NORTHERN SOUTHLAND GROUNDWATER MODEL

- 24 September 2004

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Contents

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1. Introduction

Demand for groundwater has increased in the mid-Mataura region in recent years. Public perception regarding the value of water and quantities available have also changed, and concerns over the effect of the new water allocations on spring flows and water levels in domestic bores have also been raised. These changes have increased the importance of gaining an improved understanding of the aquifer systems and quantity of groundwater available, which would enable Environment Southland (Environment Southland) as the water regulators, to make informed decisions with respect to water allocation resource consent applications.

In May 2003, Environment Southland commissioned Sinclair Knight Merz (SKM) to conduct a groundwater modelling study to assess the sustainable yield of the Riversdale Aquifer Management Zone (Riversdale Aquifer Management Zone Preliminary Sustainable Yield Assessment, SKM, 2003). Following the recommendations of this report, Environment Southland carried out fieldwork to address data-related model limitations identified during the first modelling stage. Subsequently, in May 2004 Environment Southland commissioned SKM to carry out a second stage of groundwater modelling work, extended to include the Waipounamu and Wendonside aquifers in addition to the Riversdale and Longridge Aquifer Management Zones. Collectively this is referred to as the Northern Southland Model.

This report documents the aquifer conceptualisation and model build processes for the second stage of the study. It presents results from the preliminary (transient) groundwater modelling assessment of aquifer sustainable yield and provides recommendations for future refinement of the model and understanding of the aquifer system.

The primary resource management issue for this project is that of stream flow depletion in the Mataura River and spring-fed streams resulting from groundwater abstraction within upgradient aquifers. This is the major constraint on abstraction activities in the Mataura Catchment. There are currently two pieces of current or proposed legislation relating to this issue:

- The Mataura River Water Conservation Order (1997), which effectively states that the flow at any point on the river cannot be reduced by more than 5% of the natural volume. Specific to this study is Environment Southland's interpretation that groundwater allocation in the mid-Mataura catchment be managed to ensure that no more than a 5% reduction in catchment yield is observed at the Otamita flow gauging station.
- The Proposed Regional Freshwater Plan for Southland (currently at Variation 2) will concern effects to spring-fed streams. Currently, the plan specifies a minimum flow of 66% of 7-day mean annual low flow (MALF) in streams with a MALF of less than 1 m^3/sec and all of the streams in the study area are within this cut off. These limits are likely to be interpreted such that the maximum allowable effect on stream discharge as a result of groundwater abstraction is a 33% reduction in flow.

The numerical model has been constructed to achieve the following objectives:

- Continue to improve understanding/conceptualisation of aquifer hydrogeology,
- Provide an improved means of assessing sustainable limits for groundwater abstraction in the area, and
- Quantify as far as possible the likely impacts of groundwater abstraction on stream flow within surface water bodies and particularly the Mataura River.

To achieve these objectives, the following tasks were proposed and agreed:

- Extension of the existing Riversdale model to include the Waipounamu and Wendonside aquifer zones, and
- Carry out preliminary transient calibration using all available hydrological data.

2. Available Data

Various data sets provided by Environment Southland unless otherwise stated have been collated for this study and are summarised in table 1. Original data has been manipulated for the purposes of this study and file pathways for relevant spreadsheets/documents are provided in Table 1.

- **Table 1. Summary of available data sets**

Category	Data Set	File Path*
Topographical and Hydrogeological	Topographic point data (20 m contour) from Land Information New Zealand (LINZ)	[1]…drawings\surfer\contour.dxf
	River and spring elevation survey data for the Mataura and Waikaia rivers and main spring fed streams	[2]…River and Spring Elevations.xls
	Test pumping results (hydraulic conductivity)	[2]…K Values.xls
	Available bore logs to aid in characterising aquifer lithology and estimate aquifer geometry	[2]…Bore Logs.xls
Aquifer Stresses	Permitted (consented) extraction volumes	[2]…Abstraction Consents.xls
	Historical rainfall and evaporation datasets obtained from NIWA	[2]…Dailyrain.xls
	Local recent rainfall data	[2]…Rainfall sites.xls
Ground and Surface Water Monitoring	Monthly and daily groundwater level data was for total of twelve monitoring bores	[2]…Groundwater Levels.xls
	Piezometric survey data including all bores in the project area (October 2002 and March 2004)	[2]…Piezo Survey Data.xls
	Concurrent flow gauging data for locations on the Mataura and Waikaia rivers and Meadow Burn	[2]…Flow Gaugings.xls
	River stage height data for the Mataura and Waikaia rivers	[2]…Stage Heights.xls

*SKM Network Directories:

1. I:\AENV\AE02092\WP01_Riversdale Model\…
2. I:\AENV\AE02092\WP02_Northern Southland Model\Data\Environment Southland\data…

3. Regional Setting

3.1 Hydrology

At 160 km in length and with, The Mataura is the second largest of the four major river catchments in Southland with an area of 5,360 km^2. It is 160 km long with an average width of 40 km (maximum 50 km) and the mean annual discharge is 97 cubic metres per second.

The river follows a 240 km course from headwaters in the Eyre Mountains south of Lake Wakatipu down to the south coast at Fortrose in Toetoes Bay, to the east of Invercargill. Three distinct gradient profiles are observed along it's course, a steep upper section upstream of Garston (altitude 305 m), an intermediate section from Garston to Gore (altitude ~50 m), and the lowlands section from Gore to the estuary at Fortrose.

The project area is within the mid-section of the catchment where the Mataura has numerous small- and a number of medium-sized tributaries. Also within the mid-catchment is the confluence with the Mataura's largest tributary, the Waikaia. The Waikaia River's catchment area (1,360 km^2) and it's flow are about equal to that of the Mataura immediately upstream of their confluence (SRC, 1995).

3.2 Geology and Hydrogeology

A review of the 1:250,000 scale geological map (sheet 24, Invercargill) shows that the geology of the study area consists of Quaternary age fluvio-glacial outwash deposits overlying Tertiary sedimentary sequences of varying thickness that sit unconformably within basins and faulted basins of Mesozoic basement rocks.

Quaternary deposits are the primary aquifer and groundwater resource in Southland (SRC, 1995). The outwash deposits comprising gravels, till and moraine act as a thin unconfined aquifer from which there are a number of abstractions including those supplying the towns of Riversdale, Gore and Mataura. Reworking of the gravels by different outwash events and general fluvial processes of the Mataura River has formed at least six recognised terraces. Older, less permeable deposits form the upper levels, while the valley floor comprises recent gravels exhibiting very high permeabilities. In the Mataura River catchment, seepage from the gravel aquifers provides a significant contribution to stream and river baseflow.

The underlying Tertiary sequence is known as the Gore Lignite Measures and consists of conglomerates, sandstones, siltstones and mudstones with laterally continuous lignite seams. The succession is consistent with the steady build up of a large river flood plain and delta covering much of Eastern Southland (SRC, 1995). Permeabilities within the Tertiary aquifers range from low to moderate, with highest yields are generally obtained from sandstone and conglomerate units.

The Mesozoic basement rocks are highly deformed and altered sedimentary sequences with little remaining primary pore space and consequent low permeability. Minor hard rock aquifers serving a limited number of abstractions in the catchment headwaters are generally controlled, along with groundwater flow, by secondary porosity features including fissures, fractures and foliation planes.

3.3 Local Catchment Hydrology

3.3.1 Project Area Extent

The project area comprises a large portion of the mid-Mataura catchment. The aquifer management zones in question encompass a triangular region of approximately 286 km² between the townships of Ardlussa, Waikaia and Otamita and including the confluence of the Mataura and Waikaia rivers. Otamita is situated approximately 10 km north of the town of Gore (see Figure 1).

- **Figure 1. Project area and aquifer management zones**

  (See A3 pull out at rear)

3.3.2 Sub-catchment Boundaries

Figure 2 displays a total of X sub-catchment watersheds within or connected to the project area. The catchments have been defined in terms of major streams present and therefore, small streams in areas such as those along the eastern bank of the Waikaia have been included as one catchment. Of interest for this study are catchments of spring fed streams and those known, or likely to provide additional (runoff) recharge input along the edges of the model domain. Those sub-catchments identified as likely to be significant in this respect are summarised in Table 4 and labelled on Figure 2:

- **Figure 2. Sub-catchment boundaries**

  (See A3 pull out at rear)

Conceptualisation of aquifer losses to spring fed streams is detailed in Section 4.3, while aquifer recharge from hardrock sub-catchment streams is considered in Section 4.2.2.

3.3.3 Rainfall and Rainfall Distribution

Annual average rainfall (mm), calculated from data for stations at Mandeville, Kaweku, Otama, Balfour and Wendon is summarised in Table 2.

- **Table 2. Rainfall data summary**

Rainfall Station	Period of Record (years)	Mean Annual Average (mm)
Mandeville	Feb 1998 – Oct 2004	971
Wendonside	Jan 1985 – Sep 2004	898
Balfour	Mar 1986 – May 2004	866
Otama	Jan 1972 – Oct 2004	817
Kaweku	Jan 1967 – April 1995	894

The data was used to create a rainfall gradient plot, presented in Figure 3.

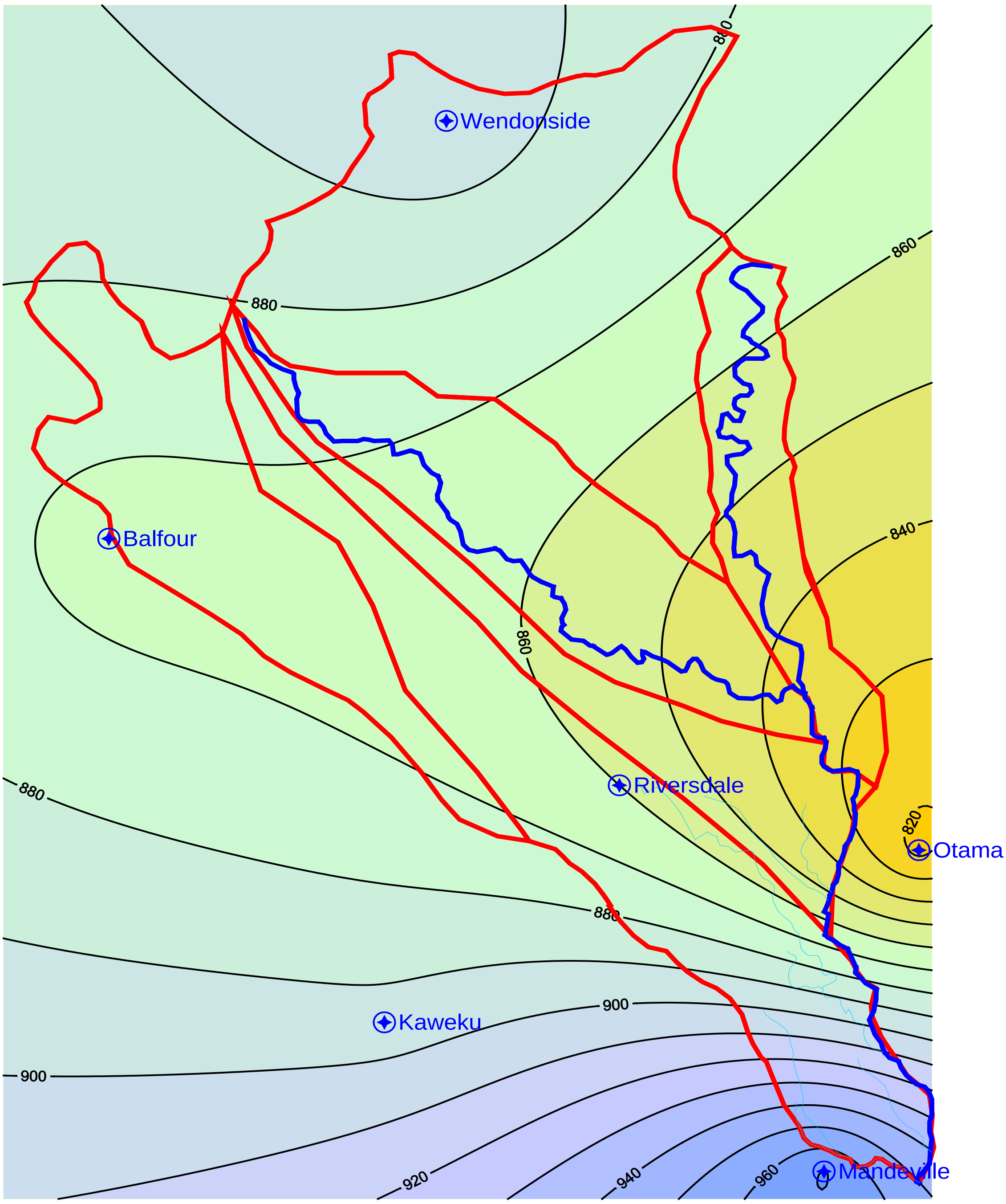


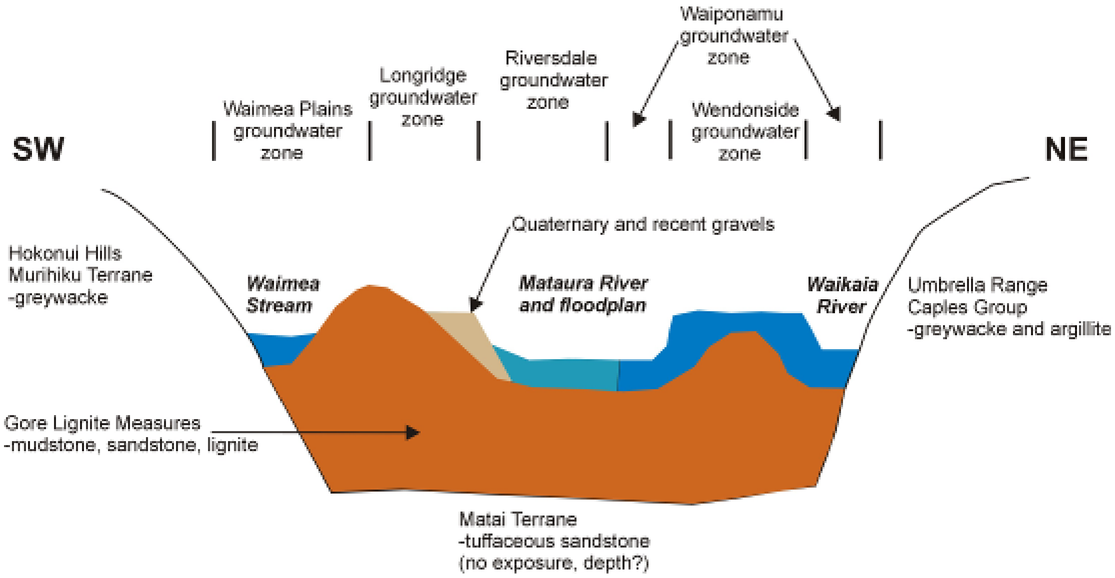
Figure 3. Rainfall Distribution Gradient

