SINCLAIR KNIGHT MERZ
SKM

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Northern Southland Groundwater Model Model Development Report

REPORT PREPARED FOR

ENVIRONMENT SOUTHLAND

- Final
- 20/05/2005

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1. Introduction

Demand for groundwater in recent years has increased significantly in the mid-Mataura catchment. Public perception of the value and quantities of water available have also changed, and concerns over potential effects of the new water allocations, particularly on spring flows and in relation to compliance with provisions of the Water Conservation (Mataura River) Order 1997 have also been raised. These changes have increased the importance of developing knowledge of aquifer hydrogeology to enable Environment Southland to guide water resource allocation decisions.

In May 2003, Environment Southland commissioned Sinclair Knight Merz (SKM) to conduct a groundwater modelling study to assess the sustainable yield of the Riversdale groundwater zone (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, Wendon and Wendonside groundwater zones in addition to the Riversdale and Longridge groundwater zones. Collectively, the study is referred to as the Northern Southland Model.

The primary resource management issue for this project is that of streamflow depletion in the Mataura River and spring-fed streams resulting from groundwater abstraction within hydraulically connected aquifers. This issue is a major constraint on water abstraction in the Mataura Catchment due to provisions of the Water Conservation (Mataura River) Order 1997, which effectively states that flow in the River cannot be reduced by more than 5 percent of the natural flow[1]. The maximum flow reduction has been interpreted to include stream depletion effects resulting from groundwater abstraction in hydraulically connected aquifers.

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, particularly the main stem of the Mataura River.

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

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[1] Note the Freshwater Plan provisions are set to change in a draft variation being prepared and the Mataura catchment is effectively going to be managed according to the Conservation Order.

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

This report documents the aquifer conceptualisation and model build processes for the second stage of the study and provides recommendations for future refinement of the model and understanding of the aquifer system.

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 also 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 (aquifer permeability)	[2]…K Values.xls
	Available bore logs to aid in characterising aquifer lithology and estimating 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 for a total of twelve monitoring bores	[2]…Groundwater Levels.xls
	Piezometric survey data including from approximately 130 bores in the project area (October 2002 and March 2004)	[2]…Piezo Survey Data.xls
	Concurrent flow gauging data for the Mataura and Waikaia rivers and the 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 Catchment Hydrological Setting

The Mataura catchment is the second largest of the four major river catchments in the Southland Region, comprising an area of approximately 5,360 km^2 and with a mean annual discharge of 93 m^3/sec in it's lower reaches. The Mataura River flows from the headwaters in the Eyre and Garvie 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 the rivers' course; a steep upper section upstream above 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 middle reaches of the catchment, where the Mataura has numerous small and a number of medium-sized tributaries. This section of the catchment also contains the confluence with the largest tributary, the Waikaia River.

The Waikaia River catchment upstream of the Mataura confluence covers an area of 1,360 km^2 and with a discharge approximately 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 20, Murihiku) shows that the geology of the study area consists of Quaternary age fluvio-glacial gravel outwash deposits overlying Tertiary sedimentary sequences of varying thickness. The Quaternary gravel deposits sit unconformably within intermontaine basins formed by extensive fault movement in the underlying Mesozoic basement rocks during the Cretaceous Period.

Quaternary gravel deposits form the primary aquifer forming units within the Southland Region (SRC, 1995). These glacial outwash deposits, comprising moderately to poorly sorted gravel, sand and clay, act as a thin unconfined aquifer from which a majority of groundwater abstraction occurs. River entrenchment subsequent to the last glacial period has formed a succession of at least six recognised terraces within the Mataura River valley. Older, less permeable deposits form the upper levels, while the valley floor comprises reworked 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 comprise sediments of the Eastern Southland Group. These deposits consist 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 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 occur in catchment headwaters where sufficient secondary porosity occurs along joints, fissures, fractures and foliation planes to form low-yielding aquifers.

3.3 Local Catchment Hydrology

The project area comprises a large portion of the mid-Mataura catchment. This area encompass a triangular region of approximately 286 km^2 between Ardlussa, Waikaia and Otamita including the confluence of the Mataura and Waikaia rivers. Otamita is situated approximately 10 kilometres northwest of Gore (see Figure 1).

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

  (See A3 attachment at rear)

Figure 2 displays a total of 31 sub-catchment watersheds within or connected to the project area. Catchments of the main spring fed streams and those likely to provide additional (runoff) recharge input along the edges of the model domain are summarised in Table 5 and labelled on Figure 2.

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

  (See A3 attachment 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 4.2.3.

3.4 Rainfall and Evaporation

Daily rainfall data is available from five locations within the vicinity of the project area at Mandeville, Kaweku, Otama, Balfour and Wendon. The period of record and annual average rainfall (mm) for these sites is summarised in Table 2.

- **Table 2. Rainfall data summary.**

Rainfall Station	Period of Record (years)	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 annual average rainfall data for each site was used to create a rainfall gradient plot for the project area as shown in Figure 3. Due to orographic effects, rainfall distribution generally follows the topography with higher rainfall near the hills and lower rainfall in the valleys.

- **Figure 3. Rainfall Distribution Gradient.**

  (See A3 attachment at rear)

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 the surrounding foothills. Environment Southland holds a rainfall gradient map for the entire Southland region, which shows the difference in annual average rainfall of up to 300-400 mm between the valley floor and top of the Hokonui Hills.

4. Aquifer Conceptualisation

4.1 Groundwater Management Zones

Figure 1 displays the groundwater zone boundaries for the Northern Southland groundwater 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.

