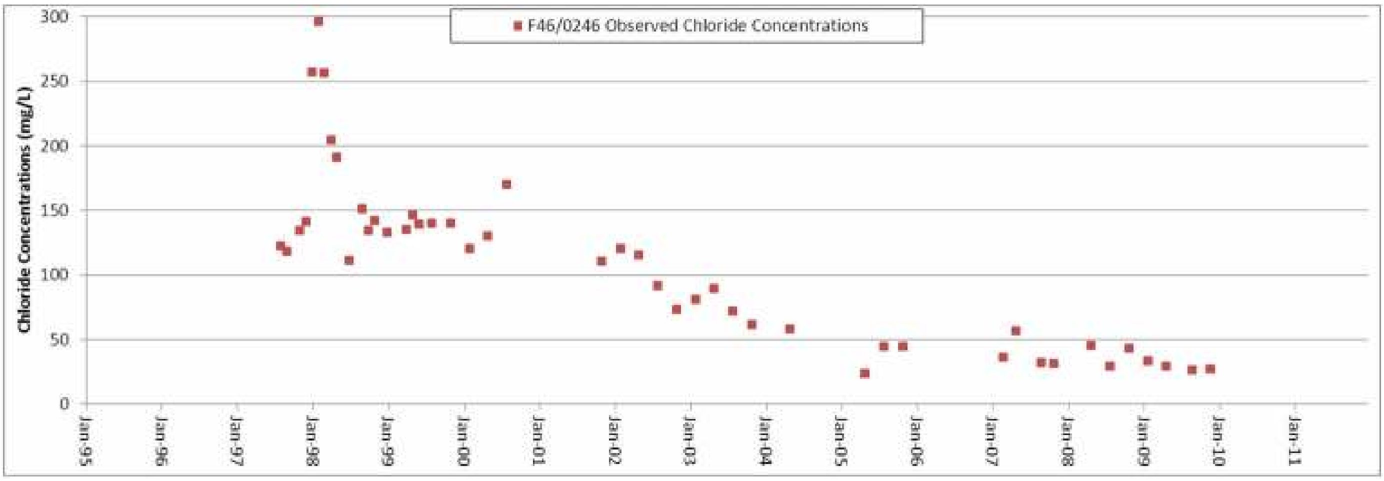
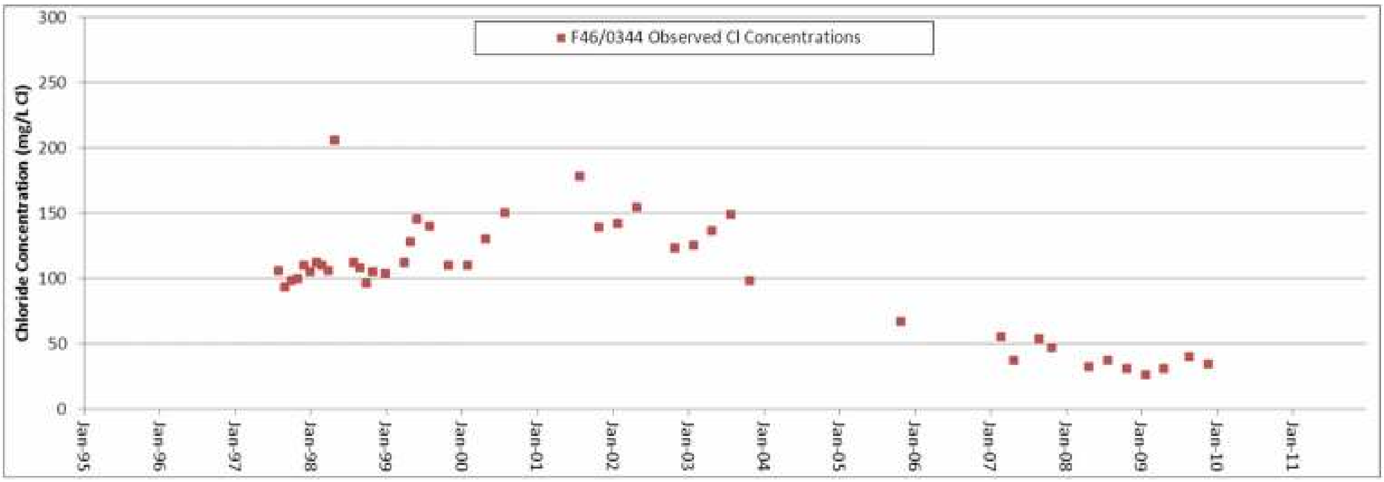


Figure 12c: Chloride Concentrations in F46/0344



Figures 12a to 12c: Long term Chloride Concentrations close to Mararua Dairy Effluent Disposal

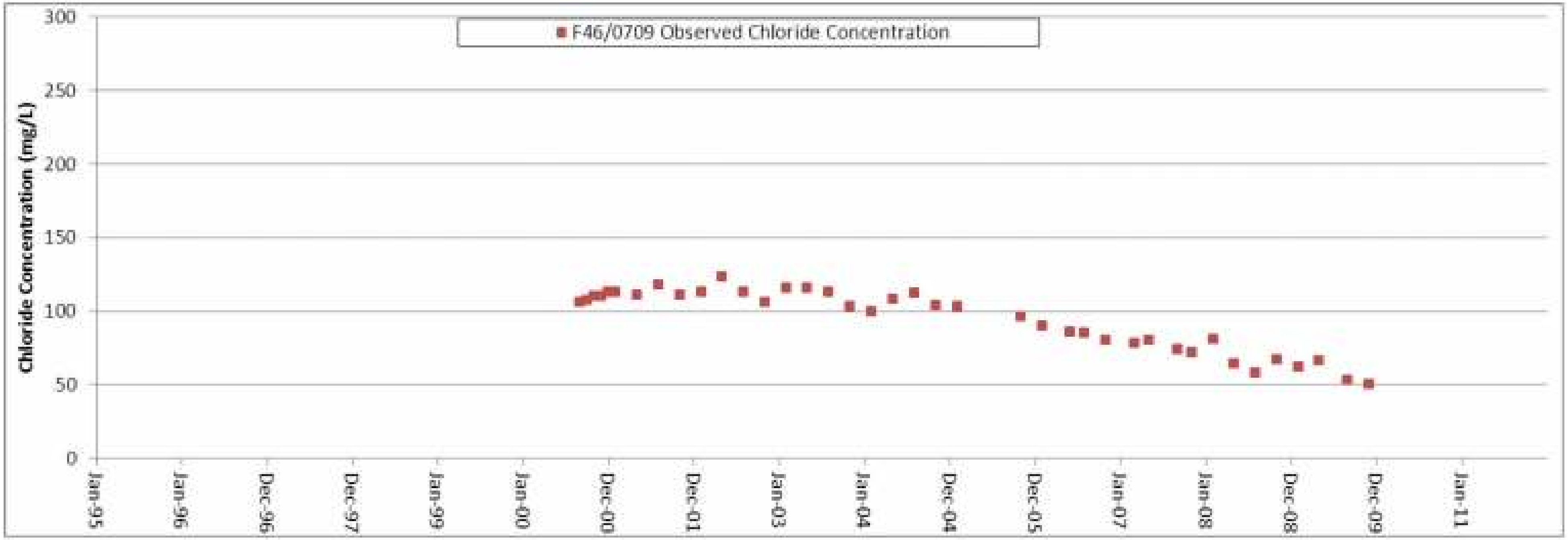
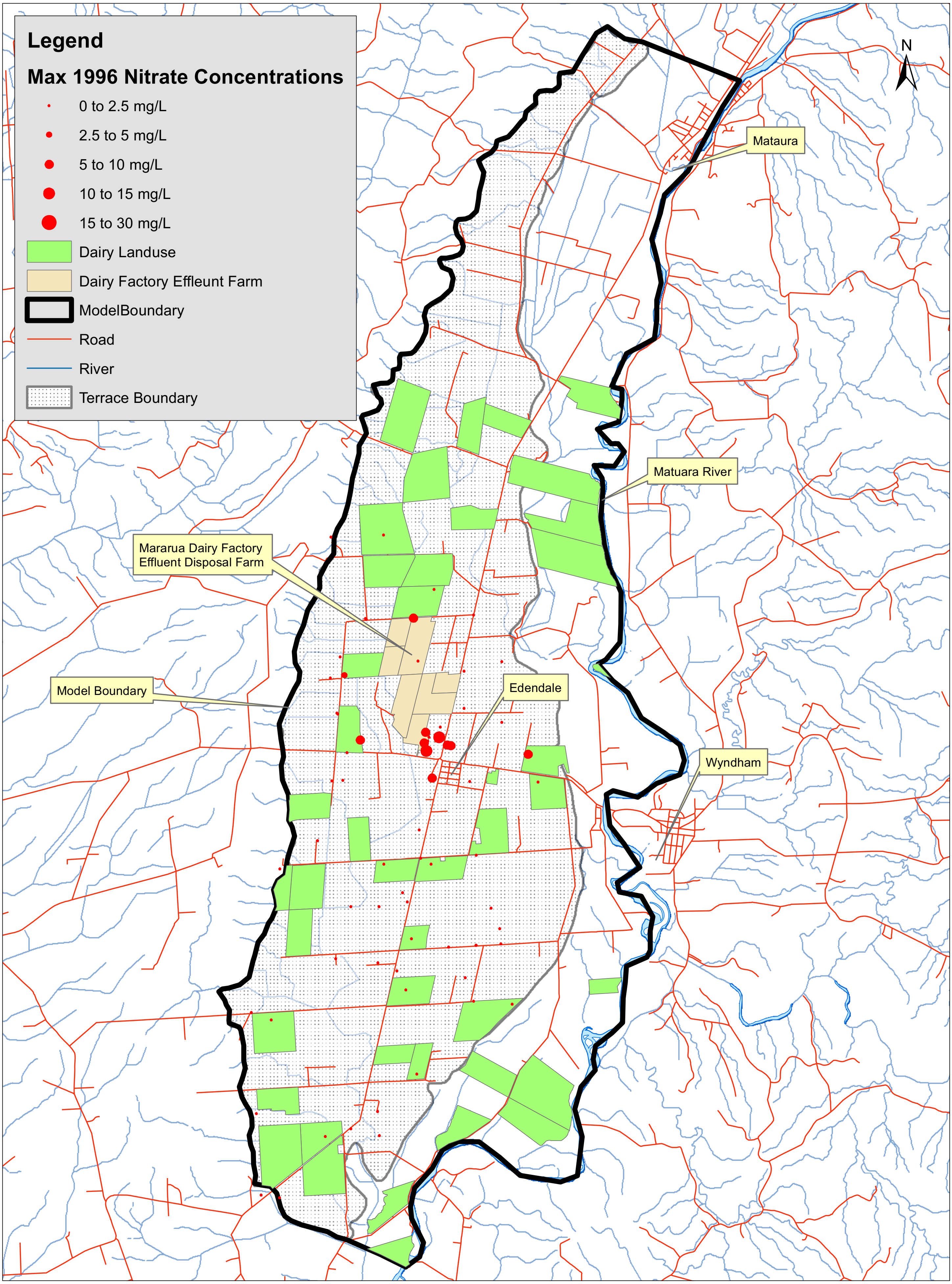


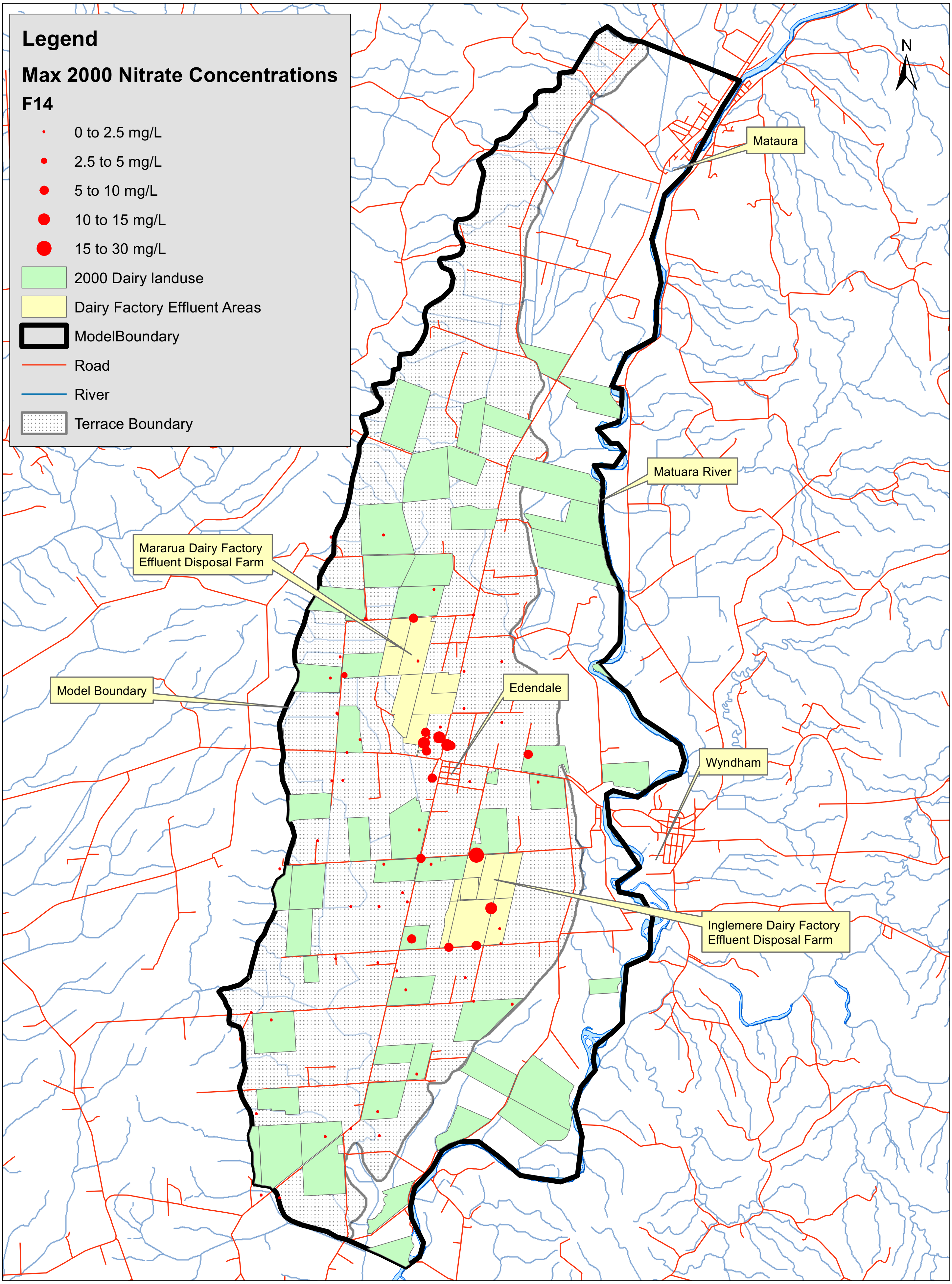
Figure 12d: Downgradient Chloride Concentrations (F46/0709)