Analysis of Figure 3 indicates a difference in annual average rainfall of up to 100 mm between the low-lying areas such as Riversdale plains and surrounding hills.

4. Aquifer Conceptualisation

4.1 Groundwater Management Zones

Figure 1 displays the groundwater zone boundaries for the Northern Southland aquifer management zones and surrounding aquifers. The transect line included on Figure 1 (southwest to northeast) identifies the location for the schematic drawing in Figure 4.



- **Figure 4. Schematic cross-section of the mid-Mataura catchment**

4.2 Aquifer Recharge

Aquifers receive recharge via a number of mechanisms including rainfall (areal) recharge, seepage from rivers/streams, and aquifer flow connection (throughflow from adjacent aquifers).

4.2.1 Rainfall Recharge

Rainfall recharge values have been derived through water balance analysis for catchment areas deemed to have similar hydrological properties, summarised as follows:

- relatively high permeability river-connected aquifer zones (Riversdale and Waipounamu)
- less permeable upper terrace aquifer zones (Longridge and Wendonside), and
- peripheral hardrock sub-catchments which discharge runoff into the model domain

Each water balance was assessed through simulation of a daily soil moisture water balance model (SMWBM). Daily rainfall data for Otama (since 1972) and mean monthly evaporation for Gore were used for modelling of the river-connected aquifers. For the upper terrace aquifers and peripheral hardrock catchments, rainfall data coverage periods were incomplete (see Table 2). Gaps in these data were addressed by applying a multiplication factor to the Otama record, derived from the difference in annual average rainfall distribution (see Table 1). Rainfall distribution is such that the upland peripheral catchments are likely to receive higher inputs of rainfall recharge than lower areas of the project area.

For the river-connected aquifer zones, soil parameters used were taken from results of investigations at a nearby site (SKM, 2004). These parameters were then adjusted to account for expected conditions in remaining areas of the model domain. The main considerations included decreasing permeability with elevation of the gravel terraces (see Section 3.2) and the relative low permeability of the Gore Lignite Measures exposed in the peripheral hardrock catchments. Decreasing permeabilities are likely to result in increasing partition of rainfall recharge to runoff.

Results of the SMWBM simulations are summarised in Table 3 and the model parameters and values employed for this study are detailed in Appendix A.

- **Table 3. Catchment water balance summary**

	Proportion of Annual Rainfall			
Component	**Riversdale / Waipounamu**	**Longridge**	**Wendonside**	**Upland Sub-Catchments**
Interception Losses (%)	29.0	29.0	33.7	29.0
Surface Runoff (%)	3.8	4.0	3.9	30.0
Soil and Plant Evaporation (%)	28.1	31.4	29.2	30.5
Rainfall Recharge (%)	38.8	35.4	33.1	12.9

Table 4 presents the likely average daily rainfall recharge for each aquifer as determined from the SMWBM data and areas derived from ArcMap geographical information software.

- **Table 4. Summary of average areal recharge volumes**

	Area		Recharge		
Aquifer Zone	**m²**	**km²**	**% ann. rainfall**	**l/sec**	**m³/day**
Riversdale	98,415,309	98.4	37	937.6	81,008
Waipounamu	56,765,872	56.8	37	798.2	68,964
Longridge	43,928,057	43.9	33.7	678.2	58,593
Wendonside	87,238,319	87.2	33.7	1346.8	116,363
Total	286,347,557	286.3	-	3761	324,928

4.2.2 River/Stream Seepage and Aquifer Flowthrough Recharge

Riversdale Aquifer Zone

As shown in Figure 1 and Figure 2, the Riversdale aquifer zone is delineated to the west by boundaries with the Longridge and Waimea Plain zones and to the east by the Mataura River, which separates the Riversdale and Waipounamu aquifer zones.

Analysis of the river/aquifer water balance (refer Section 2.2.4 below) and SMWBM indicates that seepage from the Mataura River along this reach is a significant input to the Riversdale aquifer system along with areal recharge. It is not known whether throughflow occurs between the Waipounamu and Riversdale zones (beneath the river), however analysis of piezometric contours in Figure shows that groundwater flow in that part of the model domain is perpendicular to the river and therefore throughflow is unlikely to be significant if any. Throughflow from the Longridge and Waimea zones is likely to provide recharge to the western Riversdale margin, although at less significant quantities than other recharge sources.

Waipounamu Aquifer Zone

The Waipounamu zone is chevron-shaped and can effectively be considered as two sub-zones with boundaries running either side of the Wendonside aquifer. The western limb follows and is bounded by the Mataura River and is referred to as Waipounamu-Mataura, while the eastern limb encompasses the Waikaia River, is bounded to the east by hills comprising surface exposures of the and is referred to as Waipounamu-Waikaia.

Analysis of the river/aquifer water balance indicates that there is no seepage to the aquifer from the Waikaia River and SMWBM results indicate areal recharge is the most significant recharge input. Piezometric contours indicate that throughflow from Wendonside may recharge the relevant margins, but again is considered unlikely to of significance and the Gore Lignite Measures are similarly considered due to their generally low permeabilities. As discussed earlier, throughflow between Riversdale and the Waipounamu-Mataura is also considered unlikely.

The Longridge and Wendonside Aquifer Zones

The Longridge aquifer zone is bounded by the Riversdale aquifer to the east, Waimea to the southwest and by hills comprising exposed Gore Lignite Measures to the northwest. Wendonside is bounded by the Waipounamu zone to the south and east, Cattle Flat aquifer to the northwest, and by Gore Lignite Measures to the north. Both Longridge and Wendonside are upper terrace aquifers primarily receiving areal recharge. Possible throughflow inputs from the Gore Lignite Measures are again considered to be insignificant, however runoff recharge from hard rock catchment streams is likely to be significant along relevant margins.

4.2.3 Recharge from Peripheral Hardrock Catchments

Hardrock catchments to the north of Longridge and Wendonside, and to the East of Waipounamu-Waikaia (see Figure 2) are likely to provide a further recharging element along relevant boundaries. Due to the low permeability of these catchments, much of the rainfall recharge input will be partitioned directly to runoff. When streams exiting the hills reach the terraces, they may then loose their flow to and recharge the more permeable gravel aquifers, as is observed for Boundary Creek. Boundary Creek is shown on Figure 2 as running across the surface of the Wendonside aquifer, however information from Environment Southland has indicated that stream flow generally disappears a short distance after crossing onto the surface of the Wendonside gravels. Additionally, groundwater throughflow from these catchments is also likely to act as a recharge source for adjacent aquifer zones, albeit for much less significant volumes.

Table 5 lists the relevant catchments and details estimated runoff and throughflow recharge volumes that may be available as inputs to the relevant aquifers, determined from SMWBM data (see Section 4.2.1).

- **Table 5. Summary of average runoff recharge and total catchment discharge for main peripheral catchments**

	Area outside model domain		Runoff Recharge		Total Catchment Discharge	
Aquifer Zone	m²	km²	% annual av. rainfall	m³/day	annual av. rainfall	m³/day
Boundary Creek	5,925,663	5.9	26.1	3,674	35.4	5,507
Wendon Stream	47,603,029	47.6	27.5	42,879	39.7	31,418
Waikaia Eastern Catchments	32,850,290	32.9	27.5	7,825	39.7	10,679
Pyramid Creek	24,226,942	24.2	16.5	9,556	36.6	20,084
Total	180,095,786	180	126	91,040	194	156,849

Modelling was also carried out for the Garvy Burn and Longridge Creek catchments, however when included in the groundwater modelling, the influence of input from these catchments was considered to be insufficent to warrant their inclusion within the final calibration simulation.

4.3 Groundwater/Surface Water Interaction

Environment Southland carries out concurrent flow gauging at a number of locations on the Mataura and Waikaia rivers. Further flow gauging is carried out at locations on the main spring-fed streams within the model domain. Analysis of the flow gauging information provides an indication of flow losses and gains through different reaches of the river and gauged streams. This information is summarised in Tables 6 and 7 below and diagrammatically in Figure 5. Also included in the tables are the general head boundary nodes that correspond to flow gauge locations (see Section 4.4).

- **Figure 5. Concurrent gauging locations and river mass balance**

  (See A3 pull out at rear)

River flow data for the 11 April 2003 and stream flow data for the 16 April 2003 have been utilised as these data sets are near complete and are closest to the same time of year that the area-wide piezometric survey was carried out (March 2004, see Section 4.4).

- **Table 6. Concurrent flow gauging data: Mataura and Waikaia Rivers**

River Reach	Flow (L/Sec)	(m3/day)	Model Nodes
Upper Mataura River			
Mataura River at Ardlussa	6,497	561,341	M2
Mataura River at Riversdale Bridge	5,132	443,405	M6
River loss to aquifer	*1,365*	*117,936*	
Waikaia River			
Waikaia River at Pyramid-Waiparu Rd	6,173	533,372	W2
Waikaia River at Waipounamu Bridge Rd	9,276	801,446	W5
River gain from aquifer	*3,103*	*268,075*	
Mataura-Waikaia Confluence			
Mataura River at Riversdale Bridge	5,132	443,405	M6
Mataura River at Pyramid Bridge	1,473	1,293,667	M8
River gain from aquifer	*9,841*	*850,262*	
River gain (minus Waikaia input)	*565*	*48,816*	
Lower Mataura River			
Mataura River at Pyramid Bridge	14,973	1,293,667	M8
Mataura River at Otama Flat Road	15,632	1,350,605	M11
River gain from aquifer	*659*	*56,938*	
Mataura River at Dillon Road	16,989	1,467,850	M15
River gain from aquifer	*1,357*	*117,245*	

As shown in Figure 5, the Mataura River loses approximately 118,000 m^3/day to the aquifer along the reach between Ardlussa and Riversdale Bridge. The Waikaia River gains approximately 270,000 m³/day along the reach from Freshford Bridge to Waipounamu Bridge Rd. Through the Mataura/Waikaia confluence section, the Mataura gains approximately 850,000 m^3/day, however, when the flow entering the Mataura from the Waikaia River is subtracted, the actual gain between Riversdale Bridge and Pyramid is approximately 49,000 m^3/day. Gains in the lower Mataura below Pyramid Bridge total approximately 175,000 m^3/day along the reaches to Dillon Rd. This gain is a combination of groundwater discharge directly to the river and via spring fed streams entering the river along the lower reach.

- **Table 7. Concurrent flow gauging data: spring-fed streams**

Gauge Location	Flow (L/sec)	(m3/day)	Model Reference
Spring at Tayles and Fingerpost-Pyramid Road	124	10,714	Stream A
Spring at Fingerpost-Pyramid Road	29	2,506	Stream B
Meadow Burn at Fingerpost-Pyramid Road	129	11,146	Stream C
Meadow Burn at Round Hill Road	386	33,350	Stream C
Meadow Burn gain from aquifer	*257*	*22,205*	
Spring at Mandeville-Riversdale Highway	43	3,715	Stream D
Spring at Kingston Crossing-Mandeville Road	39	3,370	Stream D

In general, spring fed streams such as Meadow Burn are located in the lower portion of the river valley where changes in aquifer hydraulic properties and/or topography leads to watertable intersection with the ground surface which results in groundwater discharge. Flow measured at gauge points on the main spring fed streams within the model domain totalled approximately 53,000 m^3/day. Meadow Burn is the largest of the spring-fed streams and has been gauged at two locations identifying a gain of approximately 22,000 m^3/day along that reach. This gain indicates that the stream is receiving water from the aquifer not just in its headwaters, but also through the streambed to least the second gauging point location. It is likely that remaining spring fed streams also receive such inputs, however further gauging is required to confirm this suggestion and quantify volumes.