Riversdale groundwater zone

Figure 1 and Figure 2 indicate that the Riversdale groundwater 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 groundwater zones.

Waipounamu groundwater zone

The Waipounamu zone follows the recent floodplain of the Mataura River and is bounded by the Mataura River to the south and the large alluvial terrace that marks the outer edge of the Wendonside terrace to the north.

Wendon groundwater zone

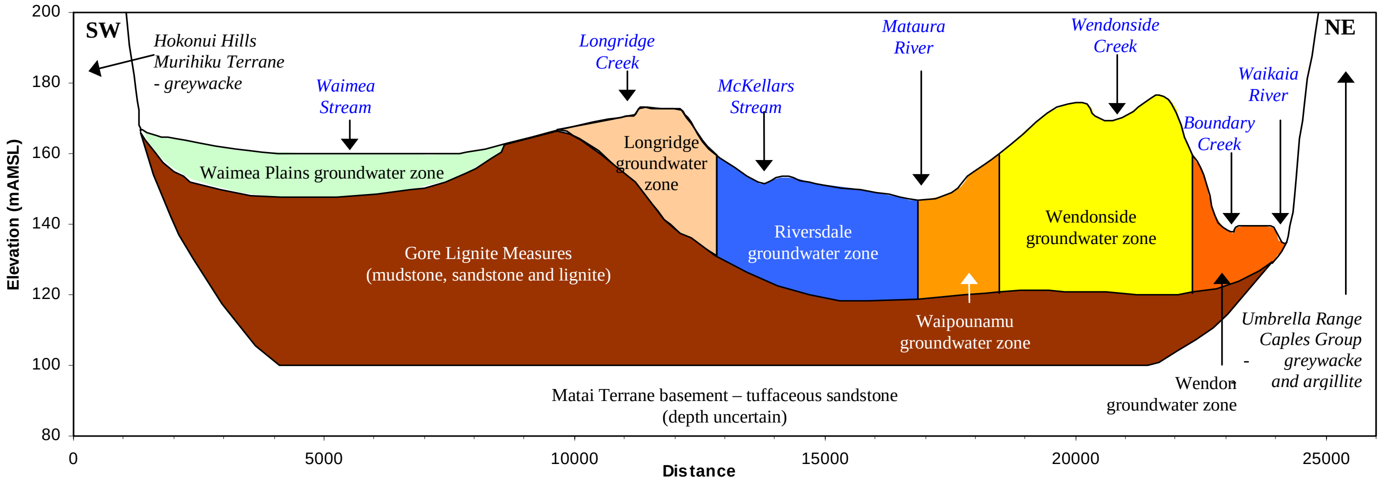
The Wendon groundwater zone follows the recent floodplain of the Waikaia River downstream of the Waikaia township. This area is differentiated from the Waipounamu groundwater zone on the basis of subsurface geology and hydraulic properties, which are likely to reflect differing parent rock materials and hydrological processes in the respective catchments.

Wendonside groundwater zones

The Wendonside groundwater zone encompasses a large alluvial terrace bounded by the Waipounamu zone to the south, the Wendon groundwater zone to the east, the Cattle Flat groundwater zone to the northwest, and by the Caples Group basement to the north.

Longridge groundwater zones

The Longridge groundwater zone is bounded by the Riversdale aquifer to the east, the Waimea groundwater zone to the southwest and by hills comprising exposed Caples Group basement to the northwest.



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

4.2 Aquifer Recharge

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

4.2.1 Rainfall Recharge

Rainfall recharge characteristics have been derived through numerical simulation of catchment water balances. Catchment areas deemed to have similar hydrological properties, and hence similar water balances are summarised as follows:

- Riversdale and Waipounamu - relatively high permeability river-connected groundwater zones;
- Longridge, Wendonside and Wendon - less permeable groundwater zones, and
- Peripheral hardrock sub-catchments that discharge runoff into the model domain.

Each catchment 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).

As indicated in Section 3.4, the upland peripheral catchments are likely to receive higher rainfall than lower areas of the project area.

Soil characteristics for the Riversdale were derived from the relevant Topoclimate soil survey data. This information, which included total available water, plant available water and internal drainage, was adjusted to parameters relevant for recharge modelling with reference to actual soil moisture measured at the Environment Southland Riversdale Aquifer at Liverpool Street monitoring site.

Soil parameters derived for the Riversdale area were then adjusted with reference to Topoclimate survey data 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 hardrock basement of Caples or Murihiku terrane exposed in the peripheral hardrock catchments. Decreasing permeabilities are likely to result in increasing proportions of rainfall partitioned into surface runoff.

Catchment water balance results from the SMWBM simulations are summarised in Table 3 and the model parameter values employed for this study are detailed in Appendix A.

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

Component	Proportion of Annual Rainfall			
	Riversdale / Waipounamu	Longridge	Wendonside /Wendon	Upland Sub-Catchments
Interception Losses (%)	29.0	29.0	33.7	32.7
Soil and Plant Evaporation (%)	27.4	27.3	18.9	18.5
Surface Runoff (%)	17.5	27.0	35.9	41.9
Rainfall Recharge (%)	24.9	16.2	11.3	6.7

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

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

Groundwater Zone	Area		Groundwater Recharge		
	Ha	km^2	% ann. rainfall	L/sec	m^3/day
Riversdale	9,842	98	24.9	631.0	54,516
Waipounamu	3,213	32	24.9	671.3	57,999
Wendon	2,464	25	11.3	1025.7	88,621
Wendonside	8,724	87	11.3	2627.0	226,969
Longridge	4,393	44	16.2	1322.8	114,288
Total	28,635	286	-	6278	542395

4.2.2 River/Stream Seepage and Aquifer Throughflow

Riversdale groundwater zone

Analysis of the river/aquifer water balance (refer Section 4.3 below) indicates that seepage from the Mataura River along the reach between Ardlussa and the Waikaia confluence is a significant recharge input to the Riversdale groundwater zone.