Source :

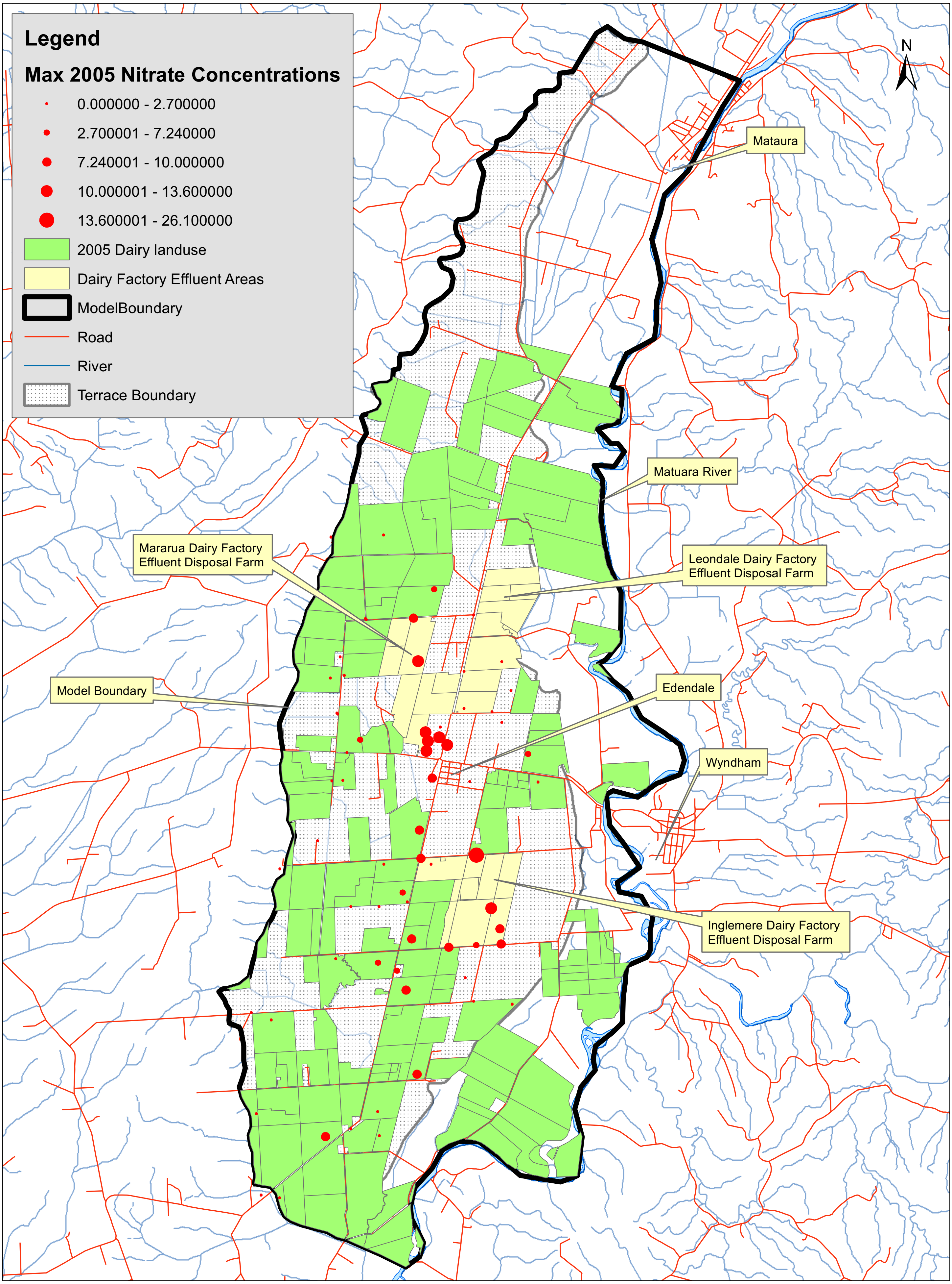
Figure 13a: 1992 Landuse and Maximum 1996 Nitrate Concentrations

Kilometres
0 0.5 1 2 3 4



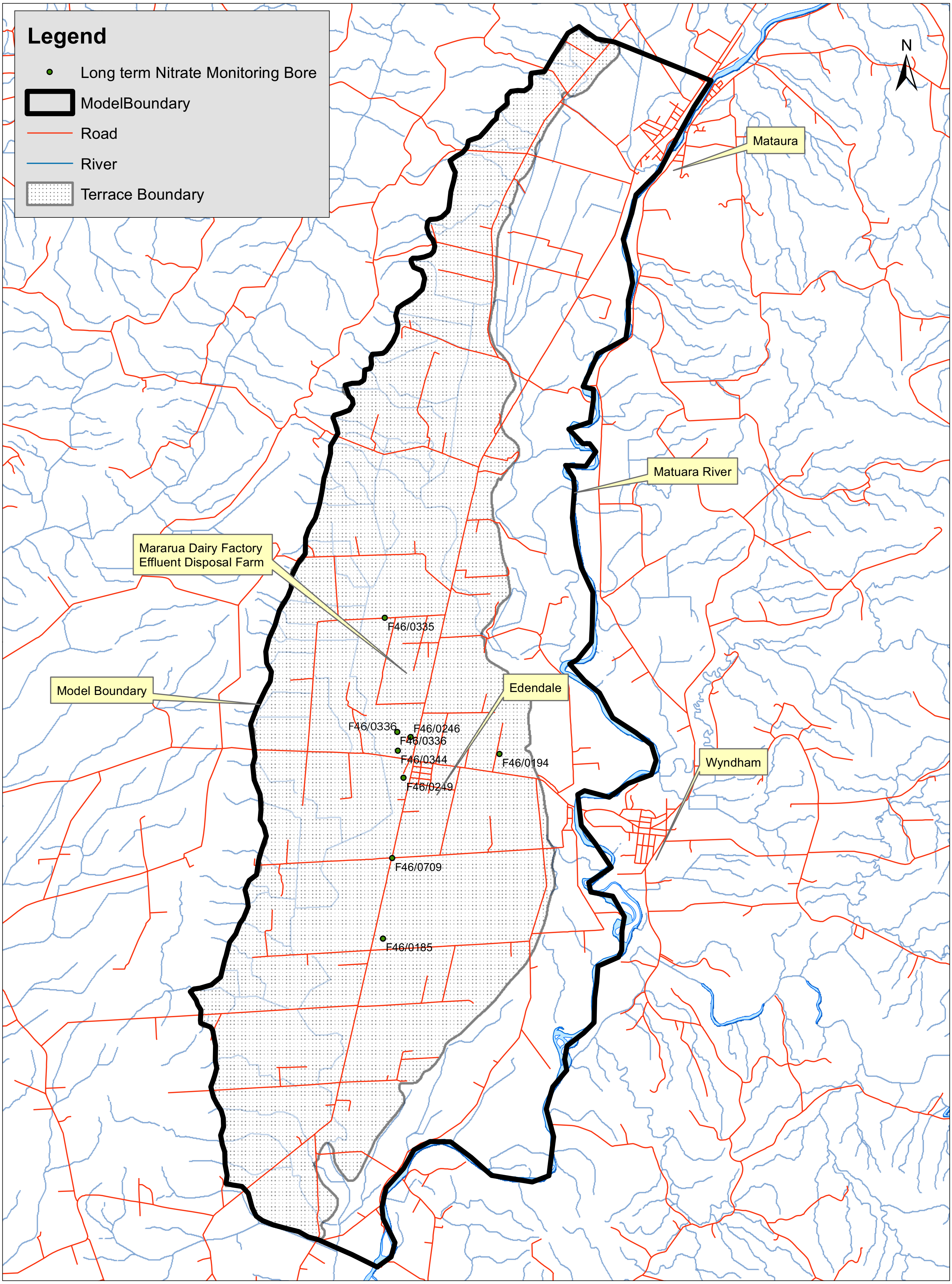
Source :

Figure 13b: 2000 Landuse dsitribution and 2000 maximum Nitrate Concentrations



Source :

Figure 13c: 2005 Landuse dsitribution and 2005 maximum Nitrate Concentrations



Source :