Longridge perched spring – knew I forgot something!

4.4 Piezometric Surface Geometry

Environment Southland conducted an area-wide piezometric survey of available bores in March 2004. This data has been used to create piezometric contour plots in meters above mean sea level (mAMSL) to provide an indication of groundwater flow patterns within the aquifers.

- **Figure 6. Mid-Mataura catchment piezometric surface (all reported data)**

  (See A3 pullout at rear)

Figure 6 depicts a groundwater surface utilising all reported data provided by Environment Southland. Analysis of Figure 6 shows the presence of a number of ridges and peaks that are not likely to reflect the natural surface of the water table. These forms are likely to result where reported water levels reflect the presence of a perched water table at that location.

Figure 7 depicts the piezometric surface after the removal of data values that are considered to be inconsistent with the expected natural water surface. Contour distribution indicates that in general groundwater flow is towards the southeast, parallel to the Mataura River. Flow within the lower reaches of the Longridge aquifer and in the upper east area of Wendonside is in an easterly direction.

- **Figure 7. Mid-Mataura catchment piezometric surface (consistent data)**

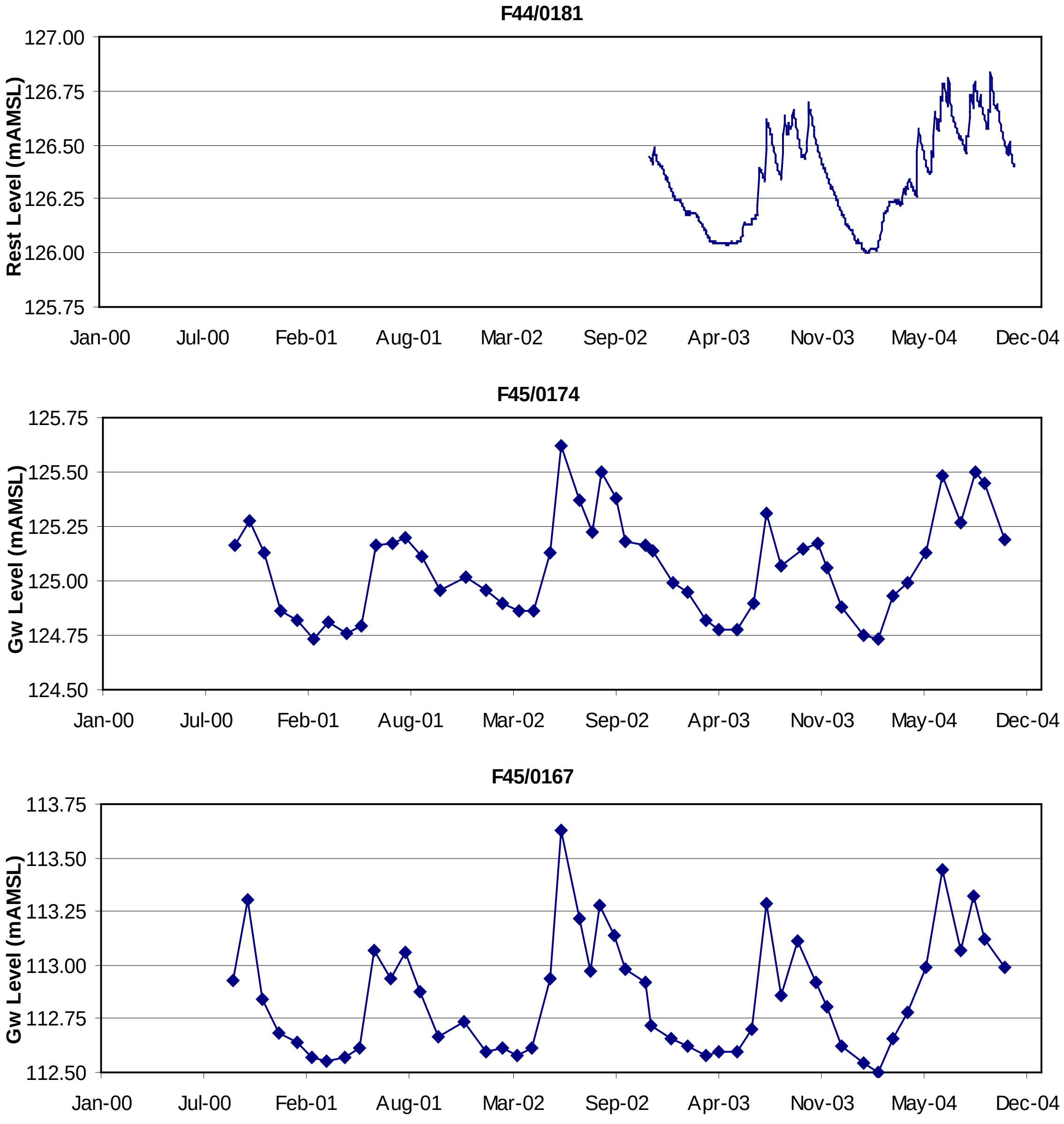
  (See A3 pullout at rear)

The hydraulic gradient (spacing of the contour lines) provides insight into the groundwater flow regime. Over much of the Riversdale and Waipounamu aquifers, and lower reaches of the Wendonside aquifer, contours are regularly spaced indicating a gentle profile. This is a result of higher hydraulic conductivity in these areas, and/or groundwater discharge to spring-fed streams and drains that act to constrain groundwater to near ground surface level so that effectively the hydraulic gradient is a function of ground surface gradients.

In upper reaches of the study area, along the interface of the Riversdale and Longridge aquifers, and in the upper reaches of Wendonside, the hydraulic gradient steepens. This is likely to be a function of the reduced permeability associated with the older more cemented gravels in these locations.

4.5 Piezometric Oscillation

Data has been provided by Environment Southland detailing groundwater levels within twelve boreholes for varying monitoring periods back to a maximum of January 2000. The data is collected manually via a monthly monitoring round or recorded daily via the use of in-well data loggers that are manually downloaded and processed by Environment Southland. Figure 6 presents hydrographs for three of the monitoring bores. Remaining observation bore hydrographs are presented in Appendix B



- **Figure 8. Environment Southland groundwater monitoring bores hydrographs**

All three bores in Figure 8 are located in the Riversdale aquifer. Bores F44/0174 and F44/0167 are monthly measurements, displayed because they have the longest coverage period of those observation bores considered representative of the true water table surface. Bore F44/0181 is displayed to highlight the difference in data resolution between monthly and daily measurements. For example, during the water table high recorded through winter and spring of 2003, the monthly data recorded two peaks while the daily record shows at least three peaks and a number of smaller scale fluctuations. This difference must be acknowledged during model calibration, as fluctuation of simulated model heads is likely to vary on a daily basis.

Monitoring bore information is used as observation point data for model calibration and accordingly these bores are referred to as *observation bores* within the model. Of the twelve monitoring bores, only eleven are used as observation bores for this study as it is considered likely that bore F44/0077 is representative of a perched water table surface and therefore has no use as a model calibration tool. The location of all monitoring bores is indicated on Figure 9.

- **Figure 9. Observation bore and hydraulic test locations**

  (See A3 pullout at rear)

Analysis of the hydrograph response indicates the following aquifer characteristics:

- All three bores show similar amplitude and phase of response, indicating similar hydraulic characteristics and response to imposed aquifer stresses.
- Groundwater levels follow a typical seasonal fluctuation pattern, receding to similar benchmarks each year during summer.
- The lack of variation in minimum groundwater levels indicates that the aquifer has a relatively constant baseflow source, likely to be the Mataura River.

Analysis of the remaining bore hydrographs in Appendix B shows that similar seasonal fluctuations are observed for those bores with sufficient data. It is also observed that bores such as F44/0019 and F44/0006, situated on the upper terraces, display more significant fluctuations than those situated in lower parts of the project area. This increased response to rainfall recharge is likely to reflect lower permeabilities in these areas as detailed in Section 2.2.2.

4.6 Aquifer Hydraulic Properties

Environment Southland provided hydraulic conductivity data for the project area compiled from tests conducted as part of resource consent applications and limited groundwater investigations.

Table 8 presents conductivity values for 19 locations predominantly within the Riversdale and Waipounamu aquifer zones and to a lesser extent Wendonside. No data is available on hydraulic properties of the Longridge aquifer. Data is presented as received and no raw test-pumping data was available for verification of analyses undertaken. Test site locations are presented in Figure 9.

- **Table 8. Aquifer hydraulic conductivity values**

Aquifer Zone	Easting	Northing	Conductivity (m/day)
Riversdale	2178700	5471600	40
Riversdale	2179500	5471400	217
Riversdale	2179100	5472600	110
Riversdale	2180100	5472500	100
Riversdale	2179400	5473300	400
Riversdale	2181900	5471700	104
Riversdale	2183000	5470500	192
Riversdale	2176800	5473300	85
Riversdale	2185000	5463500	92-105
Riversdale	2184300	5465500	29.4
Riversdale	2183500	5466900	37.5
Riversdale	2176900	5473600	175
Waipounamu-Mataura	2180500	5474400	2100
Waipounamu-Mataura	2181700	5473900	1060
Waipounamu-Mataura	2176900	5479700	750
Waipounamu-Waikaia	2185400	5471200	34
Waipounamu-Waikaia	2184200	5474800	15
Waipounamu-Waikaia	2184000	5474700	40
Wendon	2176900	5484000	21-43

Analysis of Figure 9 and Table 8 shows that available data is sparse on the scale of the project area. Values are also highly variable where sufficient coverage is present, which may be due to:

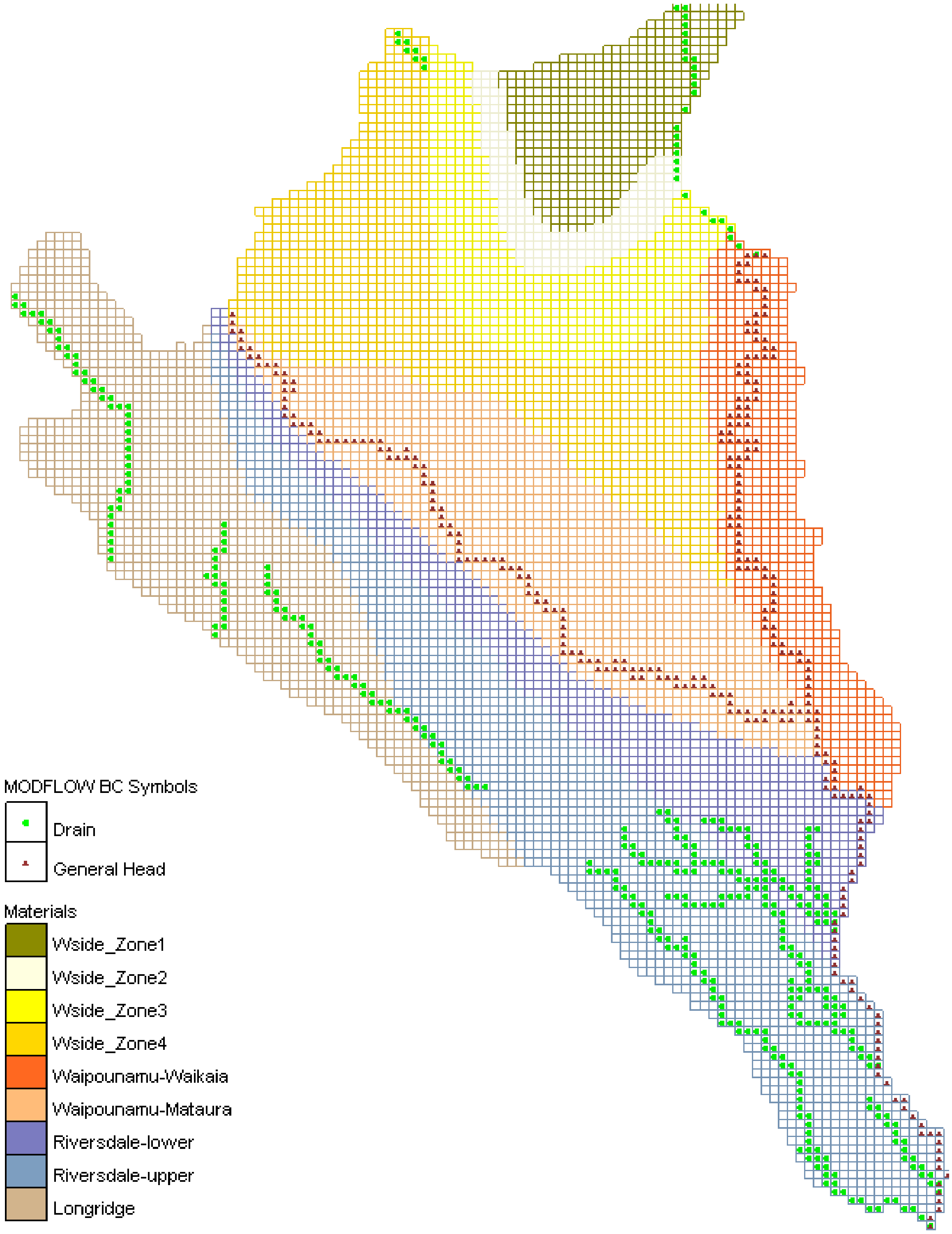
- highly variable depositional history characteristic of reworked fluvio-glacial outwash deposits
- palaeotopography-related undulating aquifer base and associated variable saturated thickness
- thin saturated aquifer in places leading to rapid de-watering during testing relative to aquifer thickness
- lack of comprehensive test pumping data

5. Numerical Model

The USGS-developed MODFLOW 2000 modelling code was chosen for this study due to its proven record through a range of analytical situations and general acceptance as the industry standard. SKM currently employs The Groundwater Modelling Software (GMS) graphical interface developed by EMS-I.