Analysis of piezometric contours shown in Figure 6 indicates that groundwater flow in this part of the catchment is near perpendicular or slightly away from the river. Significant throughflow is thus unlikely to occur between the Waipounamu and Riversdale groundwater zones.

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 groundwater zone

Groundwater throughflow to the Waipounamu aquifer occurs from the upgradient Wendonside aquifer, however it is difficult to determine the relative contributions on the basis of available flow gauging data. Analysis of piezometric contour data indicates that throughflow may be significant especially near the downstream extent of the Waipounamu groundwater zone.

Wendon groundwater zone

Concurrent flow gauging in the Waikaia catchment indicate significant groundwater input into the lower reaches of the Waikaia River. This is likely to represent drainage of rainfall (areal) recharge to the Wendon groundwater zone and throughflow from the Wendonside groundwater zone

The Longridge and Wendonside groundwater zones

Both Longridge and Wendonside are upper terrace aquifers primarily receiving areal recharge. Possible throughflow inputs from surrounding hard rock catchment streams may be of significance along relevant margins.

4.2.3 Recharge from Peripheral Hardrock Catchments

The loss of significant flow from streams exiting hardrock catchments onto surrounding alluvial fan and terrace deposits is commonly observed in many parts of the Southland Region.

Hardrock catchments to the north of Longridge and Wendonside, and to the east of the Wendon groundwater zone (see Figure 2) are likely to provide additional recharge along relevant boundaries (i.e., side fluxes). Due to the low permeability of these catchments, much of the rainfall will be partitioned directly to surface runoff.

When streams exiting the hills reach the alluvial terraces, they may recharge the underlying gravel aquifers, as is observed in the Boundary Creek catchment. Boundary Creek is shown on Figure 2 as running across the surface of the Wendonside groundwater zone, however information from Environment Southland has indicated that stream flow generally disappears a short distance after crossing onto the surface of the Wendonside gravels.

Table 5 lists the relevant catchments and details estimated runoff and total catchment discharge (combined surface runoff and groundwater seepage to streams) that may be available as inputs to the relevant aquifers, as determined from SMWBM data (see Section 4.2.1).

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

Catchment	**Area outside model domain**		**Recharge from Surface Runoff**		**Total Catchment Discharge**	
	m^2	**km^2**	**% annual av. rainfall**	**m^3/day**	**annual av. rainfall**	**m^3/day**
Boundary Creek	5,925,663	5.9	41.86%	6,899	50.99%	7,935
Wendon Stream	47,603,029	47.6	44.26%	50,595	53.30%	57,624
Waikaia Eastern Catchments	32,850,290	32.9	44.26%	12,601	53.30%	14,351
Pyramid Creek	24,226,942	24.2	25.46%	14,832	42.80%	23,471
Total	180,095,786	180	-	163,703	-	193,934

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

4.3 River Fluxes to Adjoining Aquifers

Environment Southland has undertaken concurrent flow gauging at a number of locations on the Mataura and Waikaia rivers. Additional flow gauging was also undertaken 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.

To-date, 8 river gauging rounds have been undertaken although not all locations were gauged at every visit. While the rivers have been at different flow ratings during each gauging round, a strong correlation between the river gains and losses within each reach has been observed. Therefore, for the purposes of this exercise the flow average for each location has been calculated and presented in Table 6, along with gauge data for 11 April 2003, which was used in subsequent model calibration simulations.

This information is summarised in Table 6 and Table 7 below and diagrammatically in Figure 5. Also included in the tables are the general head boundary nodes that correspond to flow gauging locations.

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

  (See A3 attachment 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).

The following provides a summary of the data shown in Figure 5 and Table 6;

- The Mataura River loses approximately 118,000 m^3/day to the aquifer along the reach between Ardlussa and Riversdale Bridge, and only 199 m^3/day between Riversdale and the Waikaia confluence. This indicates that downstream of Riversdale Bridge, the hydraulic gradient between the Mataura and adjacent groundwater becomes flat, reducing aquifer gains from the river. In fact the gradient is likely to reverse along this reach leading to river gains from the aquifer in lower reaches, as detailed below.
- The Waikaia River gains approximately 270,000 m^3/day along the reach from Freshford Bridge to Waipounamu Bridge Rd and approximately 37,000 m^3/day from there to the Mataura confluence, with a total gain of approximately 305,000 m^3/day.
- From upstream of the confluence to Pyramid Bridge, the Mataura gains approximately 850,000 m^3/day. However, when the Waikaia River input is subtracted the actual gain is approximately 11,700 m^3/day. This indicates that the Mataura River downgradient of the confluence begins to gain water.
- Gains in the lower Mataura below Pyramid Bridge total approximately 175,000 m^3/day along the reaches to Dillon Rd. The gains are a combination of groundwater discharge directly to the river and via spring fed-streams entering the river along the downstream reach.