Figure 14 : Location of Long term Nitrate Monitorng Boreholes

Figure 15a: Nitrate Concentrations in F46/0194

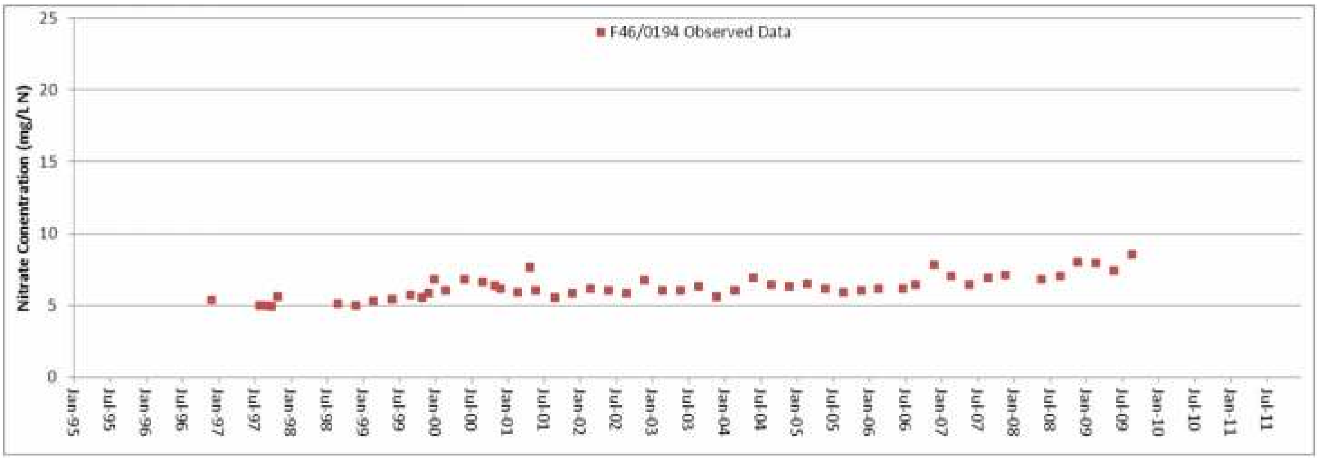


Figure 15b: Nitrate Concentrations in F46/0335

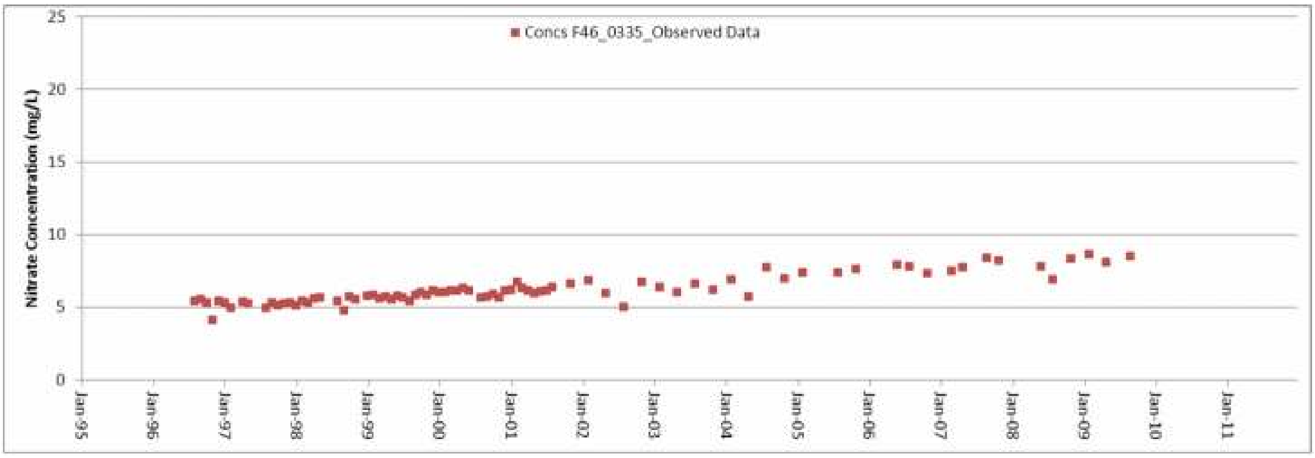


Figure 15c: Nitrate Concentrations in F46/0709

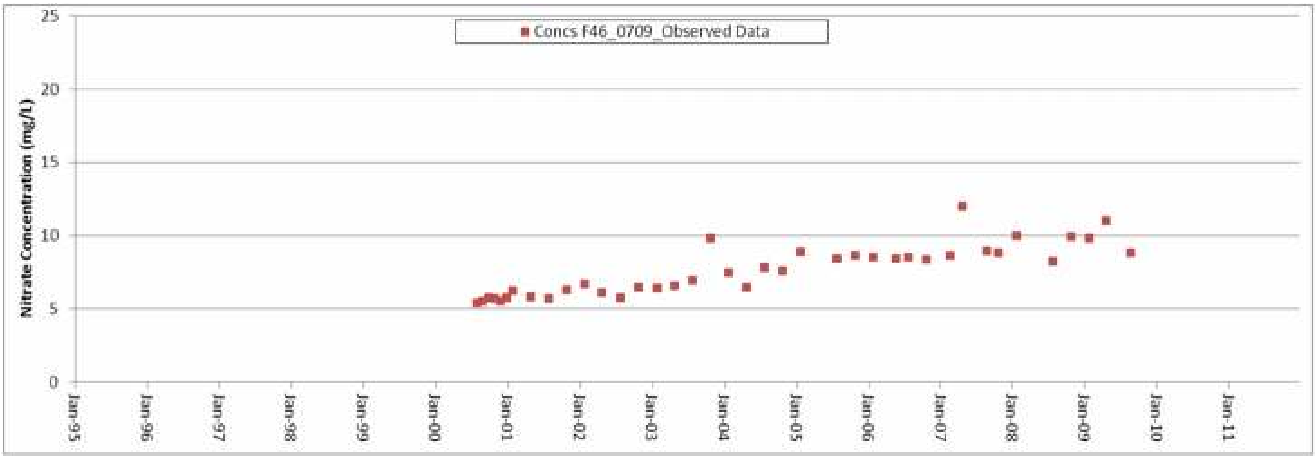
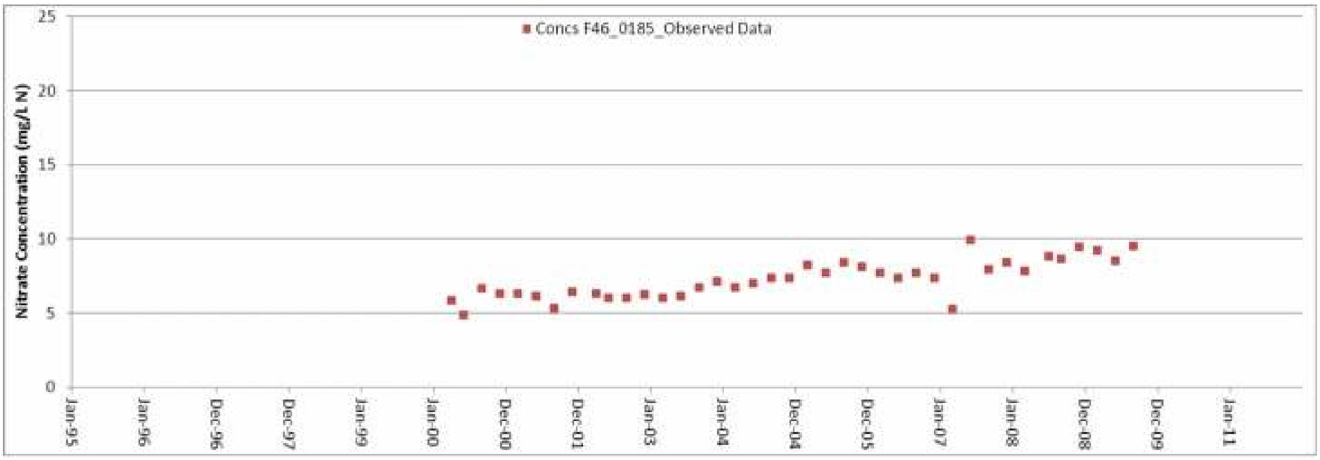


Figure 15d: Nitrate Concentrations in F46/0185



Figures 15a to 15d: Long term Nitrate Concentrations

Figure 16a: Nitrate Concentrations in F46/0249

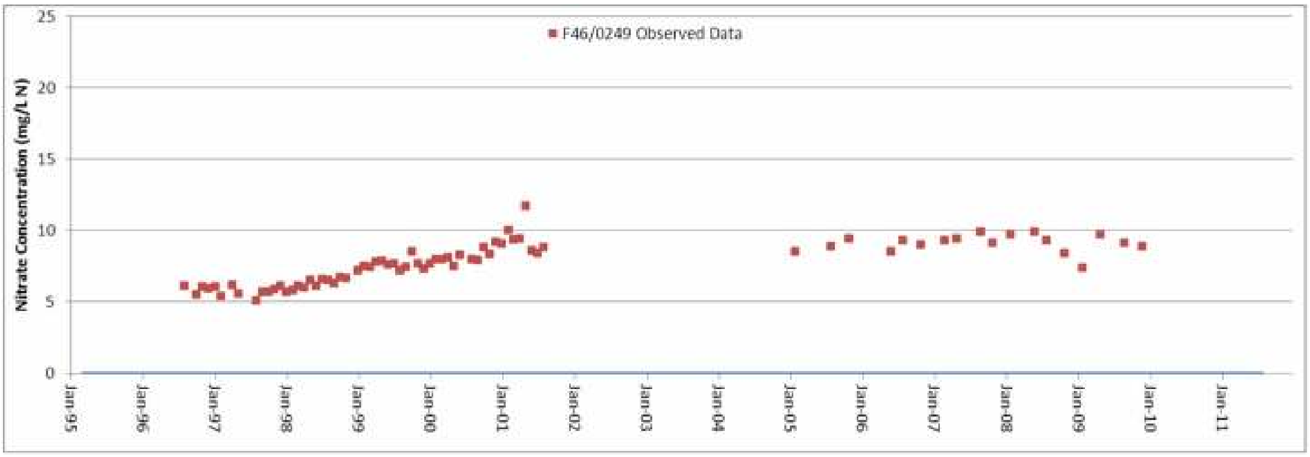


Figure 16b: Nitrate Concentrations in F46/0246

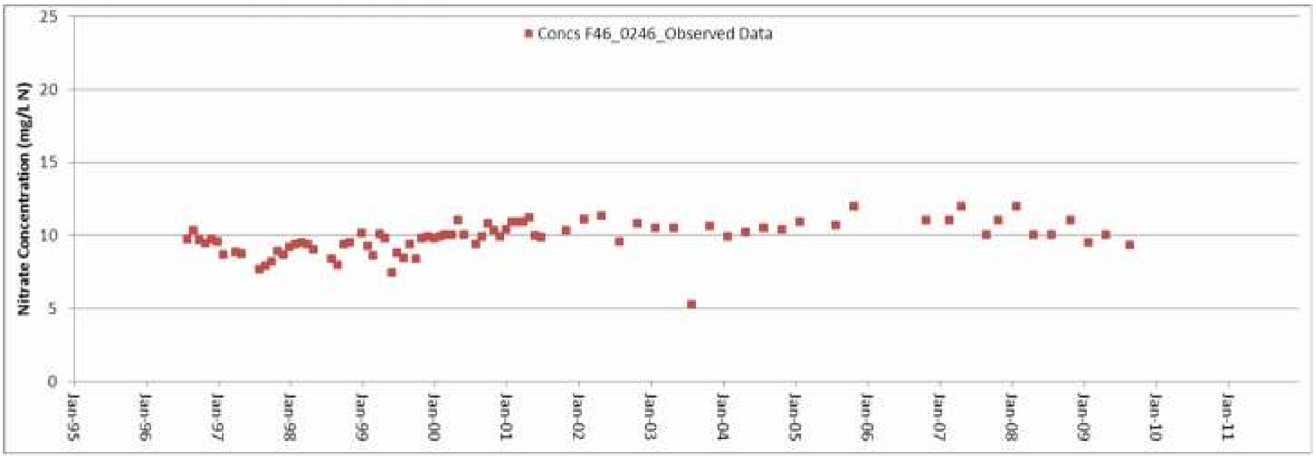


Figure 16c: Nitrate Concentrations in F46/0344

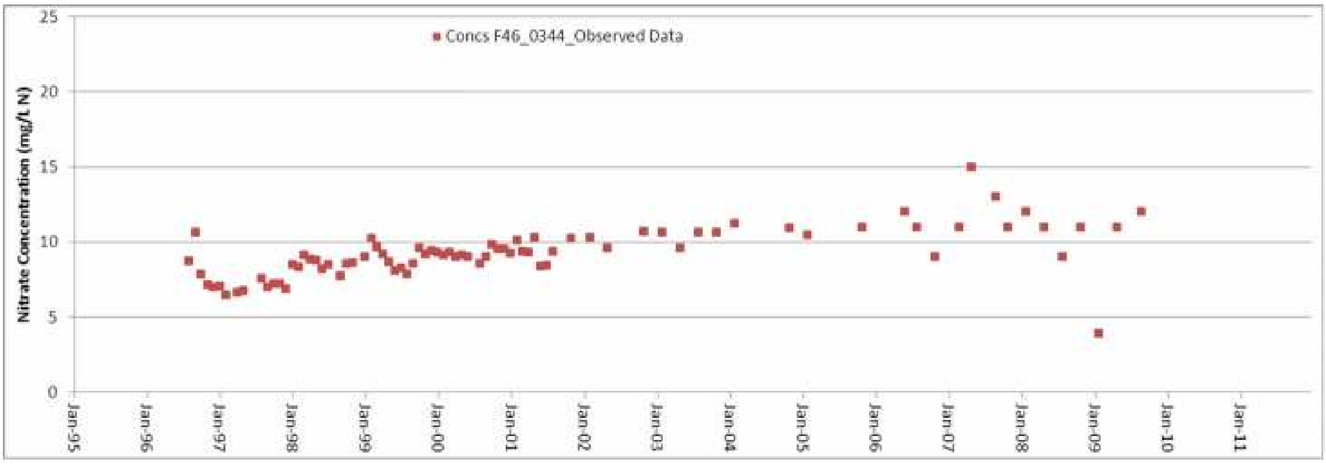
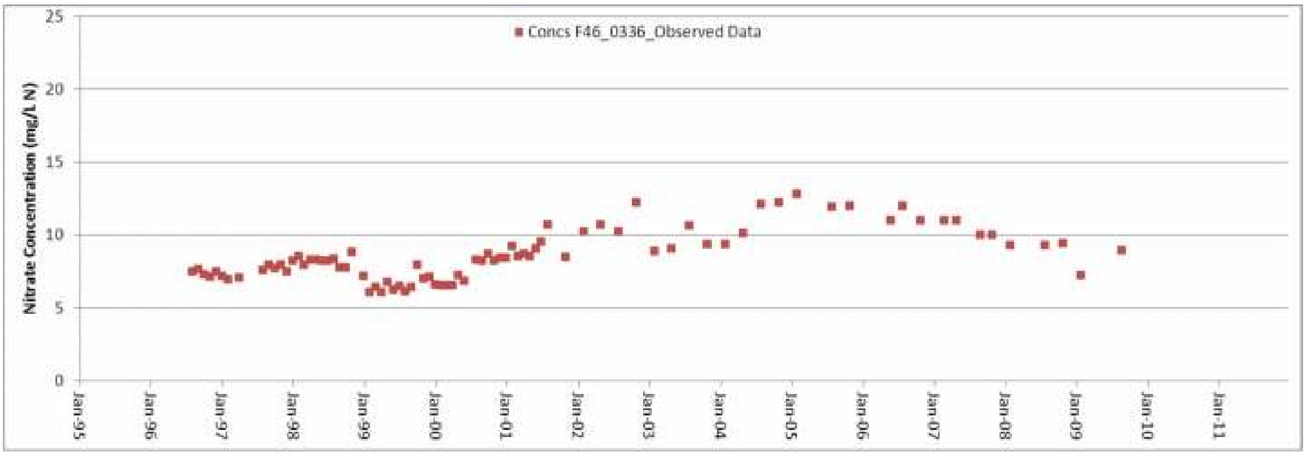
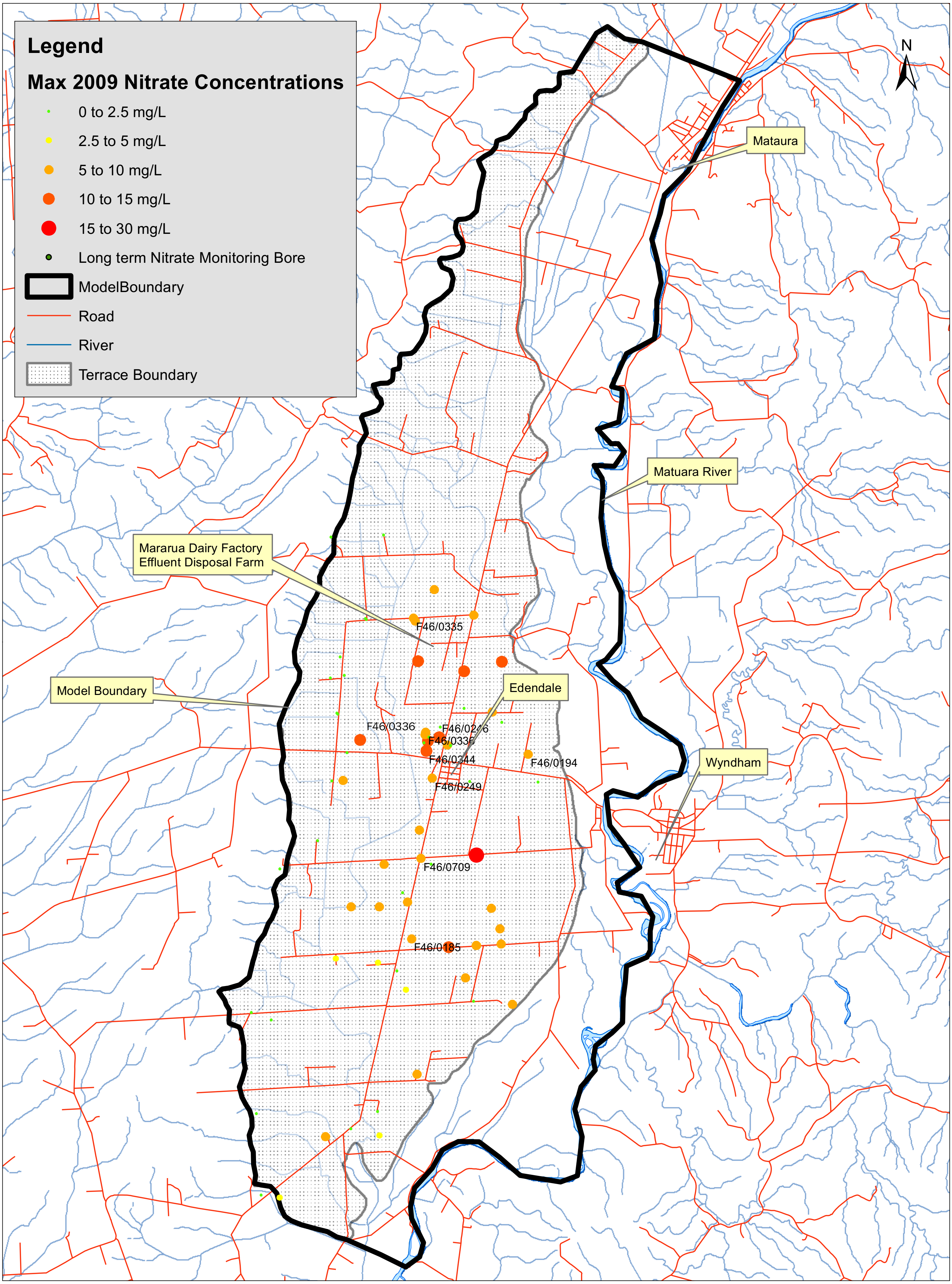