5.1 Model Grid

Figure 10 displays a plan view of the model domain. The model developed is a single layer representation of the Quaternary Gravels consisting of 7,161 cells within a north-south oriented grid. Cell granularity is uniform at 250 × 250 m and the model covers an area of approximately 286 km^2 or 28,623 hectares.

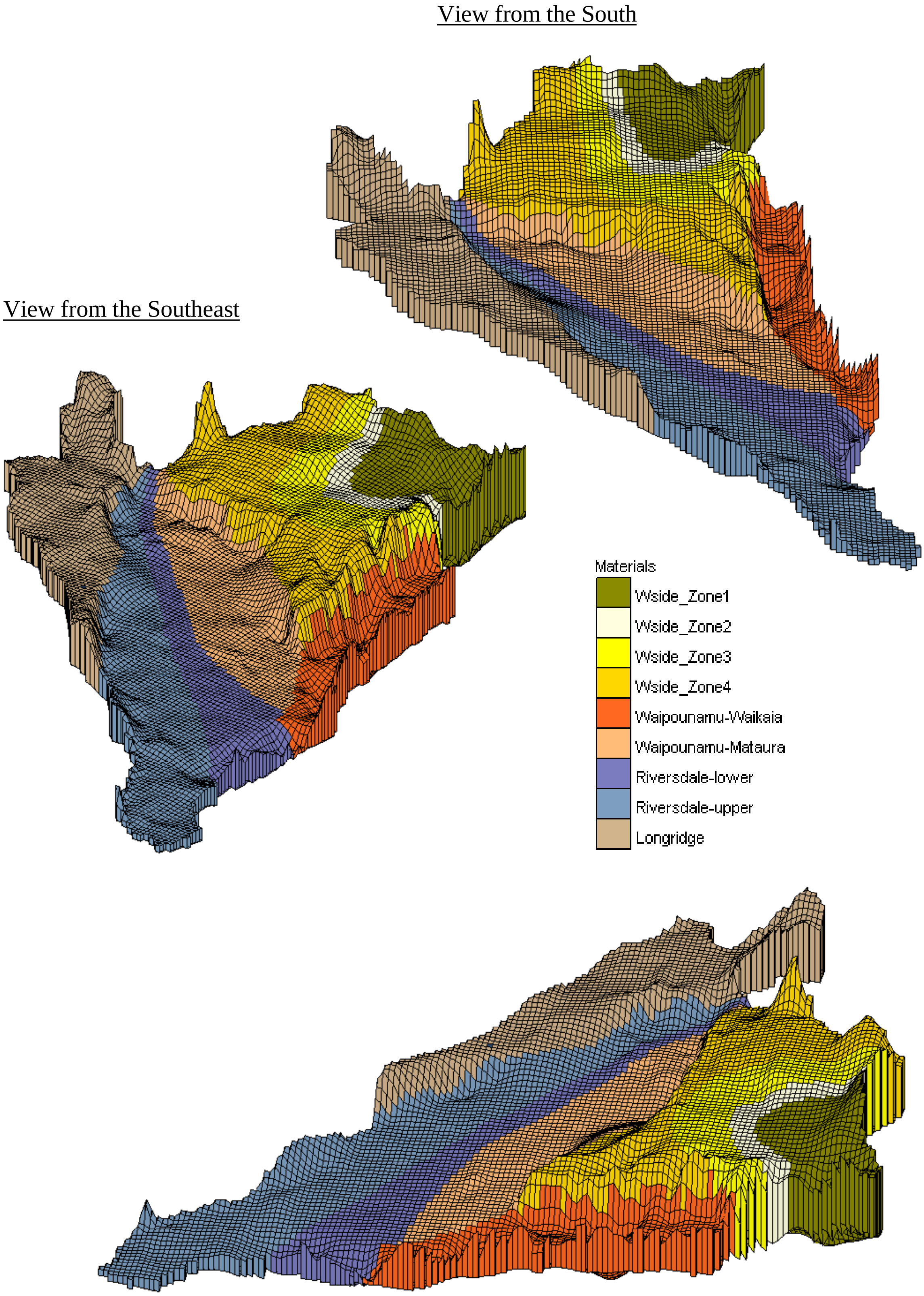


- **Figure 10. Northern Southland model grid and boundary conditions**

5.2 Layer Geometry

Model discretisation in the vertical direction is handled by specifying layers representing different lithologies or aquifer units. In practice, a compromise is usually made between the number of layers and the accuracy and computational time of the model, as each additional layer adds proportionately to the simulation time.

In this model only one layer is specified which conforms to the geometry of the Quaternary Gravels. Figure 11 displays the model in three-dimensional view from three different directions. GMS enables manipulation of the model in any direction and within a wide scale range, allowing close inspection of particular features of interest.



View from the South

View from the Southeast

- **Figure 11. Model grid projections (vertical exaggeration = 50)**

5.2.1 Layer Top Elevation

A ground surface elevation model in mAMSL was generated to represent the top elevation of the aquifer layer. This was defined using topographical data obtained from the LINZ (20 m topo contours) augmented with local survey point data for bore locations, stream bed elevation and roadside land survey. Table 9 summarises files used to generate the surface elevation of the model.

- **Table 9. Summary of files used for generating layer top elevation**

File Name	Description & Comments
All_DEM_Data.xls[3]	Compiled EXCEL data file. Data compiled from LINZ datafile (Contour.dxf[1]) and Environment Southland database file (Master Data from Environment Southland.xls[2])
GMS_DEM.grd[3]	SURFER grid file. Generated using Kriging with 500 x 500 m grid.
GMS_Top Elevation Layer 1.txt[3]	Final text file for impartation into GMS. Interpolated in GMS to Top of Layer 1.

SKM Network Directories:

1. I:\AENV\AE02092\WP01_Riversdale Model\Drawings\Surfer\
2. I:\AENV\AE02092\WP02_Northern Southland Model\Data\Environment Southland\
3. I:\AENV\AE02092\WP02_Northern Southland Model\Drawings\Surfer\DEM

5.2.2 Layer Bottom Elevation

Borelogs were provided by Environment Southland for all bores in the area with available records. A gravel thickness contour model was generated from the available borelogs that encountered the base of the gravels (7 bores) and hydrogeological interpretation based on approximations of the Mataura River valley geomorphology and likely erosional history of the river. The gravel thickness contours are presented in Figure 12.

- **Figure 12. Gravel thickness contour model**

  (See A3 pullout at rear)

The thickness of the gravels varies from approximately 5 m in the lower reaches of the Riversdale aquifer to approximately 70 m along the northern margin of Wendonside. Localised basement depressions and highs related to palaeotopography are also likely to occur within the subsurface, however borelog information is not detailed enough to determine the presence of such features. It is generally assumed that the aquifer becomes thicker towards the centre of the study area as this is likely to be the approximate location of the thalweg of the palaeotopography. The gravels are also thicker beneath elevated portions of the Wendonside aquifer that have remained throughout the most recent phase of the Mataura River valley erosional cycle.

To define the underlying aquifer boundary, a gravel-base contour plot was then interpolated using the ground surface elevation and gravel thickness contour models. Table 10 summarises files used to generate the gravel base elevation model.

- **Table 10. Summary of files used to generate the base of the gravel elevation model.**

File Name	Description & Comments
GravelThickness_digitisedV2.csv[1]	Text file generated from SURFER digitise command for the model domain.
GravelThickness_V3.grd[2]	SURFER grid file generated from the text files above. Grid file was blanked with model domain boundary file (ModelDomain.bln[1])
GMS_Layer1BaseV3.grd[2]	SURFER grid file generated from Grid Math operation in SURFER using formula [C=A-B]. A= GMS_DEM.grd. B = GravelThickness_V3.grd
GMS_Layer1BaseV3.txt[2]	Final text file for impartation into GMS. Interpolated in GMS to Bottom of Layer 1.

SKM Network Directories:

1. I:\AENV\AE02092\WP02_Northern Southland Model\Drawings\Surfer\Layer1\V2
2. I:\AENV\AE02092\WP02_Northern Southland Model\Drawings\ Surfer\Layer1\V3

5.3 Model Aquifer Zones and Hydraulic Properties

Figure 10 presents the model hydraulic conductivity zones, defined where possible from observed values. For the purposes of this exercise, the MODFLOW materials ID function was used to assign hydraulic properties to the aquifer. With this function, a materials list is defined with different hydraulic properties for each material. Model cells are then assigned a particular material and corresponding set of hydraulic properties. Model cells display the colour and pattern assigned to the relevant material as shown in Figure 10.

A total of nine materials were defined during the model build and calibration stages, based on model responses to applied stresses of property changes and consistent with observed hydraulic conductivity data (see Section 4.3). The different materials form nine conductivity zones within the four aquifers.

Section 3.6 comments on the sparse and variable nature of observed data and lack of raw data to verify values. Accordingly, during model calibration, values were adjusted to achieve a more practical representation of the expected natural conductivity distribution required to achieve a realistic simulation. Table 11 presents the aquifer zones with corresponding observed data range per zone and hydraulic conductivity values used in the calibrated model.

- **Table 11. Hydraulic conductivity**

Aquifer Conductivity Zone	Model Value (m/day)	Observed Range (m/day)
Lower Riversdale	500	100 – 217
Upper Riversdale	250	29.4 – 175
Waipounamu-Mataura	1250	400 – 2100
Waipounamu-Waikaia	500	15 – 34
Longridge	20	NOD
Wendonside Zone 1	3.5	NOD
Wendonside Zone 2	5	NOD
Wendonside Zone 3	20	21 – 43
Wendonside Zone 4	50	NOD

Notes: NOD is no observed data

In assessing potential conductivities for use in the model calibration, observed data was considered in conjunction with typical published values. Freeze and Cherry (1979) suggest upper limits for hydraulic conductivity within gravel and silty sand of 1 and 1×10^{-3} m/s respectively, which equates to a range of between 80 and 86, 000 m/day. In practice, conductivities in the upper end of this range are rare, however values used for the calibrated model sit firmly within the lower portion of these bounds.

When allowing for spatial distribution, consideration was given to the reduction in permeability known to occur in association with the age and elevation of the river terraces and distance from major rivers, as detailed in Section 2.2.2. This was incorporated into the model by reducing conductivity values away from the Mataura River through the Waipounamu and Wendonside zones, and through the Lower, and Upper Riversdale and Longridge zones.

During model calibration it became obvious that hydraulic conductivity was the governing control on aquifer response. Significant changes to both modelled heads and river fluxes were observed during conductivity sensitivity analysis (see Section 5).

5.4 Boundary Conditions

Boundary conditions are constraints imposed on the model grid to represent the interface between the model calculation domain and the surrounding environment. GMS uses point and arc elements in GIS mode to digitise a feature (object) such as a stream or river so that it is accurately positioned. Model parameters are then assigned to each feature before the 'map to mod-flow' function is used to write the parameters to corresponding model cells.