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

River Reach	Average Gauging		11 April 2003	
	(L/s)	(m^3/day)	(L/s)	(m^3/day)
Upper Mataura River				
Mataura River at Ardlussa	6,774	585,311	6,497	561,341
Mataura River at Riversdale Bridge	5,315	459,179	5,132	443,405
River loss	*-1,460*	*-126,132*	*-1,365*	*-117,936*
Mataura River upstream of Waikaia confluence	-	-	5,134[1]	443,604[1]
River loss	-	-	*2*	*199*
Total Loss on Upper Mataura	-	-	*-1,363*	*-117,737*
Waikaia River				
Waikaia River at Freshford Bridge	6,065	523,985	6,173	533,372
Waikaia River at Waipounamu Bridge Rd	8,744	755,482	9,276	801,446
River Gain	2,679	231,497	3,103	268,075
Waikaia River Upstream of Mataura confluence	-	-	9,704[1]	838,400[1]
River Gain	-	-	*3,531*	*36,953*
Total Gain on Waikaia	-	-	*6,634*	*305,028*
Mataura-Waikaia Confluence				
Mataura River Upstream of Waikaia Confluence	-	-	5,134[1]	443,604[1]
Mataura River at Pyramid Bridge	13,053	1,127,779	1,473	1,293,667
River gain	-	-	*9,839*	*850,063*
River Gain Minus Waikaia input	-	-	*135*	*11,663*
Lower Mataura River				
Mataura River at Pyramid Bridge	13,053	1,127,779	14,973	1,293,667
Mataura River at Otama Flat Road	13,328	1,151,510	15,632	1,350,605
River gain	*275*	*23,731*	*659*	*56,938*
Mataura River at Dillon Road	15,009	1,296,778	16,989	1,467,850
River gain	*1,681*	*145,267*	*1,357*	*117,245*
Total Gain on Lower Mataura	*1,956*	*168,998*	*2,016*	*174,182*

Note: [1] Pro-rata value derived from gauging on 03/05/05
- Average values not calculated as only one gauging has been carried out at confluence locations

Concurrent flow gauging data for the main spring fed streams is summarised in Table 7.

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

Gauge Location	Average Flow		16 April 2003	
	(L/s)	(m^3/day)	(L/s)	(m^3/day)
Spring at Tayles and Fingerpost-Pyramid Road	118	10,155	124	10,714
Spring at Fingerpost-Pyramid Road	67	5,789	29	2,506
Meadow Burn at Fingerpost-Pyramid Road	209	18,078	129	11,146
Meadow Burn at Round Hill Road	475	41,018	386	33,350
Spring at Mandeville-Riversdale Highway	93	8,043	43	3,715
Spring at Kingston Crossing-Mandeville Road	52	4,532	39	3,370

In general, spring fed streams such as Meadow Burn are located in the lower portion of the river valley where the watertable intersects with the ground surface at various locations resulting in the emergence of groundwater as spring flow. 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 approximately 33,350 m^3/day. This gain indicates that the stream is draining groundwater from the aquifer throughout a majority of its length. Conversely, the McKellar Stream that crosses the Riversdale aquifer has limited hydraulic connection and gains most of its flow at the point of origin. Similarly, Longridge Stream receives the bulk of its flow from headwaters outside of the Longridge groundwater zone and flows across the terrace surface with little interaction with the underlying unconfined aquifer.

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 attachment 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 mounds and troughs that are likely to result where reported water levels reflect the presence of a perched water table at that location and are considered to be inconsistent with the expected natural water surface. Figure 7 depicts the piezometric surface after the removal of such data values.

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 groundwater zone and in the upper east area of Wendonside is in an easterly direction.

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

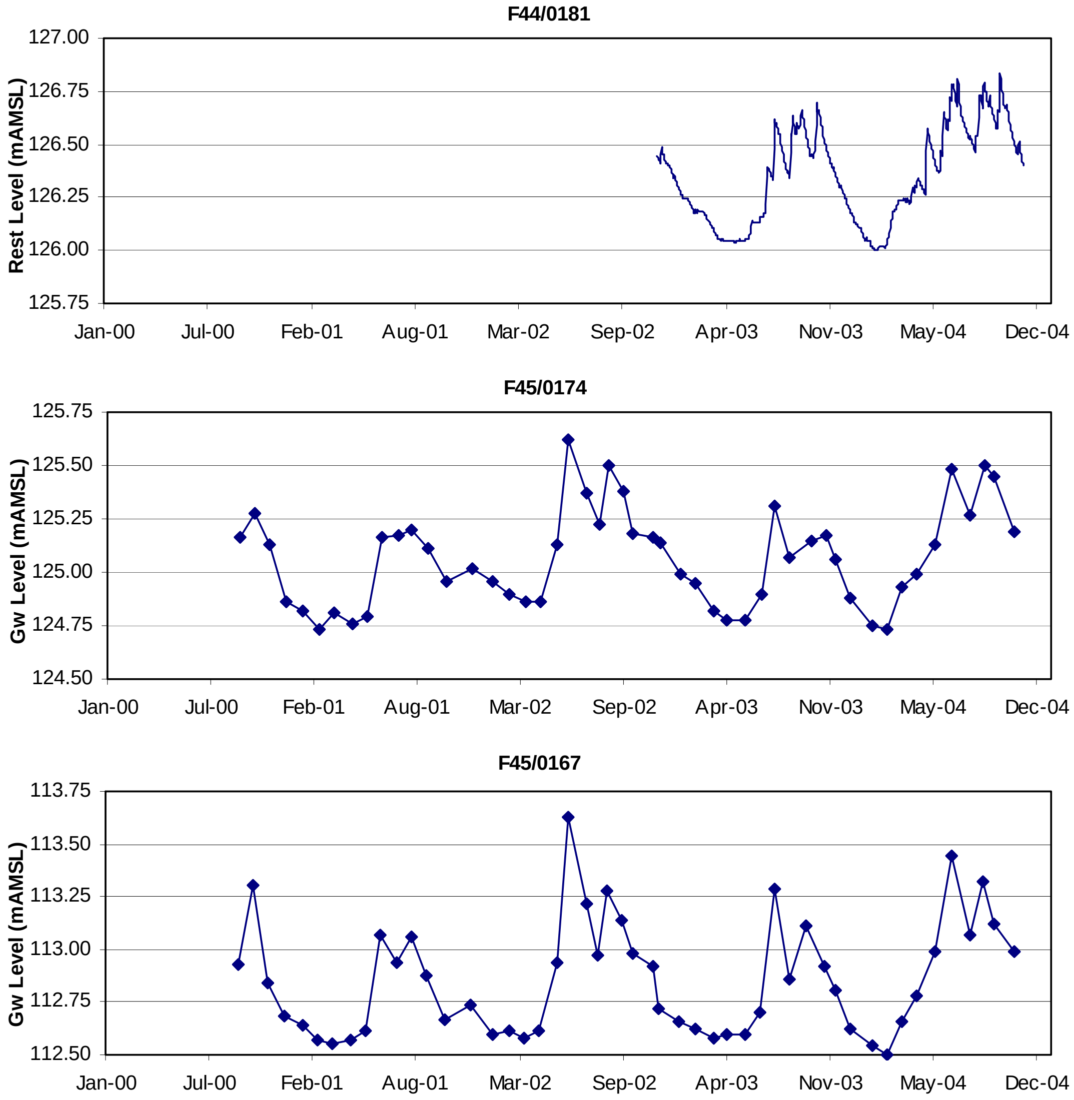
  (See A3 attachment at rear)