Figure 16d: Nitrate Concentrations in F46/0336



Figures 16a to 16d: Long term Nitrate Concentrations close to Mararua Effluent Disposal Farm



Source :

Figure 17: Maximum Observed 2009 Nitrate Concentrations

Figure 18a: Nitrate Leaching Rates at Dairy Factory Effluent Farms

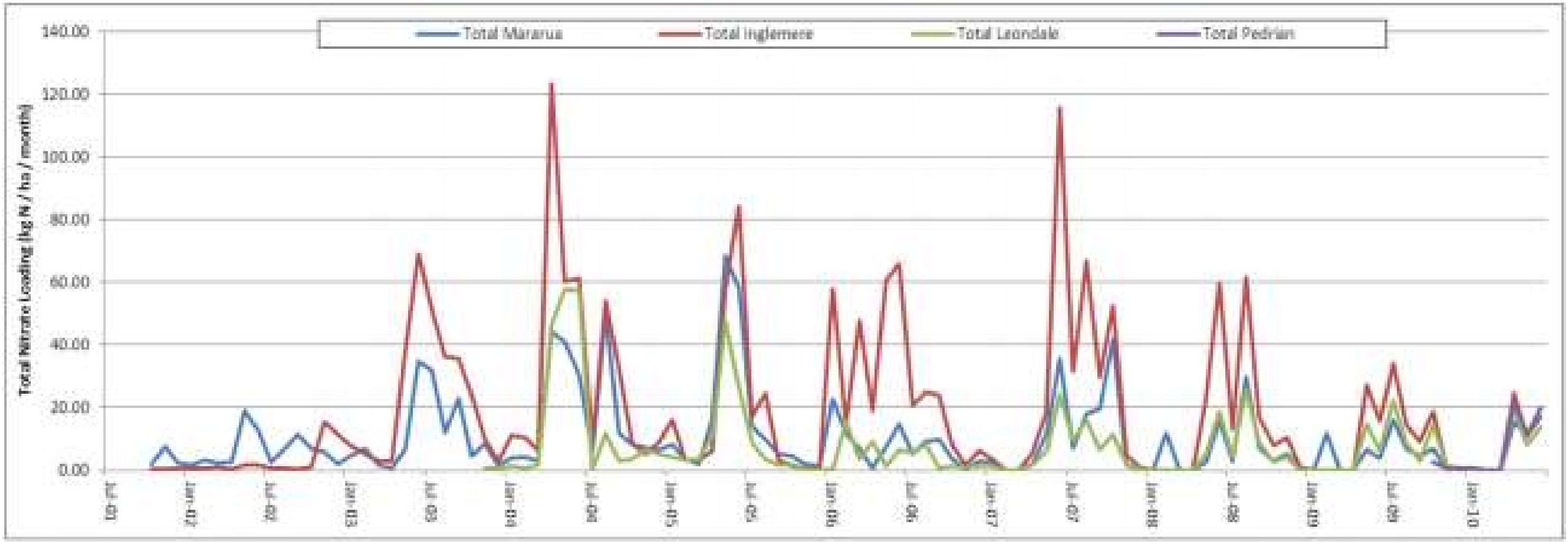


Figure 18b: Nitrate Concentrations in Leachate

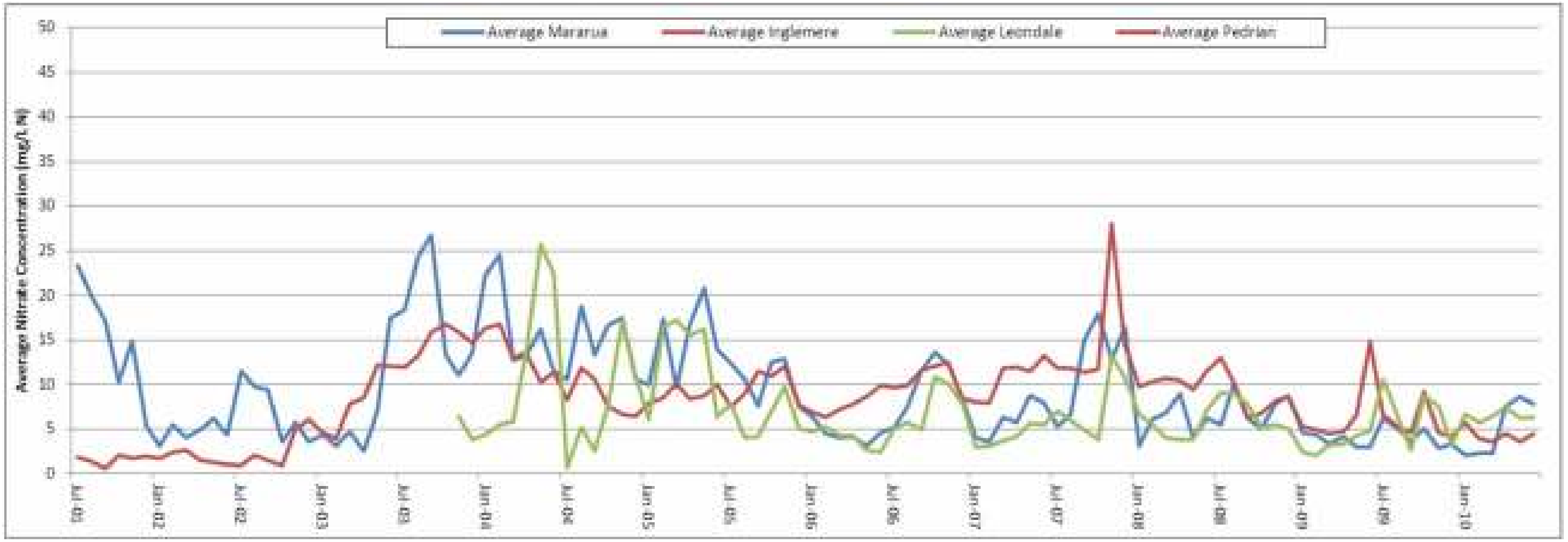


Figure 18a and 18b: Leachate Concentrations and Loading Rates at Dairy Factory Effluent Disposal Farms