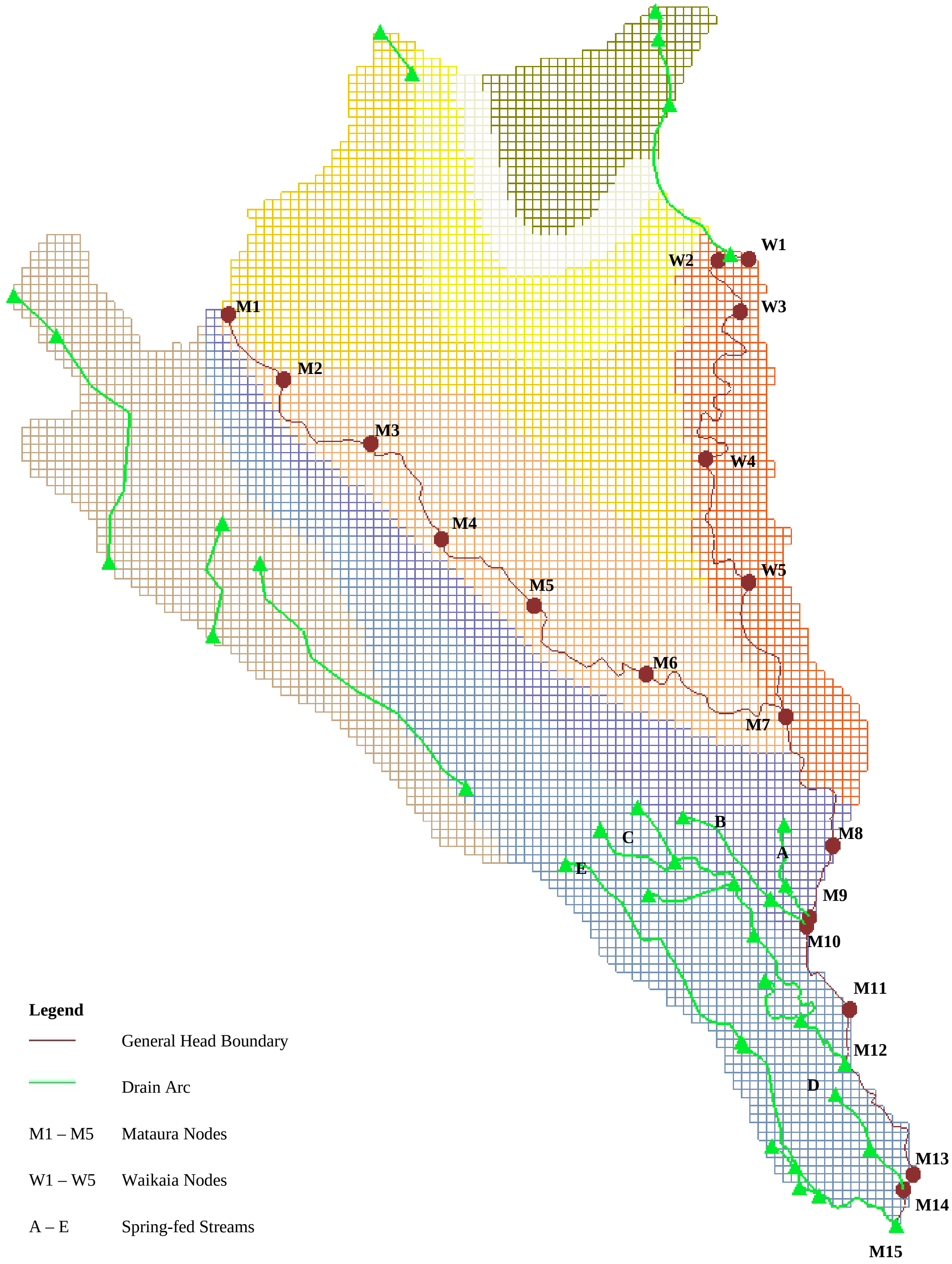
Model boundary conditions are presented in Figure 13 and can be summarised as follows:

- **General Head Boundary (GHB)** cells (Transient) are used to simulate the Mataura and Waikaia rivers. They are suited to this purpose as they allow the river stage head to be specified along with a conductance term for water passing through the riverbed. When the water table falls below or rises above the river level, water flows in to or out of the aquifer at a rate proportional to the difference in head and controlled by the assigned conductivity constant.

  For transient simulations, timeseries head data is input for each node on a GHB arc and the model interpolates the flow from the river to the aquifer for each cell on an arc. The conductivity value is then applied to each arc separately which enables modelling of different riverbed substrates where required. For this study, a conductance value of 12 m^2/day/m was assigned to the Upper Mataura and Waikaia River arcs. A value of 25 m^2/day/m was assigned to arcs below the Mataura-Waikaia convergence in order to account for influence of differences in average riverbed gradient between the upper and lower parts of the model domain.
- **Drain Cells** are used to represent the main spring fed streams in the lower reaches of the Riversdale aquifer, and to a lesser extent within Longridge and near to the model boundary in the north of Wendonside (see Figure 13). Use of drain cell permits water to exit the model when aquifer head at that location is greater than the specified drain cell elevation. However, when the opposite occurs, the drain cell is deactivated. Similar to the GHB cells, the rate at which water can be taken out of the model through the drains is controlled by a conductance value. The conductance value assigned to all drains in the model is 1000 m^2/day/m.
- **No Flow Cells** reside on the remaining boundaries of the model. Normally this boundary type is used when flow only occurs parallel to the boundary (i.e., not crossing the boundary). However, in this case the boundaries coincide with the extent of the Quaternary Gravels or aquifer management zones.
- **Well Cells** are employed to simulate consented pumping bores, however this has not yet been included in model simulations.

5.4.1 River Boundary Stage Data

River stage elevation data was available for nine locations along the Mataura River and two locations on the Waikaia River. At each location, stage height was recorded (mAMSL), whilst the height at Pyramid Bridge was recorded on the same day. This established a concurrent reference point enabling calculation of the river gradient profile relative to the Pyramid Bridge site. When constructing the general head arcs in the model, nodes were inserted along the river at each of the survey locations. Some nodes correspond approximately with river flow gauging locations (see Section 4.3) which enables model calibration to observed river fluxes. The survey points are presented in Figure 13 and stage height elevations are summarised in Table 12.



- **Figure 13. River and stream arcs/nodes**

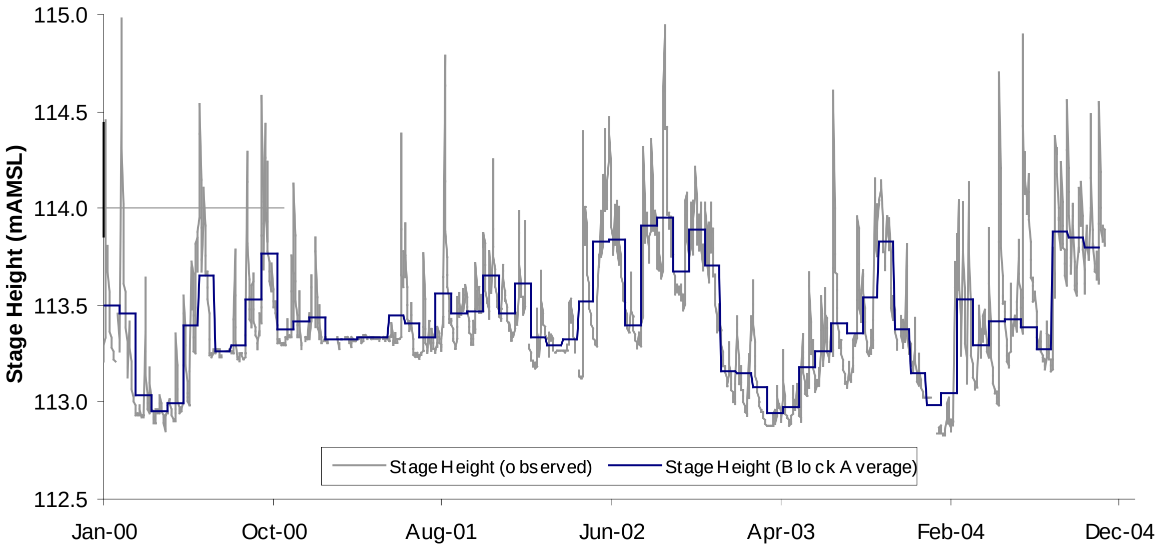
- **Table 12. River stage height survey data**

River Reach	Node	Easting	Northing	Surveyed Elevation	Model Elevation
Upper Mataura					
Northern Boundary	m1	2170714	5482092	-	164
Ardlussa	m2	2171911	5480540	158.577	158.577
	m3	2174143	5479018	151.75	151.75
	m4	2175825	5476732	146.485	144.485
	m5	2178025	5475163	137.852	137.852
Riversdale	m6	2180724	5473540	128.592	128.592
Mataura/Waikaia confluence	m7	2184066	5472524	-	120.00
Waikaia					
Northern Boundary	w1	2183181	5483437	-	148
Freshford Bridge	w2	2182439	5483386	144.83	144.83
	w3	2182951	5482177	138.64	138.64
	w4	2182152	5478662	-	126.65
Waipounamu Bridge Rd	w5	2183161	5475701	125.89	125.89
Lower Mataura					
Pyramid	m8	2185158	5469225	113.63	113.63
	m9	2184631	5467712	-	111.15
	m10	2184556	5467499	-	110.85
Otama Flat Rd	m11	2185579	5465538	107.489	107.489
Meadow Burn Confluence	m12	2185478	5464225	105.624	105.624
	m13	2187090	5461585	99.528	99.4
Dillon Rd	m14	2186863	5461215	98.87	98.87
Southern Boundary	m15	2186690	5460413	98.28	98.28

Stage elevation is one of the main factors governing flux exchange between the modelled river reaches and aquifer. Some reaches between stage elevation survey points are of sufficient length that topographical considerations (i.e. slope change) required the insertion of additional nodes (nodes W4 and M7, 9 & 10). Additional nodes were also required where the river arcs intersect the model boundary (nodes M1 & 15, and W1). Initially, the elevation applied to the additional nodes was interpolated from the gradient between the nearest up and downstream surveyed nodes. However, at node W4 simulated heads were many meters above ground level resulting in the appearance of saturated cells. Analysis of the topography at that location showed that indeed the node elevation was above ground level. During model calibration, the elevation of each additional node was adjusted to achieve the most practicable balance between reported topography, observed heads and flow gains/losses in the affected arcs.

Time series data is available for daily average stage height of the Mataura River at Pyramid Bridge, from the 1st of January 2000 to July 2004. This data was block-averaged using time units identical to model stress periods and the block average values were input into the model as transient river head data.

Figure 12 presents a time series graph showing the recorded stage height at Pyramid with block-averaged values corresponding to model stress periods.



- **Figure 14. Pyramid Bridge stage height and block average values for model input**

For remaining nodes on the Mataura and Waikaia river arcs, transient heads were interpolated from the Pyramid stage data according to their position on the river gradient profile determined from the surveyed stage elevations presented in Figure 13. For those nodes without survey elevation data, the elevation was calculated by applying the gradient between the nearest up and downstream survey locations.

5.4.2 Permitted Abstraction Bore Data

TO LATE TO DO THIS. DIDN'T HAVE TIME TO SET DUDS UP WITH THE FILES.

There are currently 35 bores that are permitted by Environment Southland to abstract in excess of 20 m^3/day. The locations and maximum daily allocations are presented in Table 13. These bores have been built into the model with their consent allocation as the specified bore discharge rate.

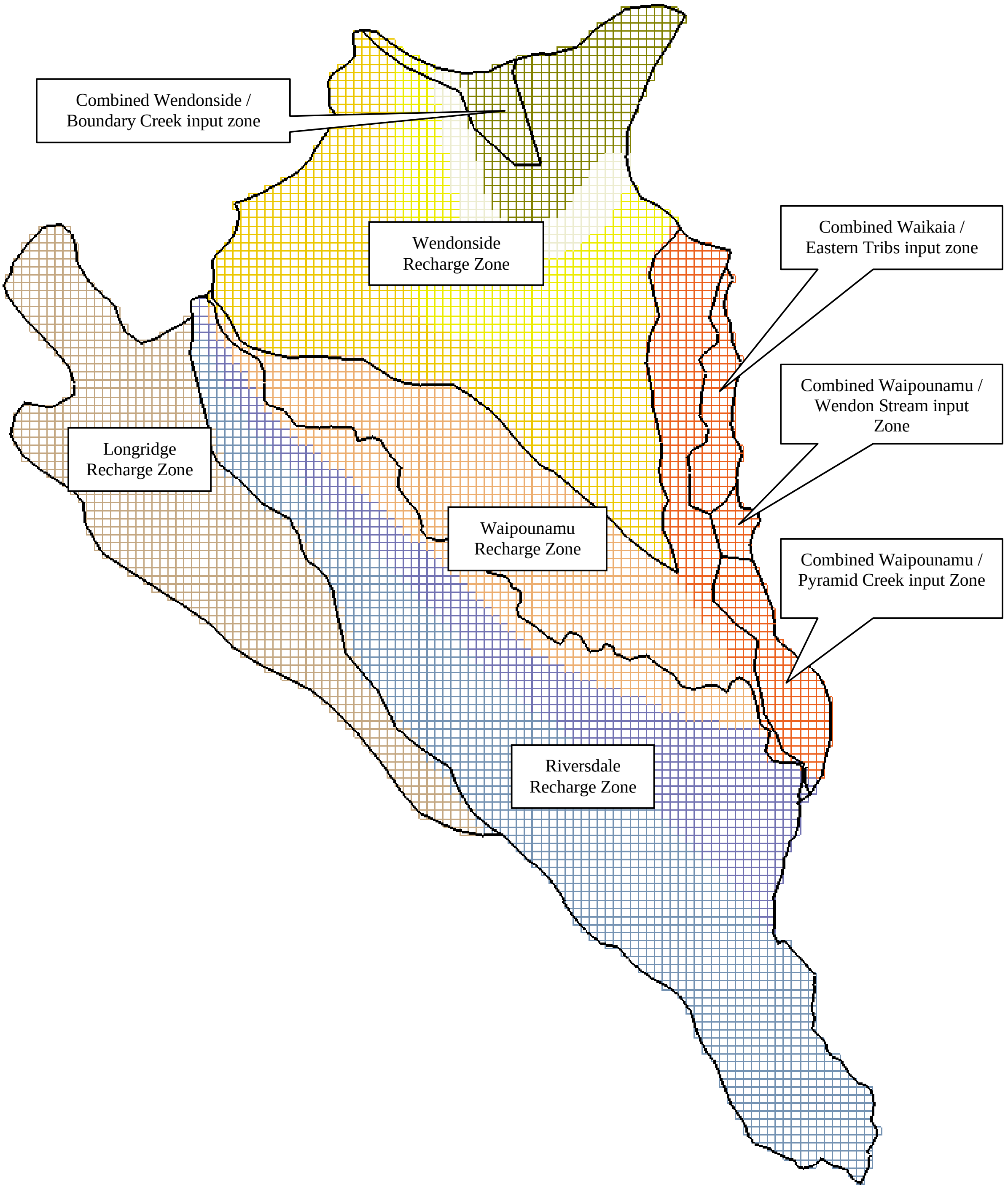
Table 13. Summary of current groundwater allocation