The hydraulic gradient (spacing of the piezometric contour lines) over much of the Riversdale and Waipounamu groundwater zones is relatively flat. In addition, the contours run approximately parallel to the topographic gradient, reflecting the relatively high aquifer permeability and/or groundwater discharge to spring-fed streams that act to constrain groundwater to near ground surface level.

In upper reaches of the study area, along the interface of the Riversdale and Longridge groundwater zones, 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 weathered 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 since January 2000. The data is collected manually via a monthly monitoring round or recorded daily via the use of in-situ data loggers that are manually downloaded and processed by Environment Southland. Figure 6 presents hydrographs (on the same scale) for three of the monitoring bores located in the Riversdale groundwater zone. Remaining observation bore hydrographs are presented in Appendix B.



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

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.

Of the twelve monitoring bores, only eleven are used as observation point data for model calibration as it is considered likely that bore F44/0077 is representative of a deeper semi-confined aquifer underlying a portion of the Wendonside groundwater zone and therefore has no use as an observation point in a single layer model. The location of all monitoring bores is indicated on Figure 9.

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

  (See A3 attachment 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 suggesting relatively constant head or baseflow source provided by river loss.
- The seasonal response reflects input of rainfall recharge during the winter months. This active component of groundwater storage is progressively drained by outflow in the downgradient section of the aquifer until aquifer levels reach the minimum determined by river loss.

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 F44/0018 and F44/0006, situated on the upper terraces, display more significant fluctuations than those in lower parts of the project area. This increased response to rainfall recharge is likely to reflect lower permeability and storage characteristics in these areas.

4.6 Aquifer Hydraulic Properties

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

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

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

Groundwater 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	2,100
Waipounamu-Mataura	2181700	5473900	1,060
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 is likely due to:

- highly variable depositional history characteristic of reworked fluvio-glacial outwash deposits;
- palaeotopography related undulating aquifer base and associated variable saturated thickness; and

- thin saturated aquifer relative to total aquifer thickness in places leading to rapid dewatering during testing and hence inconclusive test results.

5. Numerical Model

The USGS-developed MODFLOW 2000 modelling code was implemented for this study due to its proven record through a range of analytical situations and general acceptance as the industry standard. The Groundwater Modelling System (GMS) user interface software, which incorporates the MODFLOW code, was utilised on this project.

5.1 Model Grid

Figure 10 displays a plan view of the model domain. The model comprises 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 km² or 28,623 hectares.

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.