Figure 19a: Modelled and Observed Chloride Concentrations in F46/0246

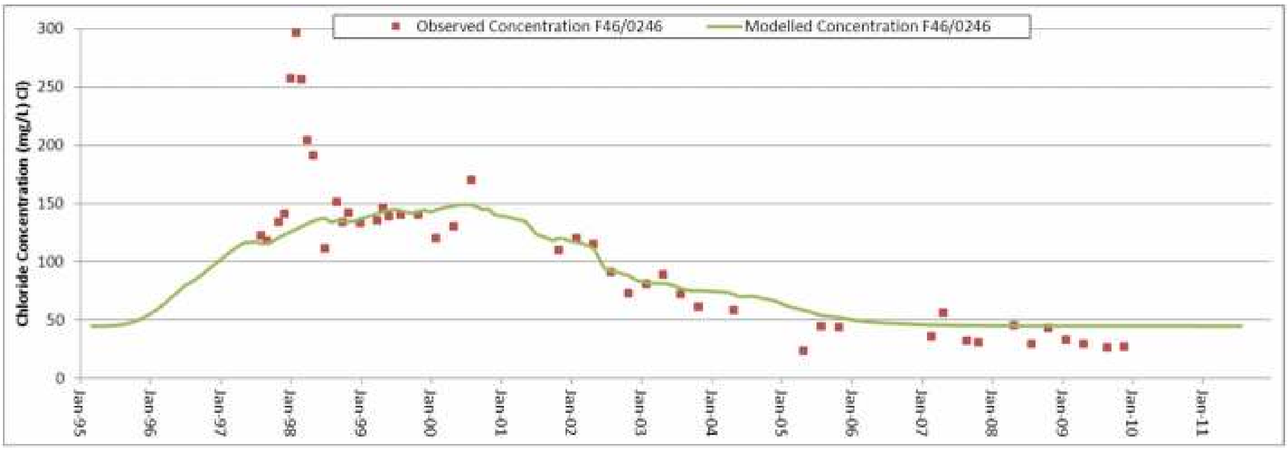


Figure 19b: Modelled and Observed Chloride Concentrations in F46/0344

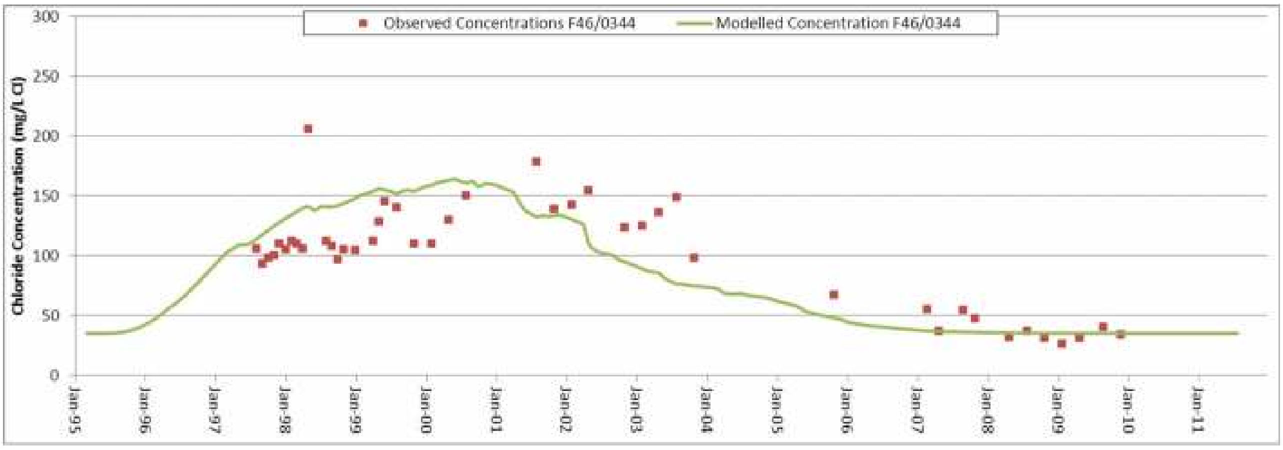


Figure 19c: Modelled and Observed Chloride Concentrations in F46/0336

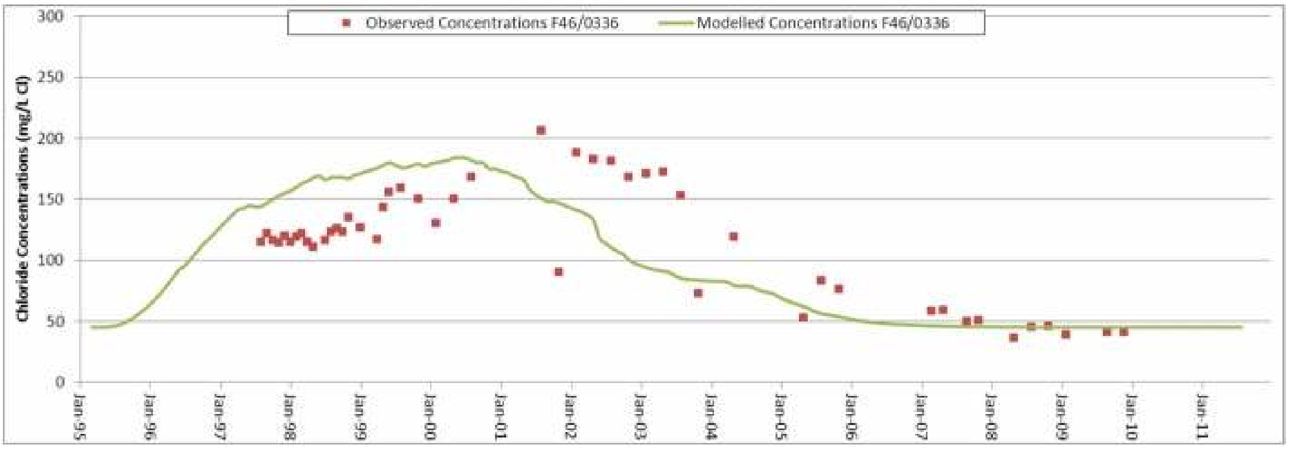
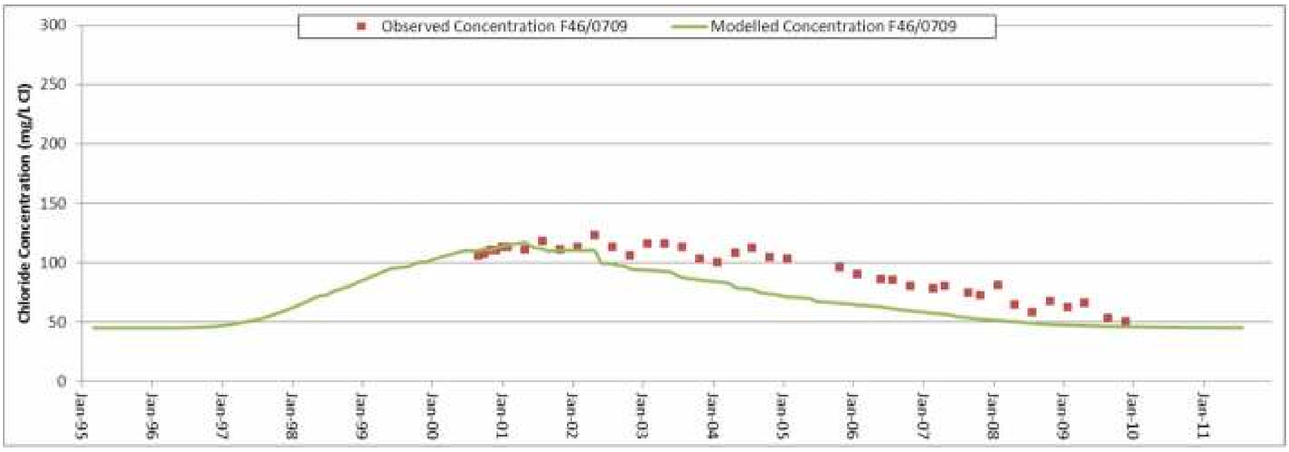
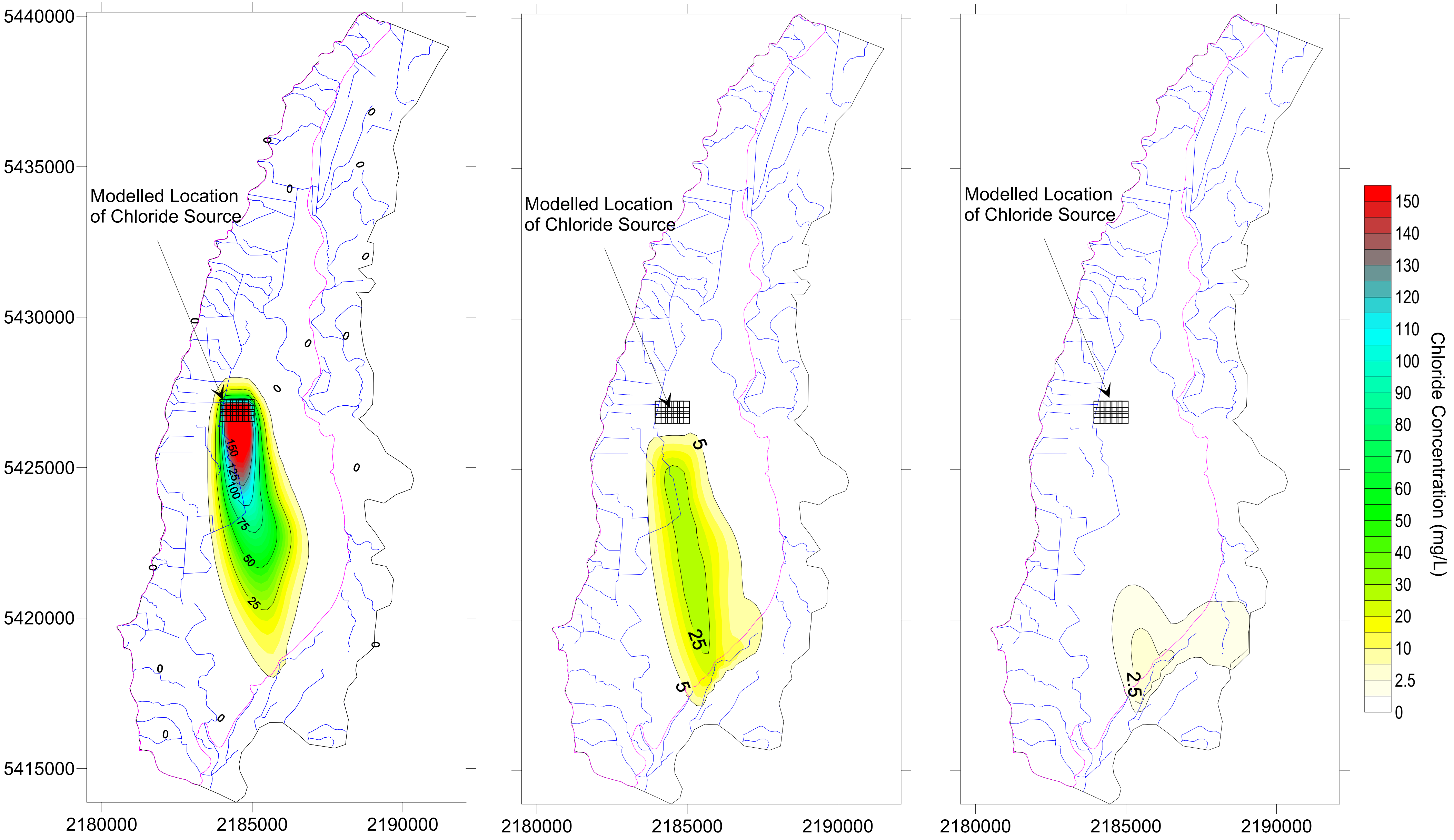


Figure 19d: Modelled and Observed Chloride Concentrations in F46/0709



Figures 19a to 19d: Modelled and Observed Chloride Concentrations

C02535 500 Edendale Groundwater Model



Plume extent at January 2000

Plume extent at January 2005

Plume extent at August 2010

Figure 20: Chloride Plume Extents (note concentrations exclude background concentrations)
Modelled source cell locations shown as a black blocks