Consent Holder	Well Number	Easting	Northing	Max Daily Rate (m^3)
Festive Fields PW1	F44/0026	2180185	5472575	2938
Festive Fields PW2	F44/0113	2179223	5472618	4406
Festive Fields PW3	F44/0206	2179400	5473300	4760
MCM Dairies PW1	F45/0402	2184700	5463500	3573
MCM Dairies PW2	F45/0403	2185131	5463465	3573
Bain	F44/0080	2182900	5470444	3024
Elder	F44/0059	2177761	5472427	2970
Morfield	F44/0183	2175500	5473500	3600
Miller	F44/0014	2177743	5470850	346
Morfield	F44/0020	2176489	5474773	224
MCM Dairies	F45/0353	2184899	5463577	112.5
Bain	F44/0182	2182911	5470461	56
Andrews Transport	F45/0417	2179730	5469370	20
Riversdale Dairies	F44/0097	2182971	5471456	181
Hilton	F45/0289	2183519	5466146	140
McCandless	F44/0024	2182163	5471467	70
McCandless	F44/0203	2181940	5471760	3570
Hilton PW1	F45/0419	2184300	5465500	4555
Hilton PW2	F45/0420	2183500	5466900	4555
McKee	F44/0205	2179500	5471300	1270
Broardacres	F44/0184	2176922	5473622	6220
King	N/A	2178900	5469850	3570
Given	N/A	2184100	5461600	988
Gatenby	F44/0180	2181885	5481729	83
Kylemore	F44/0023	2185200	5473000	100
Bain PW1	F44/0191	2183940	5474890	2200
Bain PW2	F44/0209	2183900	5474950	3200
Kylemore PW1	F44/0193	2185401	5471197	2700
Kylemore PW2*	F44/0197	2184900	5472800	4500
Elder	F44/0201	2180500	5474440	5214
Fermoy Farms	F44/0200	2181560	5473780	8380
Fermoy Farms	F44/0199	2183040	5473300	3860
Clarke	F44/0075	2176976	5479702	2160
Brooklea	F44/0077	2176576	5483108	3927.5
Brooklea	N/A	2176933	5483998	3927.5

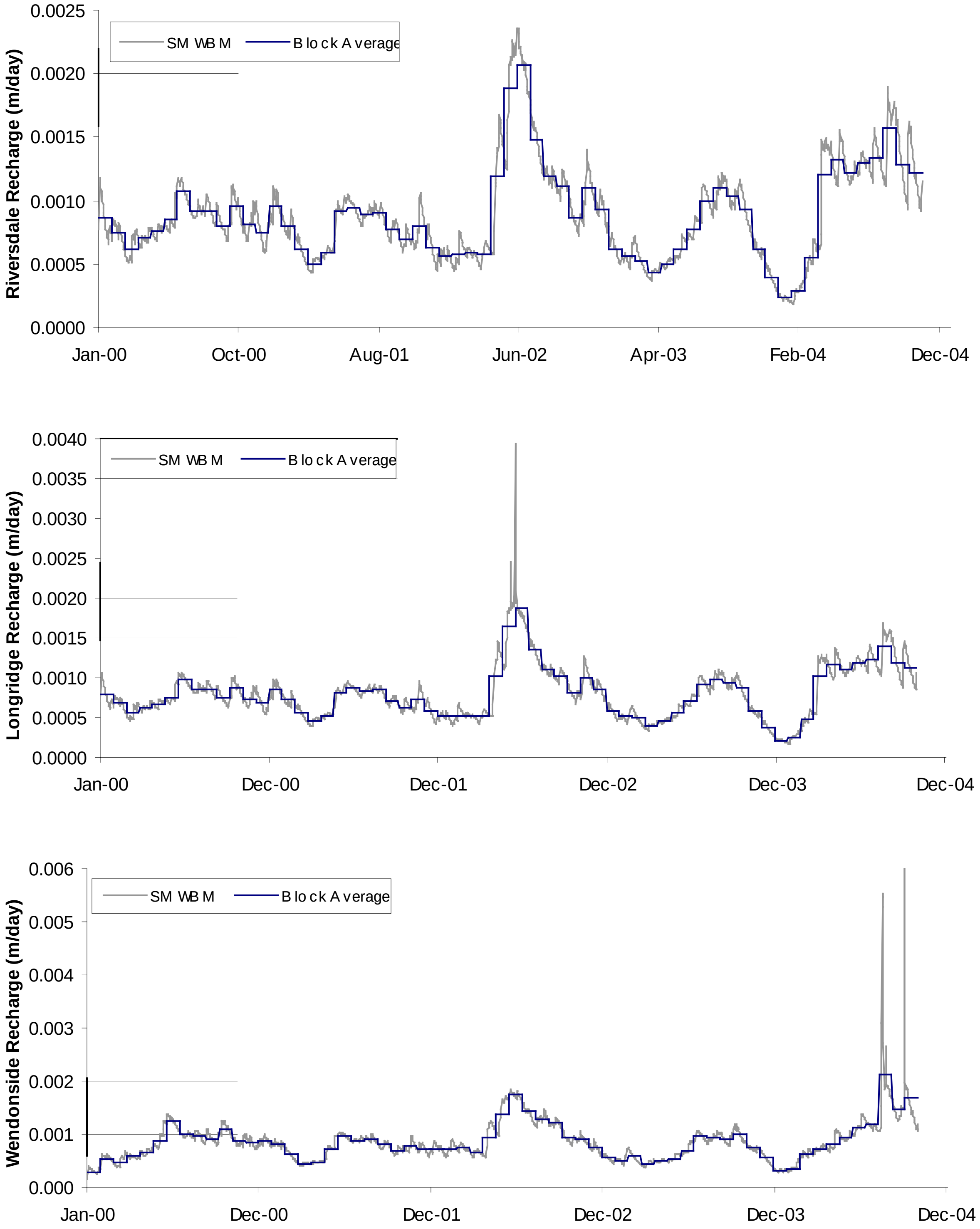
5.4.3 Rainfall Recharge

Rainfall recharge data was calculated using the SMWBM as detailed in Section 4.2.1. The SMWBM calculates daily average values for interception, runoff, evapotranspiration and percolation to groundwater/groundwater flow. Use of the SMWBM to calculate groundwater recharge component of the water balance means losses to potential evaporation and transpirations (PET) are already accounted for.

Values for daily average volume of rainwater partitioned through percolation to groundwater were block averaged using time units identical to the model stress periods. This data was then input into the model within the recharge coverage. Figure 16 presents time-series graphs showing daily recharge data from the SMWBM and block average data used in the model for the higher permeability aquifer zones (Riversdale and Waipounamu) and the less permeable Longridge and Wendonside aquifers.



- **Figure 15. Rainfall and combined rainfall/runoff recharge zones**



- **Figure 16. Rainfall recharge input data**

5.4.4 Runoff Recharge

Runoff recharge inputs from the peripheral hard rock catchments were simulated using the SMWBM (see Section 4.2.3) and assigned to additional polygons in the recharge coverage, situated to apply the extra input over an appropriate portion of the model area. Daily average runoff volumes were then added to existing rainfall recharge values to produce a combined rainfall/runoff input for that part of the model domain. The location of the combined recharge polygons is marked in Figure 15. PROBABLY NEEDS MORE TO IT THAN THIS

5.5 Model simulation control: Stress Periods and Time Steps

During every model build process the run length, length/number of stress periods and number of timesteps are necessarily a function of available computational resources i.e. computing power/memory.

For the purposes of this model, stress periods of 28 days were defined and trial runs carried out to determine the most effective combination of the number of stress periods along with the number of timesteps. Ultimately, the model was set up for simulations of 45 stress periods of 3 timesteps each.

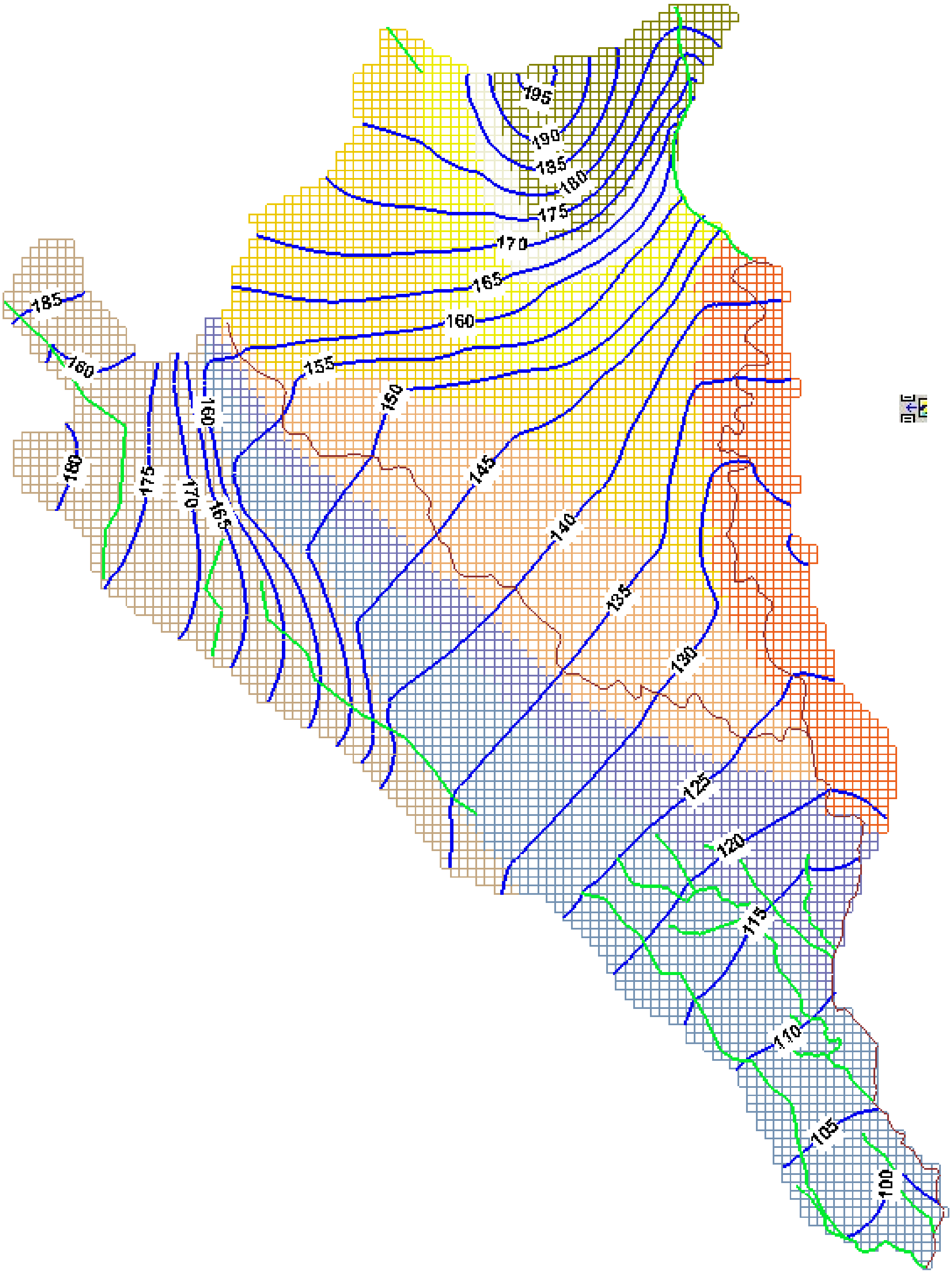
Timestep spacing was based on a multiplier of 1.5, i.e. the length between each timestep is 1.5 times the previous length starting at the beginning of the stress period. This skews timestep distribution towards the start of a stress period enabling the model to capture early water level fluctuations commonly caused by introduction of the new stresses.