5.2.1 Layer Top Elevation

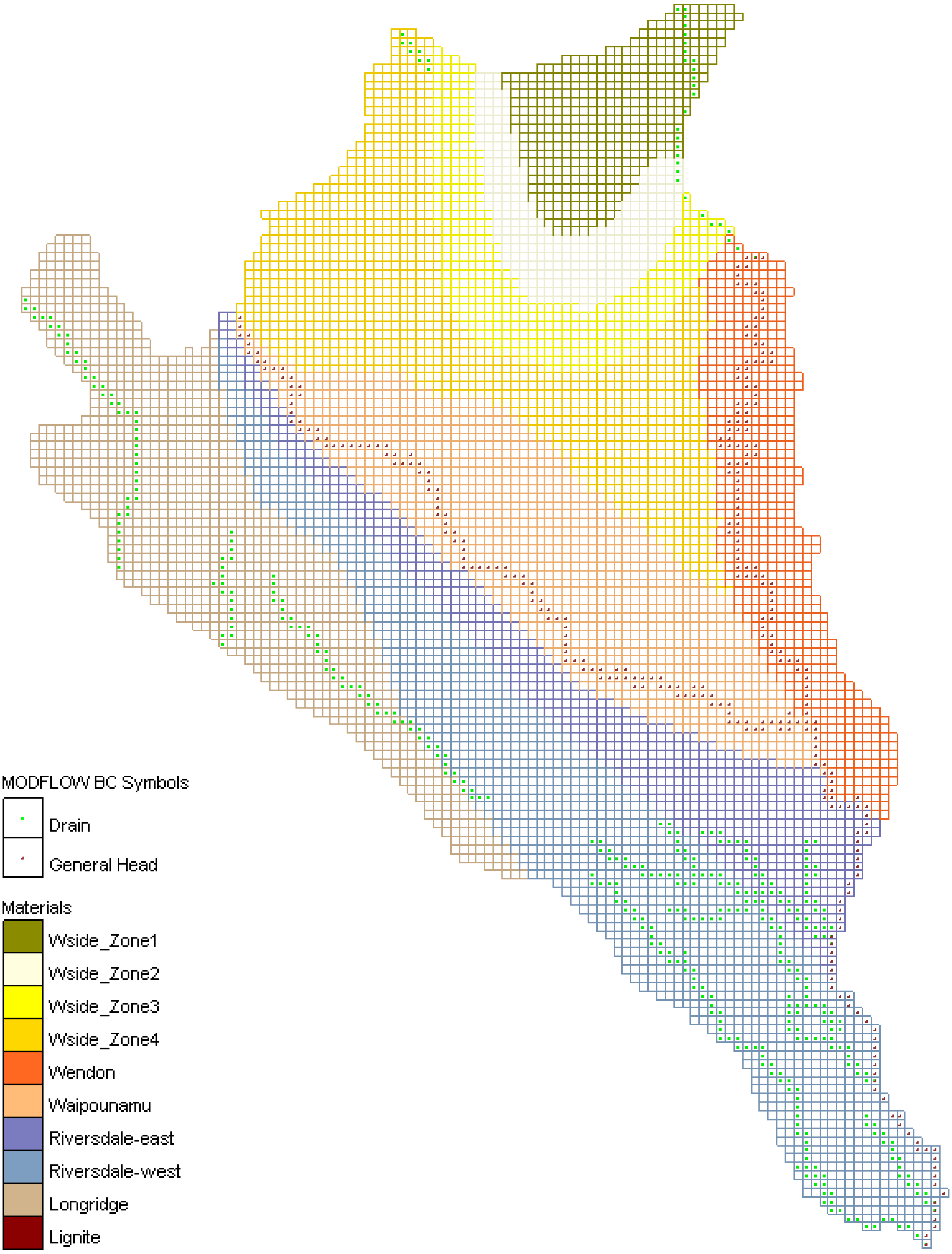
A ground surface elevation model in mAMSL was generated to represent the top elevation of the aquifer layer. This was defined using topographical data obtained from the LINZ (20 m topo contours) augmented with local survey point data for bore locations, stream bed elevation and roadside land survey.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



- **Figure 10. Northern Southland model grid, boundary conditions and hydraulic property zones.**