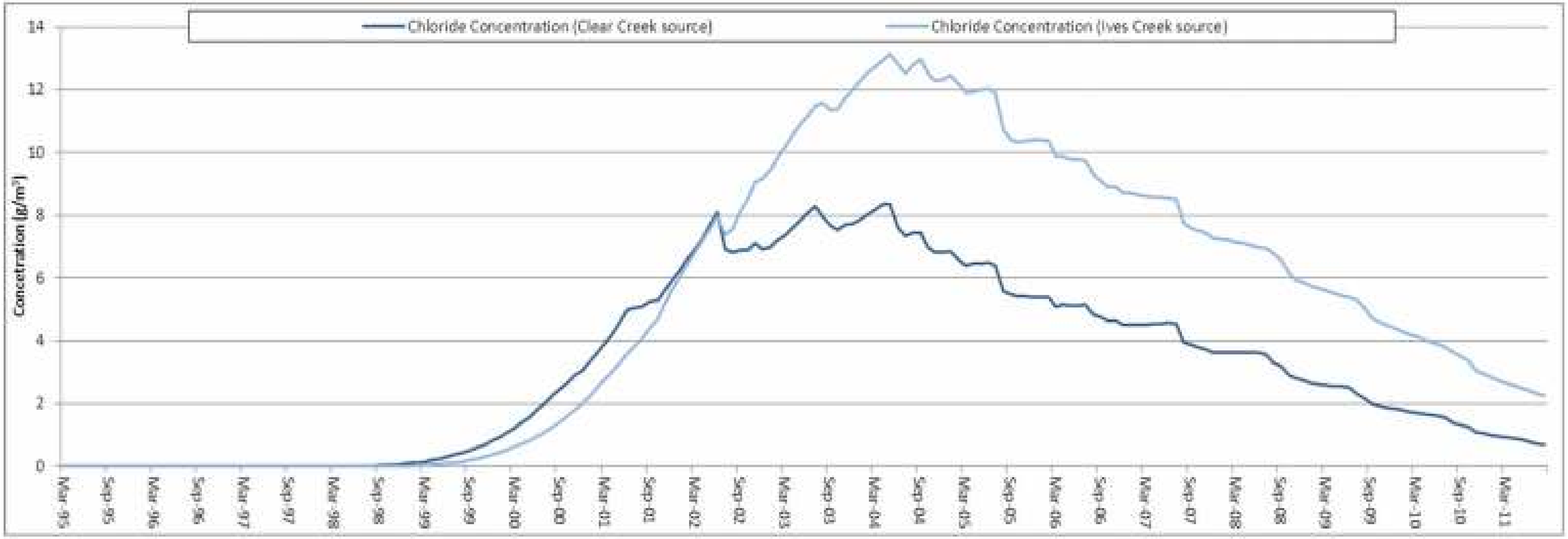


Figure 21: Modelled Chloride Concentration at Ives Creek and Clear Creek

Figure 22a: Modelled and Observed Nitrate Concentrations in F46/0185

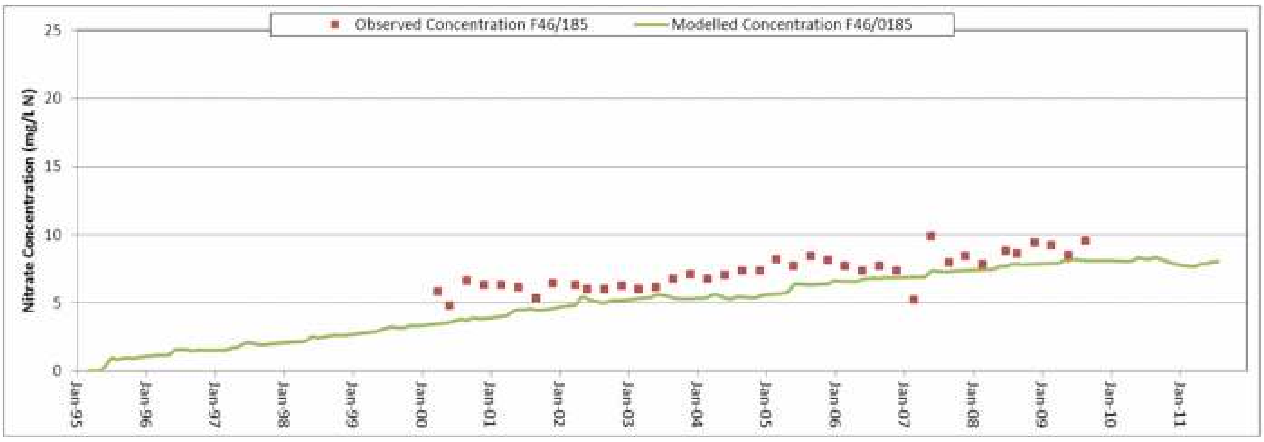


Figure 22b: Modelled and Observed Nitrate Concentrations in F46/0194

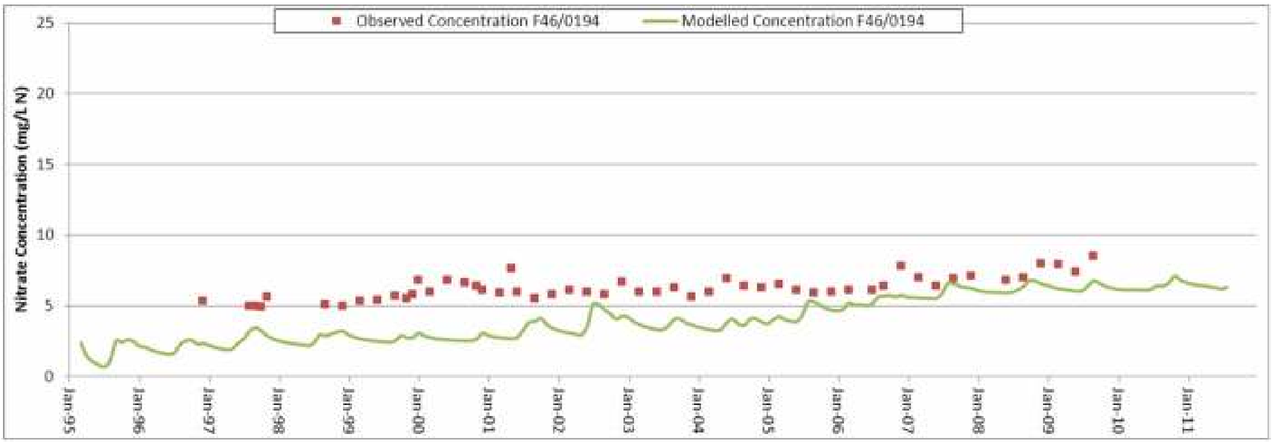


Figure 22c: Modelled and Observed Nitrate Concentrations in F46/0335

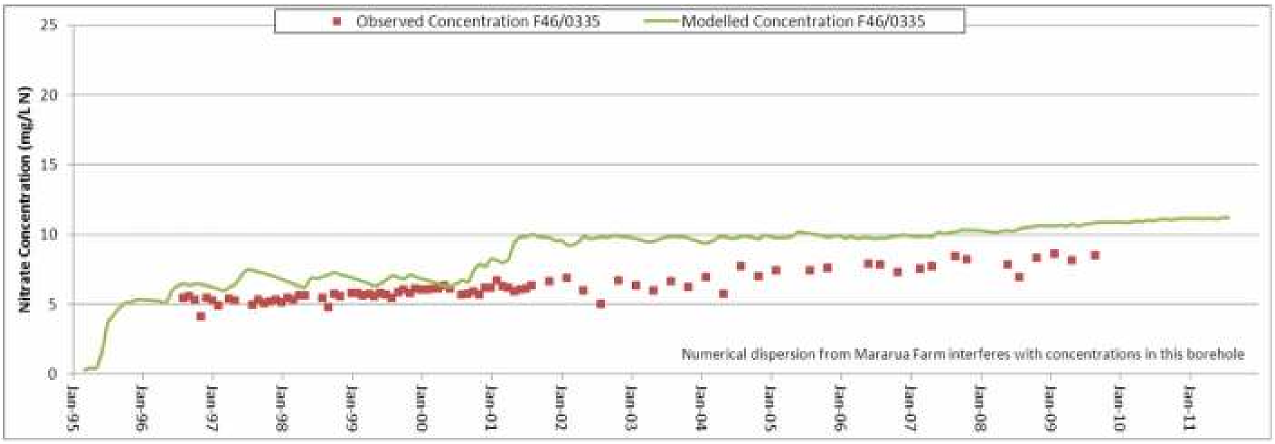
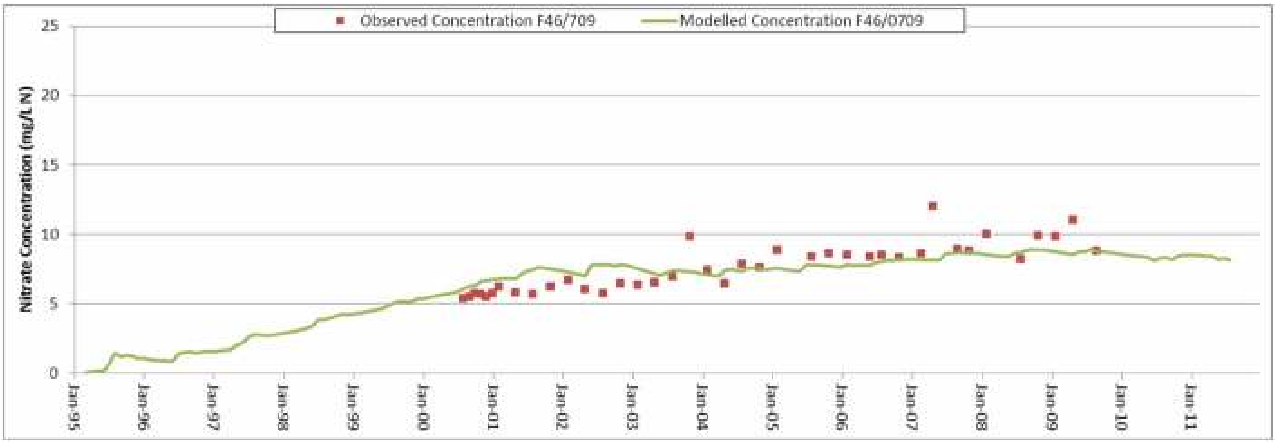


Figure 22d: Modelled and Observed Nitrate Concentrations in F46/0709



Figures 22a to 22d: Modelled and Observed Nitrate Concentrations (boreholes located away from dairy factory effluent disposal farms

Figure 22e: Modelled and Observed Nitrate Concentrations in F46/0246

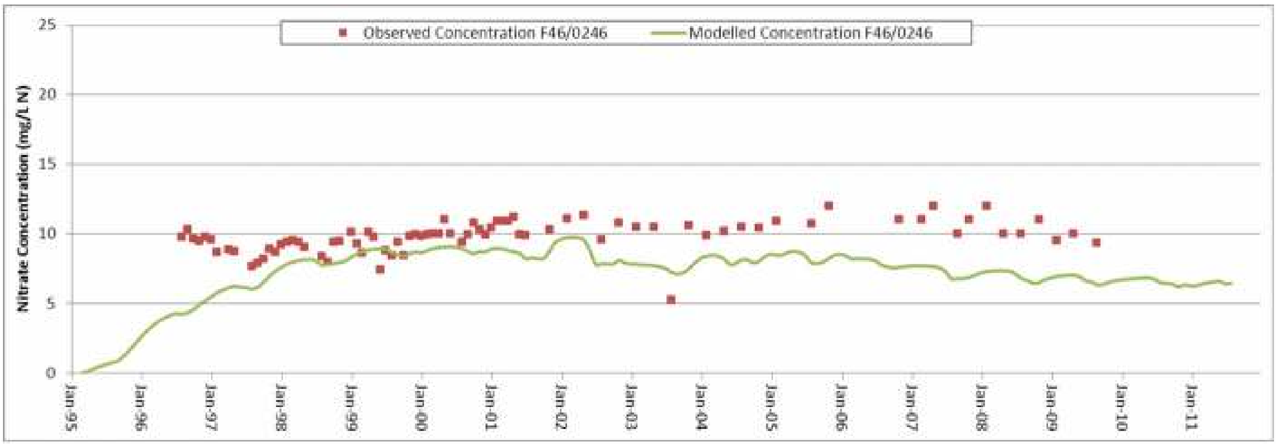


Figure 22f: Modelled and Observed Nitrate Concentrations in F46/0249

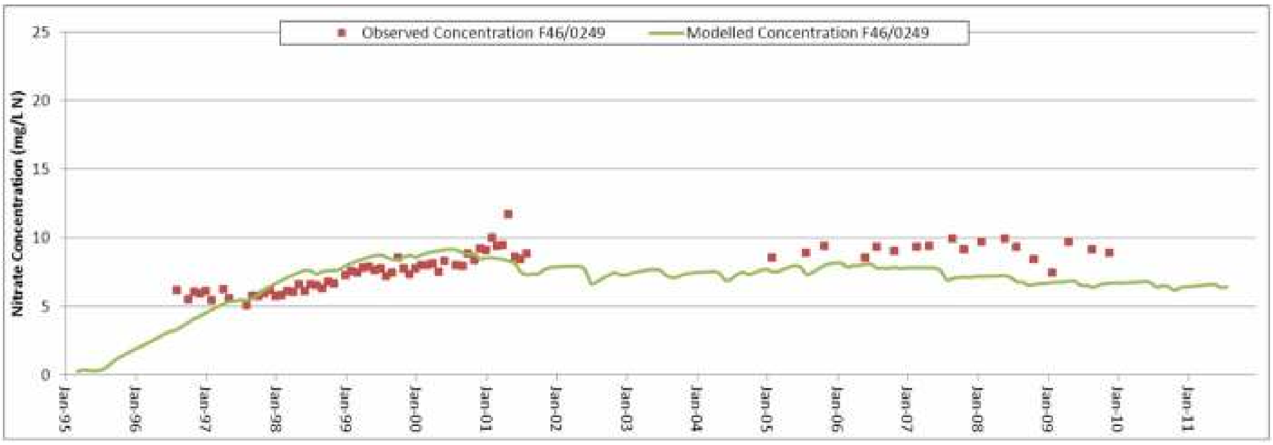


Figure 22g: Modelled and Observed Nitrate Concentrations in F46/0336

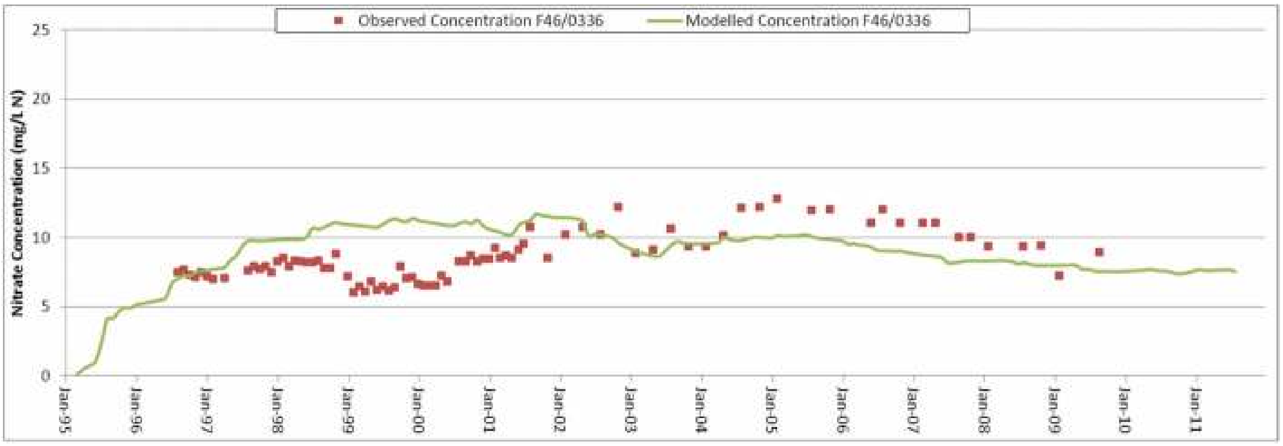
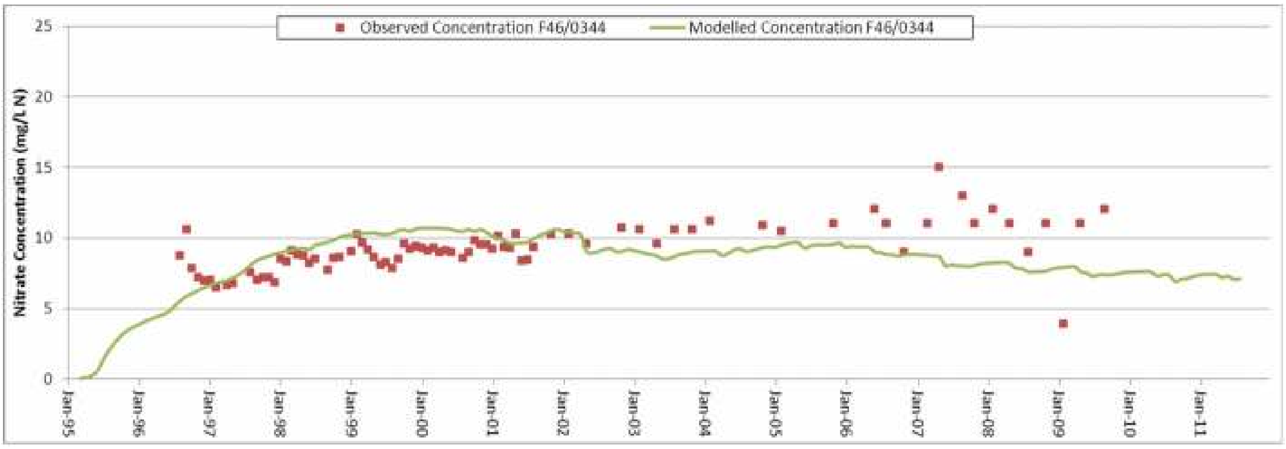
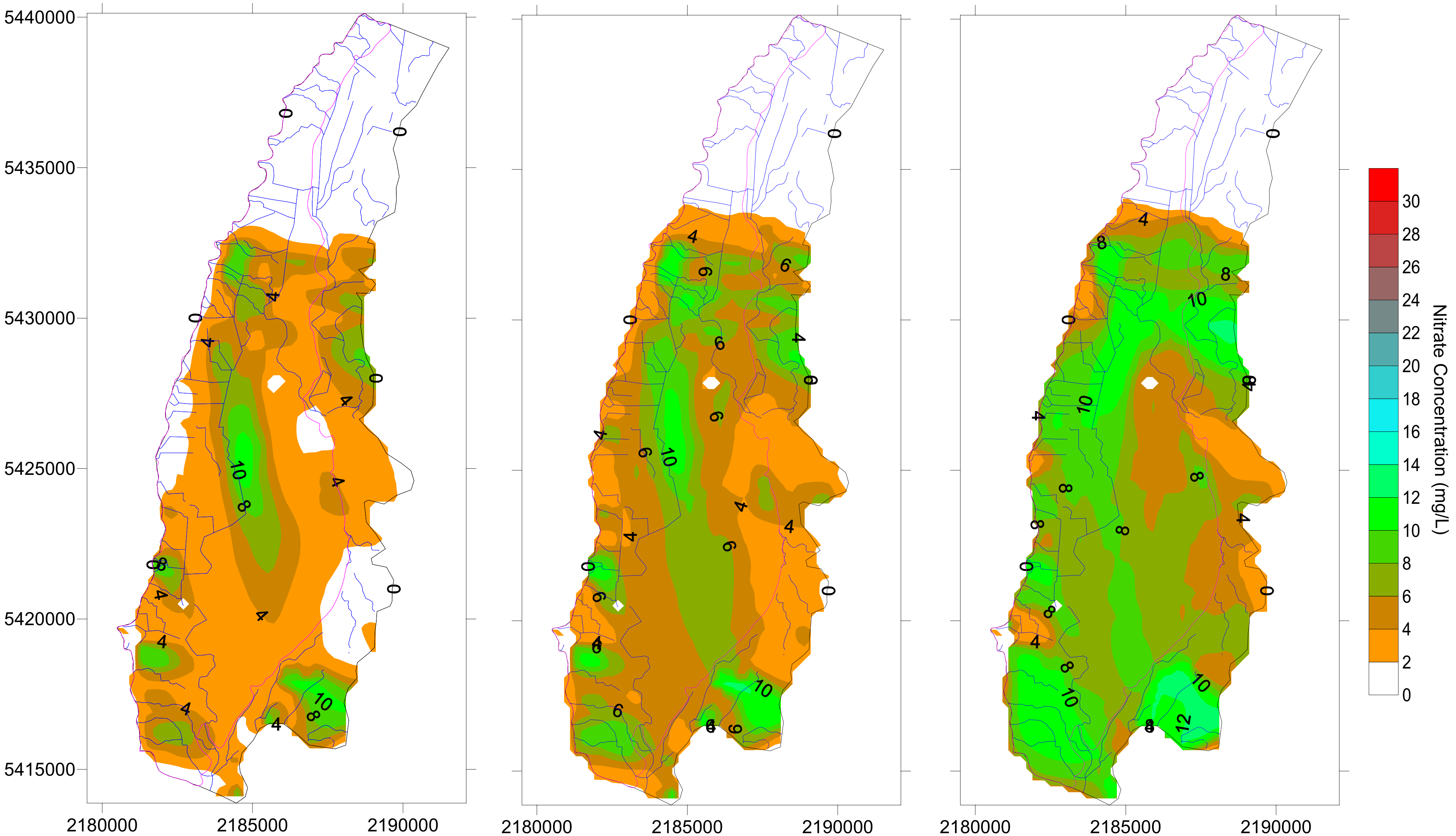