It was intended that the simulation period for model calibration would extend from the date of the earliest available observation bore data (Jan 1 2000) to present, however computational restrictions imposed a shorter run time that would ideally be required. As more observation data is available for the period after 2002, particularly the daily data from monitoring wells, the final model simulation period was moved forward to include the more recent data and was set from May October 30 2004.

5.6 Initial Conditions

The initial (or starting) conditions of the model define the head distribution for all areas of the model domain at the start of a simulation. Steady state simulations are carried out to precondition the modelled heads to the unique set of parameters and stresses applied to the model. This results in a reasonable representation of the observed hydraulic gradient across the model domain, which is then used as the starting conditions for transient modelling. Figure 17 presents the starting heads used in the calibrated transient model.

It should be noted that modelling is an iterative process and as such during various stages of the transient calibration, the steady state model was revisited to derive new starting conditions that reflected subsequent calibration-related changes to the model configuration.



- **Figure 17. Model starting conditions (mAMSL)**

6. Sensitivity and Uncertainty Analysis Methods

- Most Sensitive to K
- Well constrained by river heads
- Less Sensitive to recharge due to volume of river flux constraints
- Fluctuations not very sensitive to changes in stress periods. As quite sensitive to river heads, tried using river heads as basis for block averaging to try and capture some of the shorter duration flow peaks and troughs. Very difficult to do this without increasing the number of stress periods. Was only achievable using 2 time steps for each period, and produced no difference within any bores, not even Riversdale/Waipounamu bores.

7. Calibration and Sensitivity Analysis

Intro blurb

7.1 Water Balance

- **Table 13. Water balance calibration**

River Reach	Observed Fluxes (m^3/day)	Model Fluxes (m3/day)
Upper Mataura		
Mataura River from Ardlussa to Riversdale Bridge	117,936	104,735
Waikaia and confluence section to Pyramid Bridge		
Waikaia River from Waiparu Rd to Waipounamu Bridge Rd	-268,075	-135,167
Mataura from Riversdale to Pyramid minus Waikaia input	-48,816	-257, 072
Total Flow on Waikaia and Confluence section	*-316, 891*	*-392,867*
Lower Mataura River		
Mataura River from Pyramid to Otama Flat Rd	-56,938	-113,227
Mataura River from Otama Flat Rd to Dillon Rd	-117,245	-52,576
Total flow on Lower Mataura	*-174,182*	*-165,803*

Notes:

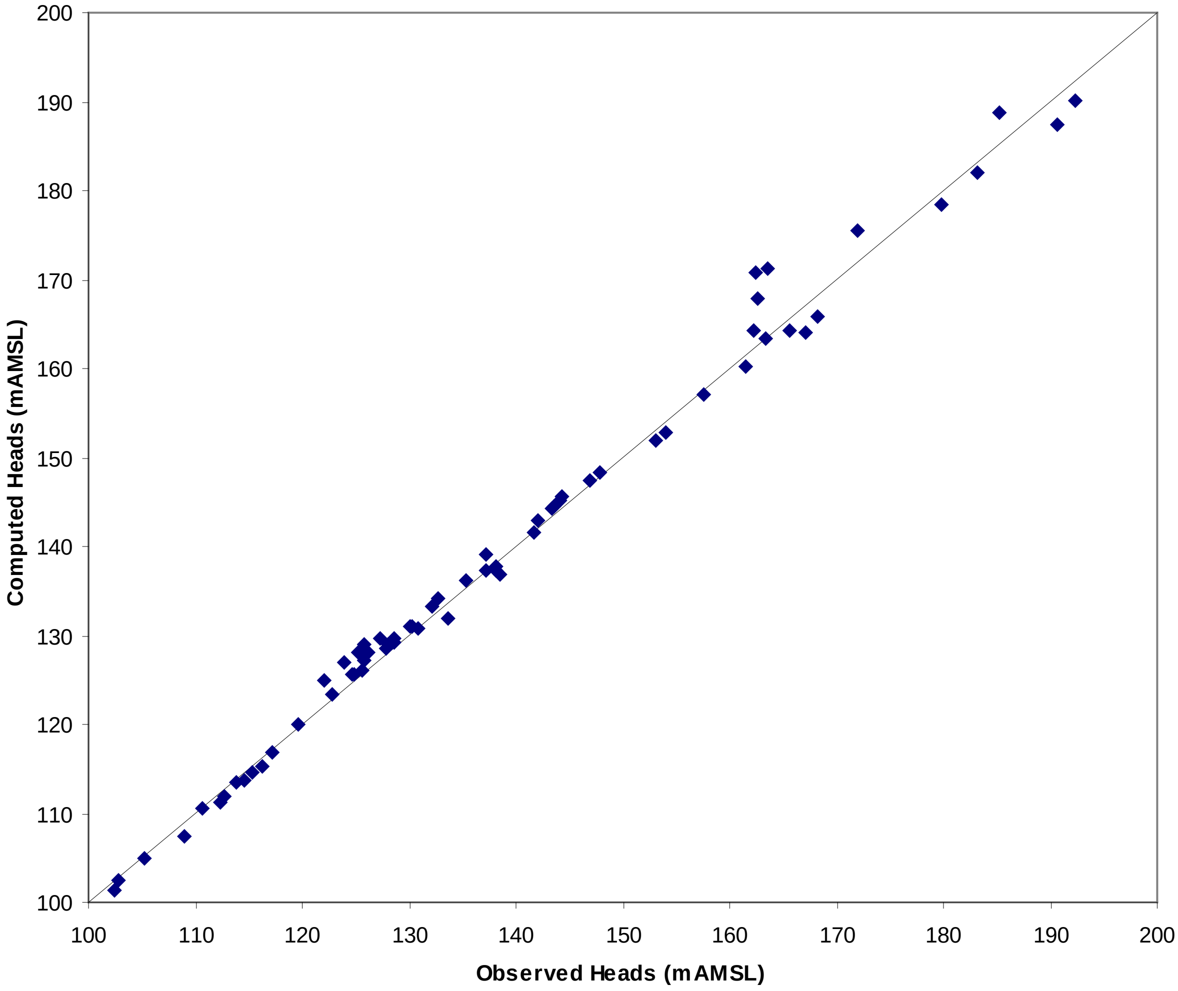
Fluxes are presented as reported by model, i.e. minus number represent a modelled aquifer loss or observed river gain and vice versa.

[1] Value includes total modelled flow for streams

[2] Value includes total modelled flow for streams

Could the difference be to do with the extra input from the Waikaia catchments?

7.2 Model Head Distribution


200
190
180
170
160
150
140
130
120
110
100
Computed Heads (mAMSL)
100
110
120
130
140
150
160
170
180
190
200
Observed Heads (mAMSL)

8. Model Limitations

Improvements:

- More accurate (variable rate) block averaging of transient recharge and head data. Currently neither picks up enough of peaks/troughs to gain representative model fluctuations.
- Flow gauging around Mataura/Waikaia confluence.
- Further gauging on spring-fed streams and thorough walk over to determine nature of streams in upper Longridge and Wendonside.
- Hydraulic Conductivity data coverage, variability and reliability.

9. Conclusions

10. Recommendations

11. References

Aquaterra Consulting Pty Ltd, November 2000. Murray-Darling Basin Commission: Groundwater Flow Modelling Guidline.

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Sinclair Knight Merz, 2004. Assessment of Environmental Effects of a Medium Density Fibreboard Plant, Mataura, Southland. Prepared for Rayonier MDF (New Zealand) Ltd.

Southland Regional Council, 1995. Mataura Catchment: Water Quality Review

Appendix A SMWBM

The soil moisture water balance model (SMWBM) is a deterministic lumped parameter model originally developed by Pitman (1976) to simulate river flows in South Africa. Modification of these algorithms and reworking of the code into a Windows environment now permits soil moisture accounting and assessment of the various components of the catchment water balance. In this study the SMWBM is employed as a preconditioner for assigning groundwater recharge fluxes to the MODFLOW model.

The model operates on a maximum timestep of daily during dry days, with smaller timesteps (hourly) implemented on wet days. When a rainday occurs, daily rainfall is disaggregated into the hourly timesteps based on a pre-defined synthetic rainfall distribution, which includes peak intensities during the middle of the storm. The model time stepping ensures that rainfall intensity effects and antecedent catchment conditions are considered in a realistic manner.

The model utilises daily rainfall and mean-monthly evaporation data to calculate soil moisture conditions and rainfall percolation to the aquifer. The model incorporates parameters that characterise the catchment in terms of:

- interception storage,
- evaporation losses,
- soil moisture storage capacity,
- soil infiltration rates,
- soil moisture percolation rates;
- surface runoff (quickflow);
- stream baseflows (groundwater contribution); and
- parameters that govern the recession and/or attenuation of groundwater and surface water flow components, respectively.

The fundamental operation of the model is as follows:

Daily rainfall is disaggregated into hourly intervals when a rainday occurs to allow refined accounting of soil infiltration and evaporation losses. Rainfall received must first fill a nominal interception storage (PI – see below) before reaching the soil zone, where the net rainfall is assessed as part of the runoff/infiltration calculation.

Water that penetrates the soil fills a nominal soil moisture storage zone (ST). This zone is subject to evapotranspiration via root uptake and direct evaporation (R) according to the mean monthly evaporation rate and current soil moisture deficits. The soil moisture zone provides a source of water for deeper percolation to the underlying aquifer, which is governed by the parameters FT and POW.

If disaggregated hourly rainfall is of greater intensity than the calculated hourly infiltration rate (ZMAX, ZMIN) surface runoff occurs. Surface runoff is also governed by two other factors, which are the prevailing soil moisture deficit and the proportion of impervious portions of the catchment directly linked to drainage pathways (AI).

Rainfall of sufficient intensity and duration to fill the soil moisture storage results in excess rainfall that is allocated to either surface runoff or groundwater percolation depending on the soakage and slope characteristics of the catchment (DIV).

Finally, the model produces daily summaries of the various components of the catchment water balance and calculates the combined surface runoff/percolation to groundwater to form a total catchment runoff discharge.

A.1 Model Parameters

The most significant parameters used in the soil moisture accounting model are described below and parameter values that are the same for all catchment models are included where appropriate. Table A1 summarises those values that are necessarily different for each model in order to simulate expected conditions for the aquifer zones and peripheral sub-catchments.

ST: Maximum soil moisture capacity

The parameter ST is of major importance in that it is the most significant factor governing the ability of the catchment to regulate runoff for a given rainfall event. The higher the value of ST, potentially the greater the amount of rainfall absorbed during wet periods, and results in more sustained baseflow during dry periods.

The depth of the ST zone basically prescribes an active zone above the water table (vadose zone) within which plant root uptake can occur. Depending on the vegetative and lithological characteristics of the catchment, this may coincide with the soil zone or may be deeper (i.e. forests and in sands).

SL: Soil moisture storage capacity below which percolation ceases

There is a definable soil moisture state below which percolation ceases due to soil moisture retention. For practical purposes this has been assigned zero.

ZMAX & ZMIN: Maximum and minimum soil infiltration rate

ZMAX and ZMIN are nominal maximum and minimum infiltration rates in mm/hr used by the model to calculate the actual infiltration rate ZACT. ZMAX and ZMIN regulate the volume of water entering soil moisture storage and the resulting surface runoff. ZMAX is usually assigned the saturated infiltration rate from field testing. ZACT may be greater than ZMAX at the start of a rainfall event. ZACT is usually nearest to ZMAX when soil moisture is nearing maximum capacity.

FT: Percolation rate from soil moisture storage at full capacity

Together with POW, FT (mm/day) controls the rate of percolation to the underlying aquifer system from the soil moisture storage zone. FT is the maximum rate of percolation through the soil zone.

POW: Power of the soil moisture-percolation equation

The parameter POW determines the rate at which percolation diminishes as the soil moisture content is decreased. POW therefore has significant effect on the seasonal distribution and reliability of percolation, as well as the total yield from a catchment. Through previous experience a value of 2 has been assigned to POW.

AI: Impervious portion of catchment

This parameter represents the proportion of impervious zones of the catchment directly linked to drainage pathways (AI).

R: Evaporation-soil moisture relationship

Together with the soil moisture storage parameters ST and SL, R governs the evaporative process within the model. The rate of evapotranspiration is estimated using a linear relationship relating evaporation to the soil moisture status of the soil. As the soil moisture capacity approaches full, evaporation occurs at a near maximum rate based on the mean monthly pan evaporation rate, and as the soil moisture capacity decreases, evaporation decreases linearly according to the predefined function. A value of 1 has been assigned to R.

DIV: Fraction of excess rainfall allocated directly to groundwater.

Assigned a value of 1.

TL: Routing coefficient for surface runoff.

TL defines whether excess rainfall that does not infiltrate directly go flow overland to surface water course or pond in situ and remain for later infiltration to groundwater. As we are dealing with an irrigation situation, we will assume all water remains in situ for later infiltration and assign a value for TL of 1.