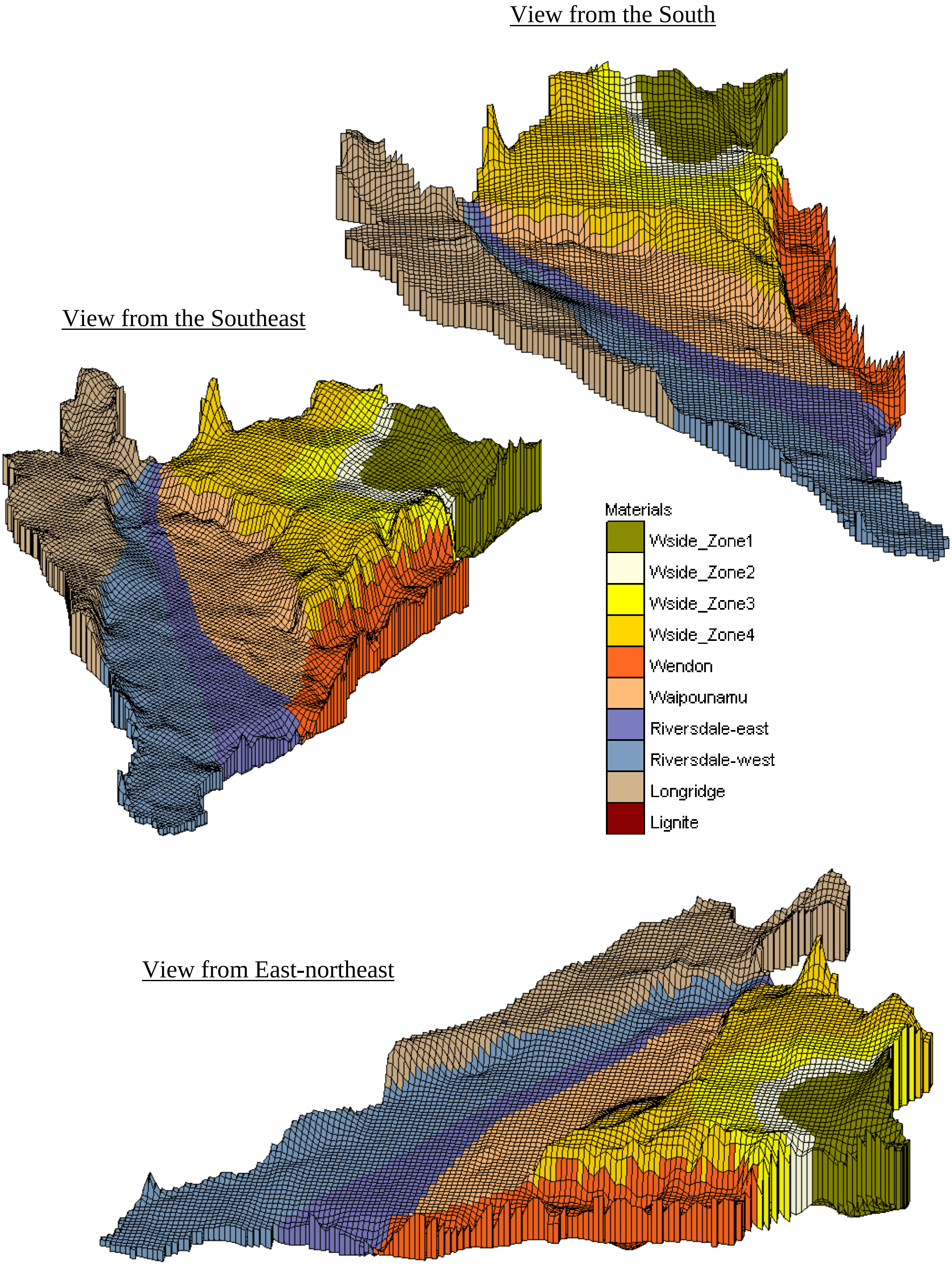


Figure 11. Model grid projections (vertical exaggeration = 50).

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 attachment at rear)

The thickness of the gravels varies from approximately 5 m in the lower reaches of the Riversdale groundwater zone to approximately 70 m along the northern margin of Wendonside groundwater zone. 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 groundwater zone 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 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 also shows the model hydraulic property zones, defined during the course of the model calibration and where possible consistent to observed values. The hydraulic property zones were essentially required to maintain high heads in upland areas by specifying lower permeability zones in these areas.

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. 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 demonstrated in Figure 10.

A total of nine materials were defined during the model build and calibration stages, based on model responses to applied stresses and property changes, consistent with observed hydraulic conductivity data (see Section 4.6). The different materials form nine conductivity zones. In practice, conductivity changes would be more gradual than that represented in the model. This is acknowledged as a necessary simplification of the modelling process.

Section 4.6 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)
Riversdale East	300	100 – 217
Riversdale West	100	29.4 – 175
Waipounamu	1250	750 – 2100
Wendon	350	15 – 40
Longridge	20	NOD
Wendonside Zone 1	2.5	NOD
Wendonside Zone 2	6	NOD
Wendonside Zone 3	15	21 – 43
Wendonside Zone 4	40	NOD

Note: NOD is no observed data

Due to the general lack of testing data, during 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 to 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, the values used within the calibrated model sit 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 3.2. This was incorporated into the model by reducing conductivity values away from the Mataura River through the Waipounamu/Wendon and Wendonside zones, and through the Riversdale (East and West), and Longridge zones.

It should be noted that the observed and model values for the Wendon zone are near to one order of magnitude lower than that for Waipounamu. These values are likely to reflect a difference in sediment characteristics between the Waikaia and Mataura catchments in that the predominantly schist Waikaia catchment results in less reworking of alluvial sediments with resulting higher fines content and reduced permeabilities in the Wendon alluvium.

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 5.7).

5.4 Boundary Conditions

Boundary conditions are constraints imposed on the model grid to represent the interface between the model domain and the surrounding environment.

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

- **General Head Boundary (GHB)** cells are used to simulate the transient head within 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 transmission through the riverbed. When the groundwater 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 the assigned conductance constant.

  For transient simulations, time series 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 conductance value is then applied to each arc separately which enables modelling of different riverbed substrates where required. Table 12 details the bed conductance values assigned to each river arc and Section 7 discusses the sensitivity with respect to the conductance values specified.

- Table 12. Riverbed conductance values (m/day/m^2)

Mataura		Waikaia	
River Arc	**Conductance**	**River Arc**	**Conductance**
M1 – 2	100	W1 – 2	30
M2 – 3	40	W 2 – 3	25
M3 – 4	10	W3 – 4	20
M4 – 5	10	W4 – 5	15
M5 – 6	5	W5 – 6	10
M6 – 7	5		
M7 – 8	20		
M8 – 9	20		
M9 – 10	20		
M10 – 11	20		
M11 – 12	20		
M12 – 13	20		
M13 – 14	20		
M14 – 15	20		

Note: Arcs are defined by river nodes as detailed in Section 5.4.1

For this study, conductance values for the upper Mataura and Waikaia reaches were set to simulate the effects of reducing permeability towards the Mataura/Waikaia confluence resulting from increasing fines derived from the Waikaia catchment (see Section 5.3).

Additionally, recent gauging by Environment Southland suggests that the Upper Mataura gains only a negligible volume on the reach from Riversdale Bridge to the confluence, whilst the Waikaia continues to gain a significant volume below Waipounamu Bridge Road. This indicates that the bulk of throughflow from Wendonside is likely to be discharged via Wendon into the Waikaia. One reason for this may be related to saturated thickness as a recent log from bore E44:82298-73343 (located close to the confluence) places mudstone at 10 metres indicating that aquifer saturated thickness may pinch out beneath Waipounamu near to the confluence, controlling throughflow distribution. Early model runs reported large river gains from Riversdale to the confluence whilst under reporting gains on the Waikaia below Waipounamu Bridge Rd and the low conductance values on model arcs in the confluence area were employed to address this problem. However, although a significant improvement was achieved, it was not possible to simulate observed flows for these reaches. Further field investigations in the confluence area are likely to be required to solve this problem.

A value of 20 m^2/day/m was assigned to arcs below the Mataura-Waikaia convergence, based on the smaller gradient between river and groundwater levels.