Figure 22h: Modelled and Observed Nitrate Concentrations in F46/0344



Figures 22e to 22h: Modelled and Observed Nitrate Concentrations (boreholes close to Mararua dairy factory effluent disposal farm



Modelled Nitrate concentrations at January 2000

Modelled Nitrate concentrations at January 2005

Modelled Nitrate concentrations at August 2010

Figure 23: Modelled Nitrate Concentrations

Figure 24a: Modelled Nitrate Concentrations at Ives Creek and Clear Creek

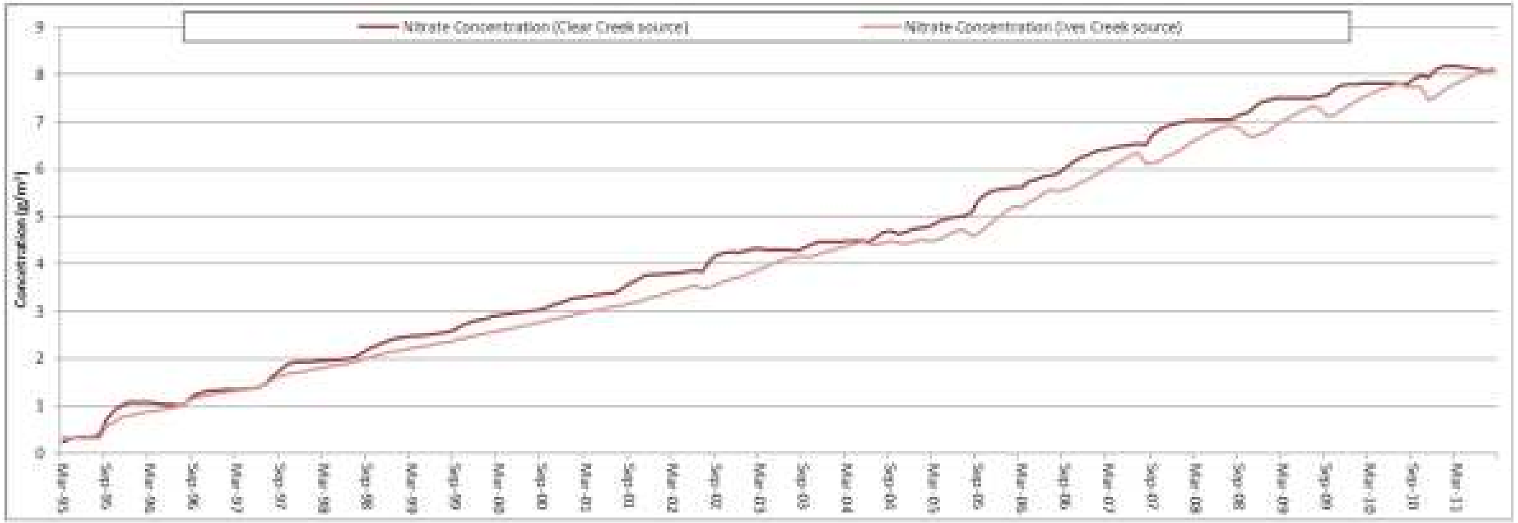


Figure 24b: Modelled Nitrate Loading Rates at Ives Creek and Clear Creek

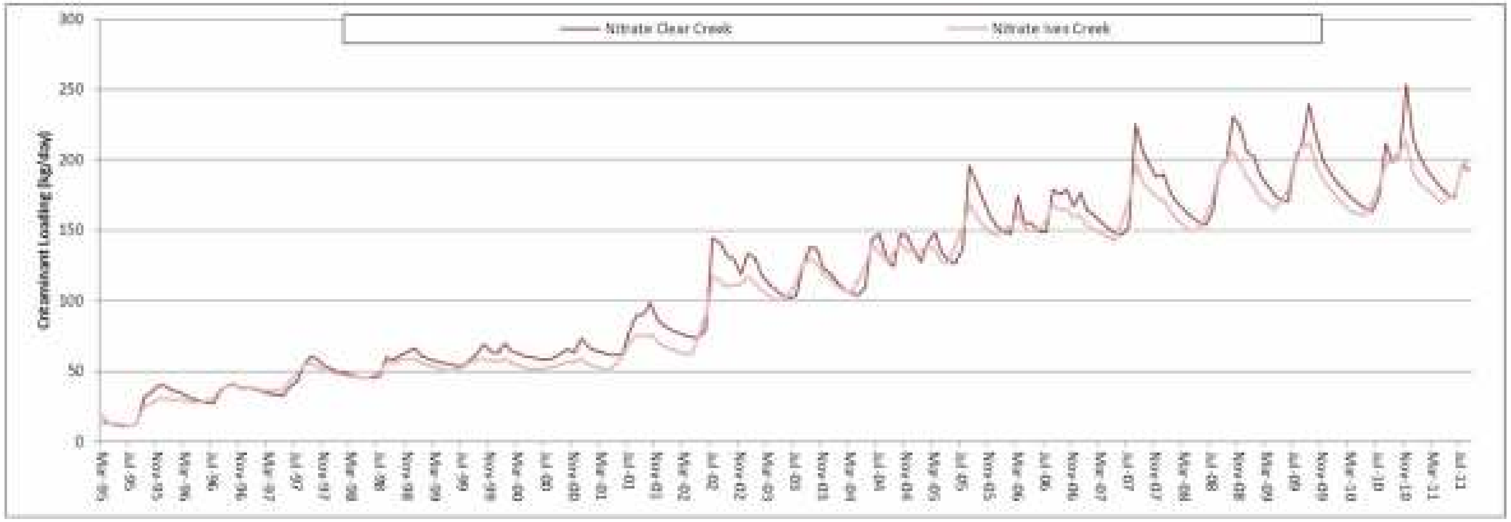


Figure 24a and 24b: Modelled Nitrate Concentrations and Loading Rates at Ives Creek and Clear Creek

Addendum to report C02535500 R002: Edendale Contaminant Model Sensitivity Analysis

Prepared for
Environment Southland

July 2012

Quality Control Sheet

TITLE	**Addendum to report C02535500 R002: Edendale Contaminant Model Sensitivity Analysis**
CLIENT	Environment Southland
VERSION	Draft
DATE	July 2012
JOB REFERENCE	C02535 500 R001
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Prepared by

SIGNATURE

Neil Thomas

Directed, reviewed and approved by

SIGNATURE

Peter Callander

Limitations:

The report has been prepared for Environment Southland, according to their instructions, for the particular objectives described in the report. The information contained in the report should not be used by anyone else or for any other purposes.

Table of Contents

Table of Tables

Appendices

1.0 Introduction

Pattle Delamore Partners were engaged by Environment Southland (ES) to develop a groundwater flow model, and associated contaminant transport model, for the Edendale Aquifer. The model was developed between October 2011 and April 2012. Subsequent liaison with ES regarding the model indicated that an assessment of uncertainty in the parameters used for contaminant transport would be useful to guide further development and use of the model.

This addendum presents an assessment of uncertainty regarding the results of the contaminant model. Full details of the model conceptualisation, construction and development are not provided in this addendum, and, therefore, this addendum should be read in conjunction with the main reports provided with the model (C02535500 R001 and C02535500 R002).

Section 1.1 of this report discusses the key parameters that influence the contaminant model calibration and asseses which are the main parameters that need to be varied as part of the uncertainty assessment. Section 2 discusses the results of the uncertainty assessment and Section 3 presents a conclusion based on the results of the assessment.

1.1 Factors influencing the contaminant model calibration

The results of the contaminant modelling indicated that the modelled concentrations showed good agreement with observed concentrations at various points across the model area, both temporally and spatially, suggesting that the model provided a reasonable representation of processes taking place within the aquifer. However, there are a number of factors that govern the modelled distribution of contamination throughout the aquifer and it is possible that a different combination of parameters could produce an equally good fit to the observed data. In addition, the results of the model may be more sensitive to the changes in the values of some parameters than others and therefore some parameters could vary by more than others.

The parameters which control the distribution of contamination within the modelled aquifer include the following:

- Modelled recharge to the model;
- Initial contaminant concentrations;
- Modelled hydraulic conductivity;
- Modelled porosity; and
- Modelled dispersivity values

Diffuse contamination is input to the model as a mass flux, which is calculated on a cell by cell basis depending on the recharge and concentration applied to that cell. Given that the contaminant flow is based on a reasonably well calibrated flow model, recharge is not considered to be a factor which should be varied as part of the uncertainty analysis for contaminant transport as changes to the recharge would also require changes to the flow model. However, modelled nitrate contaminant concentrations are based on an average values. They are therefore subject to uncertainty and will be varied as part of the sensitivity analysis. Initial concentrations of Chloride were unknown at the start of the project and were derived as part of the modelling process. Whilst there is therefore some uncertainty with regards to the initial Chloride concentrations, the extent of possible variations are unknown and there is little benefit in varying their concentrations as part of the uncertainty assessment.

The modelled hydraulic conductivity will affect the rate at which contaminants travel through the aquifer, however, in keeping with the approach used for recharge, hydraulic conductivity is based on calibration of the flow model and its potential variation has already been assessed as part of the flow model sensitivity analysis. That sensitivity analysis indicated that the model is sensitive to the value of hydraulic conductivity within the palaeochannel and around the southern end of the aquifer, close to where the springs emerge from the aquifer. Given that the value of conductivity within these two key areas is reasonably constrained, changing the values of these parameters may not be helpful in assessing the sensitivity of contaminant distributions as changes would result in changes to the calibration of the flow model on which the contaminant model depends.

The modelled value of porosity will have a strong effect on the velocity at which contaminants move through the aquifer, and as such will affect the rate at which concentrations within the aquifer vary both spatially and temporally. Porosity is often poorly constrained and in general limited field data is available to determine the most likely value, or its spatial distribution. The value of porosity will therefore be varied as part of the sensitivity analysis to determine its influence on the possible results. However note that porosity is the same as the specific yield within the aquifer which was varied as part of the flow model uncertainty analysis. The flow model uncertainty analysis indicated that the model is relatively insensitive to specific yield.

Modelled dispersivity within the model is not scale dependent, in that the value of dispersivity does not change with distance from a contaminant source and dispersivity is set to a defined value (in metres) at the start of a simulation. Within the model, Nitrates are modelled as a dispersed source and consequently dispersion is a much less significant factor controlling the resulting distribution of contamination. In contrast, Chloride is modelled as a point source and therefore the value of dispersion used will impact on the subsequent results.

In summary, the following parameters will be varied as part of the uncertainty assessment, based on the information described above:

- Initial contaminant concentrations;
- Modelled porosity; and
- Modelled dispersivity values.

The other parameters, recharge rate and hydraulic conductivity, have already been subject to a sensitivity analysis as part of the original groundwater flow model calibration described in report C02514500R002i2.

1.2 Factors varied as part of the sensitivity analysis

1.2.1 Initial Contaminant Concentrations:

The initial nitrate contaminant concentrations used in the model were derived from two sources, the first from known dairy factory wastewater concentrations which were applied to cells where the dairy factor wastewater disposal farms were present and the second from literature values of nitrate concentrations, where similar modelling was conducted by Rekker and Thorrold. The values were applied based on the known landuse information at different points in time.

Table 1 below provides a range of different concentrations for the different landuses present in the model area, based on literature values

Table 1: Possible Range of leached concentrations for different landuses

Landuse	**Baseline concentration (mg/L)**	**Potential Range of Concentrations (mg / L)**	**Comment**
Dairy	13.7	9.4 to 16.3	Range of concentrations taken from ECan lookup tables. Concentrations depend on irrigation practices and stocking rates
Sheep and Beef	2.6	Up to around 10	Higher concentrations have been observed in Canterbury, but range depends on irrigation and ratio of sheep to beef on farm. Low concentrations used in baseline are based on values from previous studies across the area.
Forestry	2.8	Up to 3.9	Low leaching values are typical of Forestry and nursery and the potential range is limited. Thorrold indicates higher concentrations than Rekker (3.9 mg/L to 2.8 mg/L)
Residential	16.3	-	Residential landuse makes up a very small part of the total landuse in the model area and its potential variation will have a limited effect.
Industry	0		The dairy factory in the area represents the key industrial activity in the area and wastewater from the factory is dealt with separately.
Dairy Factory Wastewater	-		Observed data is available for dairy factory wastewater concentrations which is used in the model.