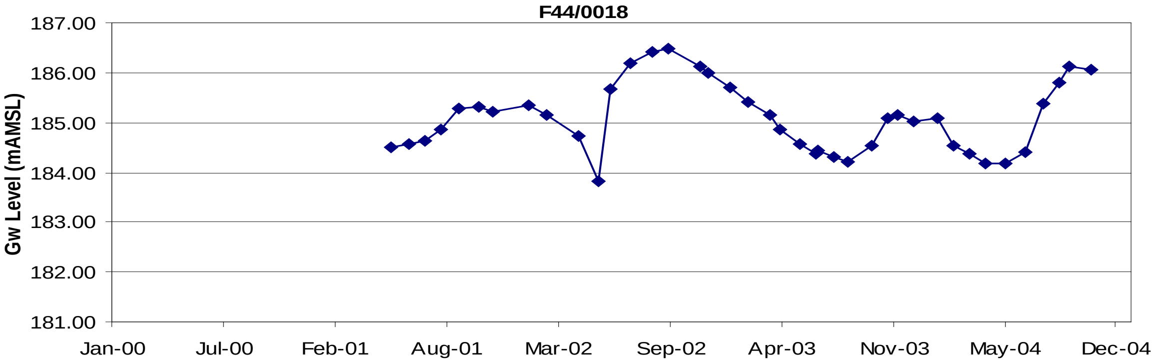
GL: Groundwater recession parameter.

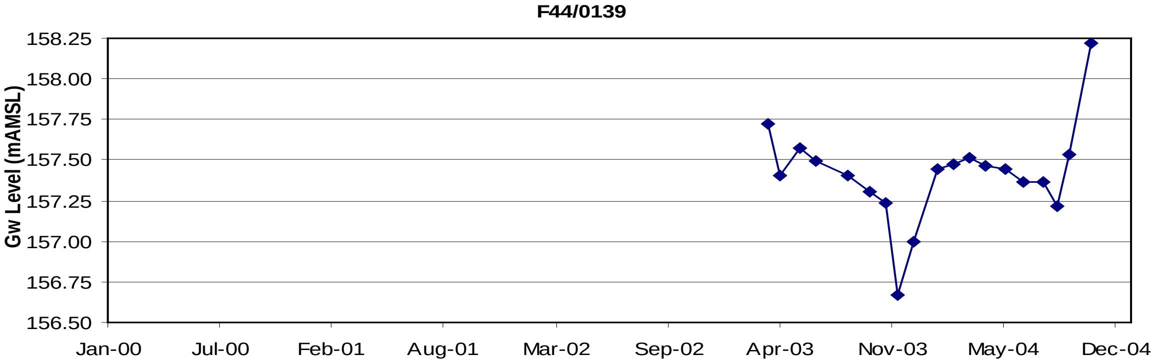
Has no effect in this application of the model as we are only interested in infiltration and percolation to groundwater, not the discharge of groundwater to surface water bodies.

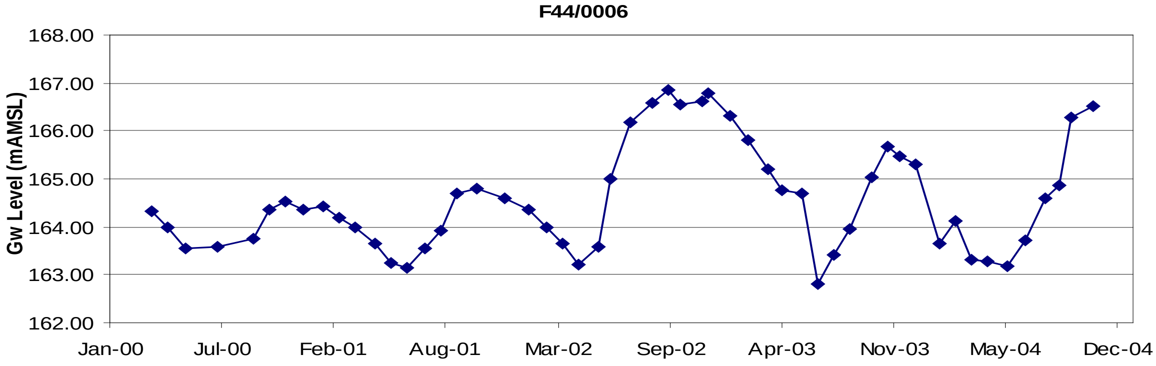
- **Table A1. SMWBM parameters for main**

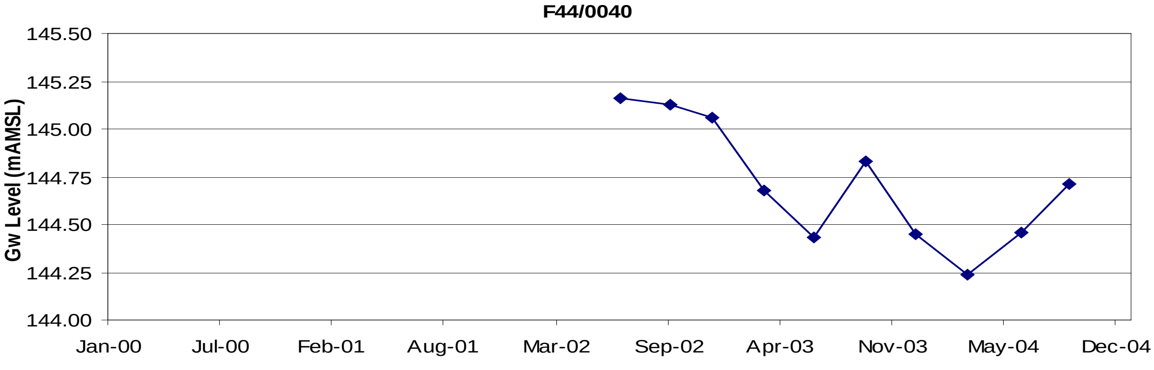
Catchment/Aquifer Zone	ST	FT	AL	Zmax
Riversdale/Waipounamu	275	2.5	0.05	80
Longridge	275	2.0	0.05	60
Wendonside	275	2.0	0.05	60
Garvy Burn	150	0.5	0.15	10
Boundary Creek	100	1.0	0.15	10
Wendon Stream	100	0.5	0.175	6.5
Waikaia Eastern Catchments	100	0.5	0.175	6.5
Pyramid Creek	150	1.0	0.15	10

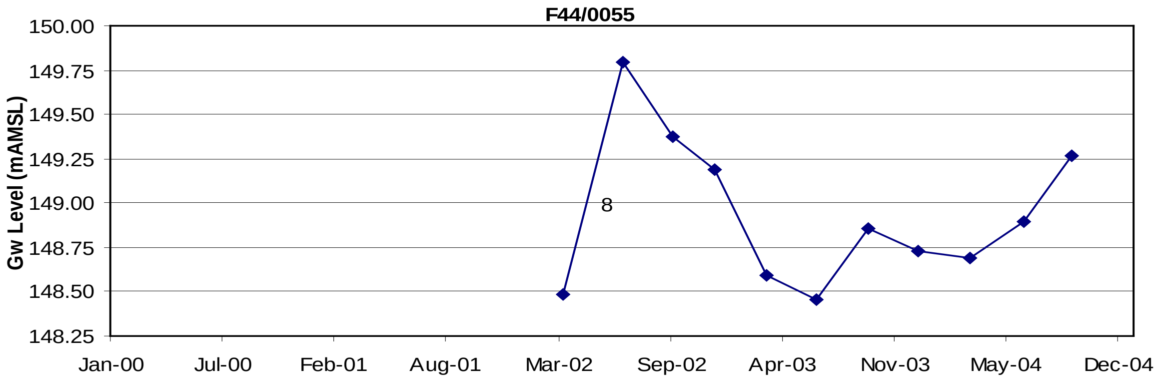
Appendix B Observation Bore Hydrographs

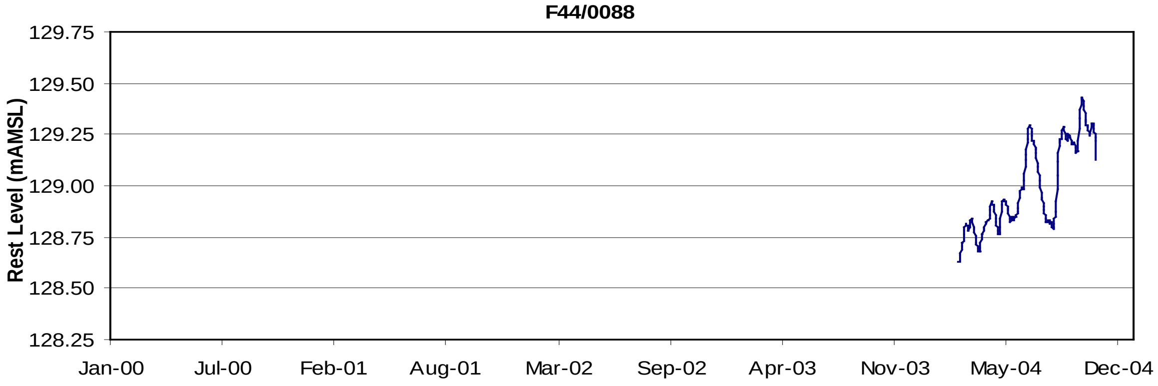


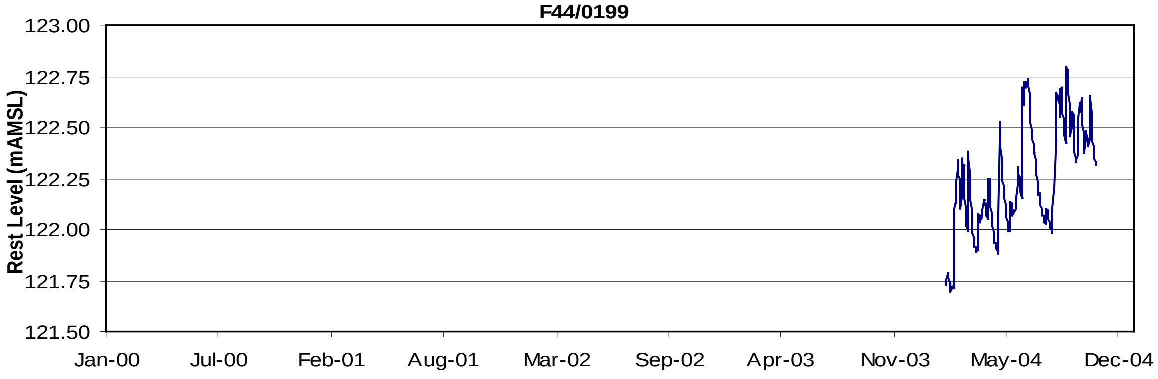







F44/0055
Gw Level (mAMSL)
150.00
149.75
149.50
149.25
149.00
148.75
148.50
148.25
8
Jan-00
Jul-00
Feb-01
Aug-01
Mar-02
Sep-02
Apr-03
Nov-03
May-04
Dec-04


F44/0088
Rest Level (mAMSL)
129.75
129.50
129.25
129.00
128.75
128.50
128.25
Jan-00
Jul-00
Feb-01
Aug-01
Mar-02
Sep-02
Apr-03
Nov-03
May-04
Dec-04


F44/0199
Rest Level (mAMSL)
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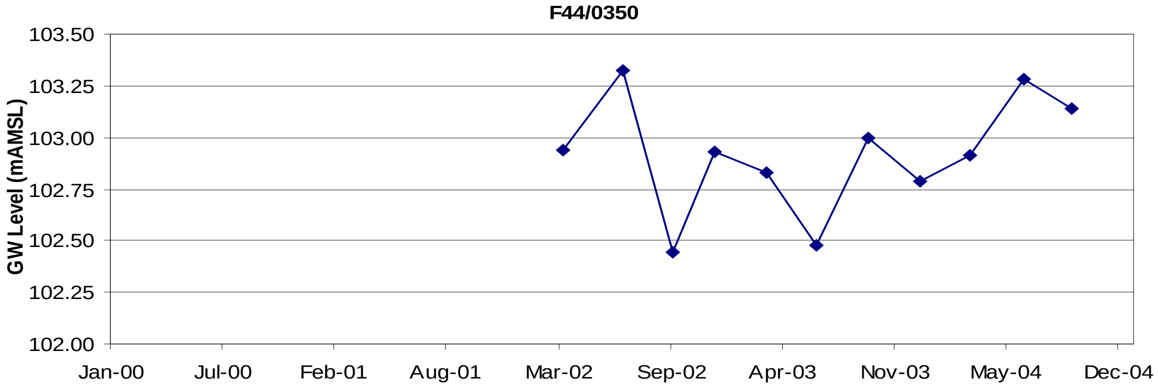
122.75
122.50
122.25
122.00
121.75
121.50
Jan-00
Jul-00
Feb-01
Aug-01
Mar-02
Sep-02
Apr-03
Nov-03
May-04
Dec-04


F44/0350
GW Level (mAMSL)
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103.25
103.00
102.75
102.50
102.25
102.00
Jan-00
Jul-00
Feb-01
Aug-01
Mar-02
Sep-02
Apr-03
Nov-03
May-04
Dec-04