1.2.2 Modelled Dispersivity

As noted above, dispersivity in the model is not scale dependent and values are set constant throughout the modelled simulation. Dispersivity values were altered as part of the Chloride modelling, to help match observed concentrations at wells distant from the Chloride source and were eventually set to values between 150 m and 1000 m depending on proximity to the source, with the smallest values set closest to the source. However there is some variation possible in the values used and with regard to the nitrate modelling a single global value (1000 m) has been used across the whole model, as the contamination does not originate from a point source. This value will be altered as part of the uncertainty analysis

Typically, dispersivity is in the order of 10 % of the travel distance for a contaminant downgradient of the source, depending on the type of aquifer encountered and the sinuosity of the travel path. The overall drainage points for the Edendale aquifer are the springs (Ives Creek and Clear Creek) that occur at its southern edge. Travel distances to these springs vary up to a maximum of around 10 km, suggesting that a dispersivity of around 1500 (15 %) m may represent the upper bound of dispersivity values. The lower bound has been assessed to be around 500 m (5 %), representing a limited degree of dispersion occurring within the aquifer.

1.2.3 Modelled Porosity

Groundwater velocity (and therefore solute transport velocity) is calculated as a function of the groundwater gradient, hydraulic conductivity and the porosity, and lower values of porosity will increase the velocity of groundwater flow. Porosity in the calculation is represented by effective porosity and is the same as the specific yield within the aquifer. During the sensitivity analysis for the flow model the specific yield was varied in the range 0.05 to 0.2, which are typical values of specific yield within a gravel aquifer and a similar range will be used as part of the uncertainty analysis for the contaminant model.

2.0 Results of uncertainty analysis

Results from the uncertainty analysis for the nitrate contamination model are presented in Table 2 and in Figures 1 to 6. Note that the effect of varying two parameters simultaneously has not been assessed. All parameters were varied between their maximum and minimum values, as discussed in Section 1.2.

Note that a similar uncertainty analysis has not been undertaken for the Chloride contamination model. The Chloride contamination model was based around point source contamination and, given that the initial concentrations simulated using the model were altered to match the observed groundwater quality results, changes to the initial concentrations are considered unnecessary.

Table 2: Sensitivity Analysis (Nitrate contamination).

Model Parameter	Sensitivity (and effect)	Conceptual Range of values (and selected value)	Resulting Range in RMSE[1] values for Bore Concentrations (RMSE for selected value)
Initial Concentrations	High (distribution of contamination)	See Table 1	0.06 (0.5 to 0.56) (0.51)
Dispersivity	Medium (distribution of contaminants)	500 to 1500 **(1000)**	0.015 (0.50 to 0.515) (0.51)
Effective Porosity	Very low (distribution of contaminants)	0.05 to 0.2 **(0.15)**	0.002 (0.509 to 0.0511) (0.51)

1. Bore concentrations taken from 2009 Nitrate Survey

The results presented in Table 2 indicate that the key parameters governing the modelled distribution of contaminants are the initial concentrations and the dispersivity value used in the model. Neither of these parameters are well constrained and both have been adjusted to achieve a ‘best ‘fit with the observed data.

Figures 1 and 2 present the results of different initial concentrations in two representative boreholes within the model area and Figure 5 shows the resulting difference in the spatial pattern of concentrations for September 2009 (the same year for which a survey of nitrate concentrations took place). Whilst the overall effect is unsurprising, in that higher input concentrations result in higher modelled concentrations, the relative difference between the higher input scenario, compared to the baseline scenario and the lower input scenario compared to the baseline scenario is notable. However, based on a comparison with the observed levels, the concentrations within the baseline simulation appear to be reasonable and overall the plots indicate that it is unlikely that the initial concentrations are subject to significant variation.

Similarly, Figures 3 and 4 present the results of different dispersivity values on the model results in two boreholes and Figure 6 shows the spatial pattern of concentrations for September 2009. The results indicate that relatively widely varying values of dispersion could be used to fit the modelled results to the observed data equally well, suggesting that the model is insensitive to the value used.

The results of the sensitivity analysis for effective porosity presented in Table 2 indicate that the model is very insensitive to the value of porosity used and that relatively large changes in its value have little effect on the modelled distribution of contamination. This result is largely in keeping with the results of the sensitivity analysis for the flow model, which indicated that the modelled heads are relatively insensitive to the value of specific yield.

3.0 Conclusion

The results of the analysis above indicate that the model is most sensitive to the values of the initial concentrations input into the modelled recharge, However, given that the model is relatively insensitive to the values of other key parameters that affect contaminant transport, for example dispersivity and effective porosity, the value of the initial concentrations can be reasonably well constrained by comparison with the observed data. This result is to be expected as the nitrate model simulates a continuous and dispersed source of contamination and dispersion and effective porosity often have more influence on the pattern of a single plume of contamination originating from a point source. Such a plume of contamination has been previously identified within the Edendale Aquifer, resulting from Chloride contamination originating from the Mararua wastewater disposal farm. Modelling of this plume used baseline values of effective porosity and dispersivity and indicated good agreement with observed values, providing confidence in the baseline values used.

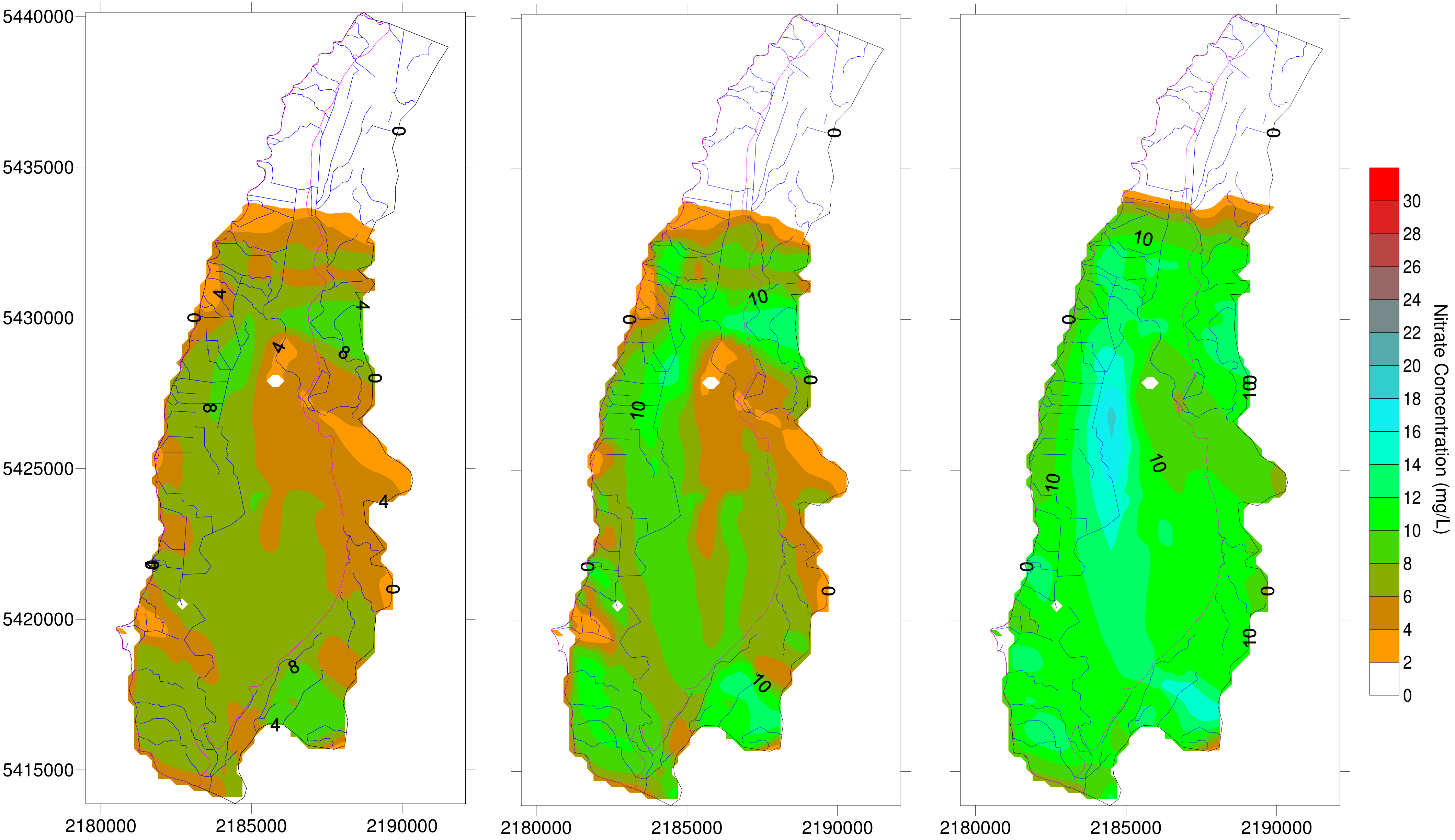
Figure 1: Observed and Modelled Nitrate Concentrations at F46/0336 under high, baseline and low concentrations

Figure 2: Observed and Modelled Nitrate Concentrations at F46/0709 under high, baseline (average) and low concentrations

Figure 3: Observed and Modelled Nitrate Concentrations at F46/0336 under high, baseline (average) and low dispersivities

Figure 4: Observed and Modelled Nitrate Concentrations at F46/0709 under high, baseline (average) and low dispersivities

C02535 500 Edendale Groundwater Model

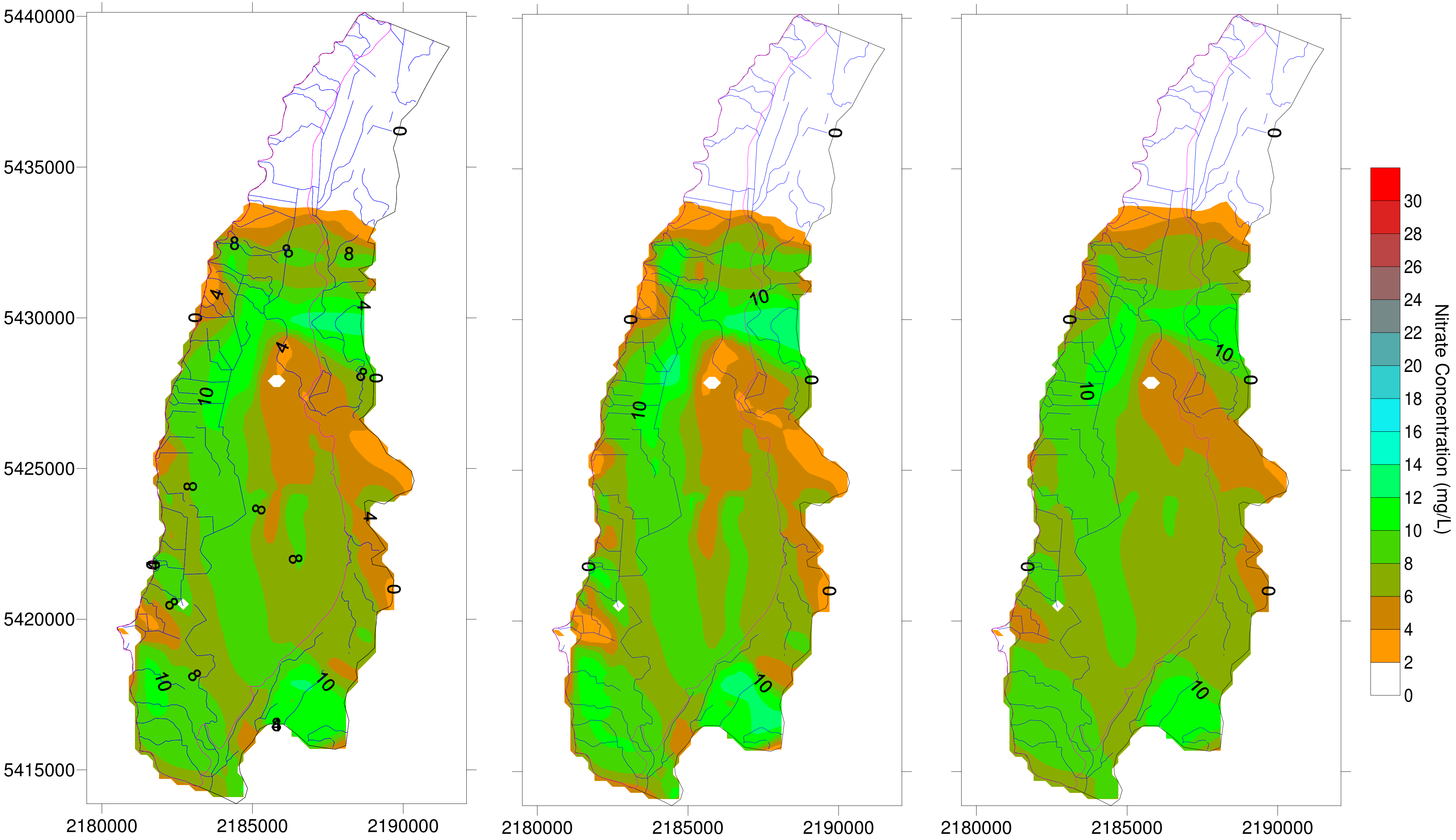


Modelled Nitrate concentrations
at September 2009 (Low concentrations)

Modelled Nitrate concentrations
at September 2009 (Baseline, average concentrations)

Modelled Nitrate concentrations
at September 2009 (High concentrations)

Figure 5: Modelled Nitrate Concentrations under different initial concentrations



Modelled Nitrate concentrations
at September 2009 (Dispersivity = 500 m)

Modelled Nitrate concentrations
at September 2009 (Baseline, dispersivity = 1000 m)

Modelled Nitrate concentrations
at September 2009 (Dispersivity = 1500 m)

Figure 6: Modelled Nitrate Concentrations under different dispersivity parameters