- **Drain Cells** are used to represent the main spring fed streams in the lower reaches of the Riversdale groundwater zone, and to a lesser extent within Longridge and near to the model boundary in the north of Wendonside (see Figure 10). Use of drain cell permits water to exit the model when aquifer head is greater than the specified drain cell elevation at that location. However, the drain cell is deactivated when the opposite occurs. 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. However, unlike the GHB, drain cells can not transmit water into the model, hence their sensitivity to conductance term is not as significant (i.e., only relevant when groundwater is above drain elevation). The conductance value assigned to all drains in the model is 5 m^2/day/m, given that the spring-fed streams are finer sediment indicative of a lower energy depositional environment.
- **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 basement control on east side of Wendon, and north of Longridge and Wendonside.
- **Well Cells** are employed to simulate consented pumping bores.

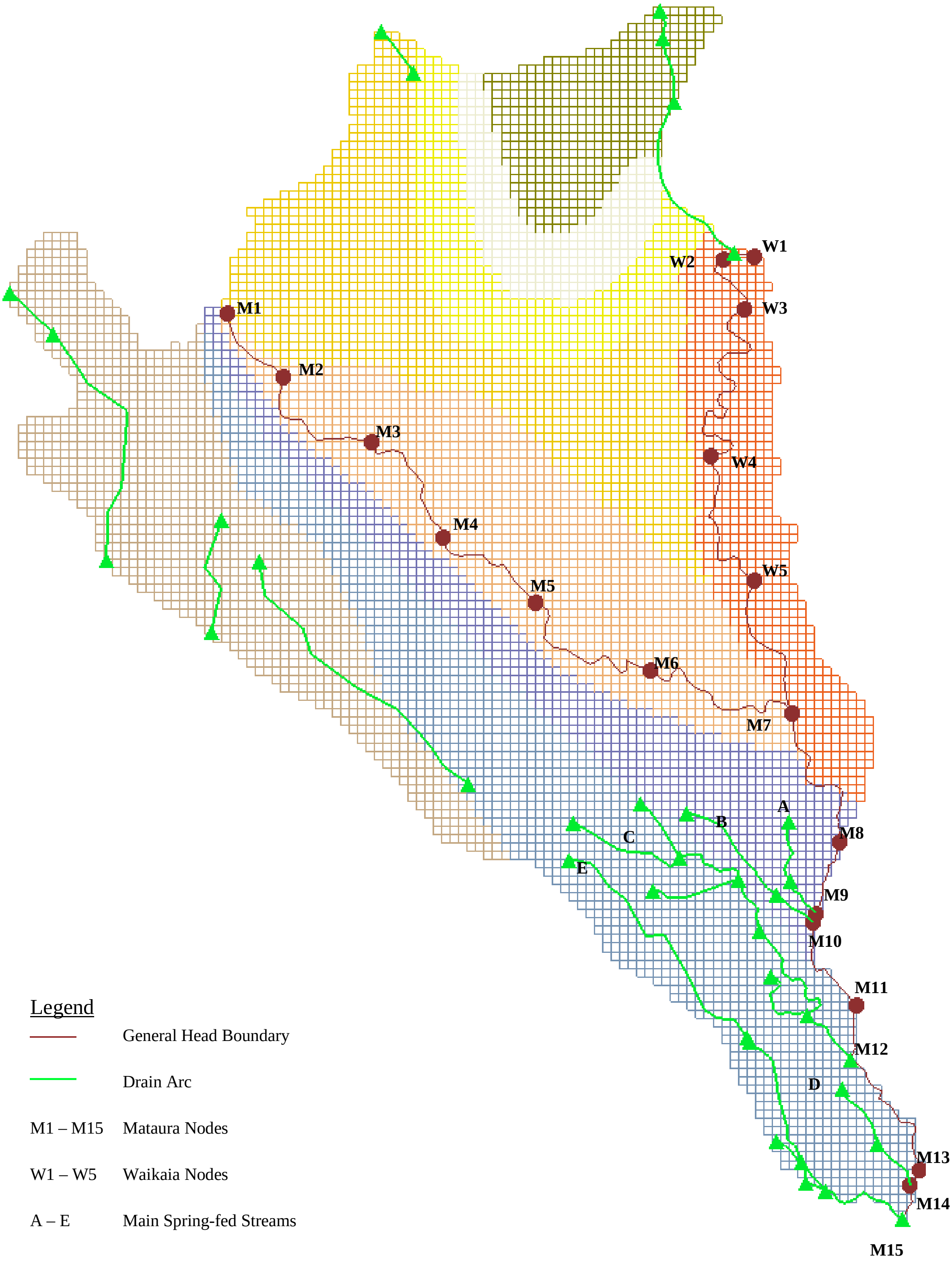
5.4.1 River Boundary Stage Data

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) to enable correlation with stage height measured at the Environment Southland Mataura River at Pyramid Bridge floodwarning site. This enabled enable calculation of temporal variations in river stage across the model domain.

When constructing the general head arcs in the model, nodes were inserted along the river at each of the survey locations. Some stage locations 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 13.

Table 13. River stage height survey data.

River Reach	Node	Easting	Northing	Surveyed Elevation	Model Elevation
Upper Mataura					
Northern Boundary	M1	2170714	5482092	N/a	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	N/a	121.00
Waikaia					
Northern Boundary	W1	2183181	5483437	N/a	148
Freshford Bridge	W2	2182439	5483386	144.83	144.83
	W3	2182951	5482177	138.64	138.64
	W4	2182152	5478662	N/a	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	N/a	111.15
	M10	2184556	5467499	N/a	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



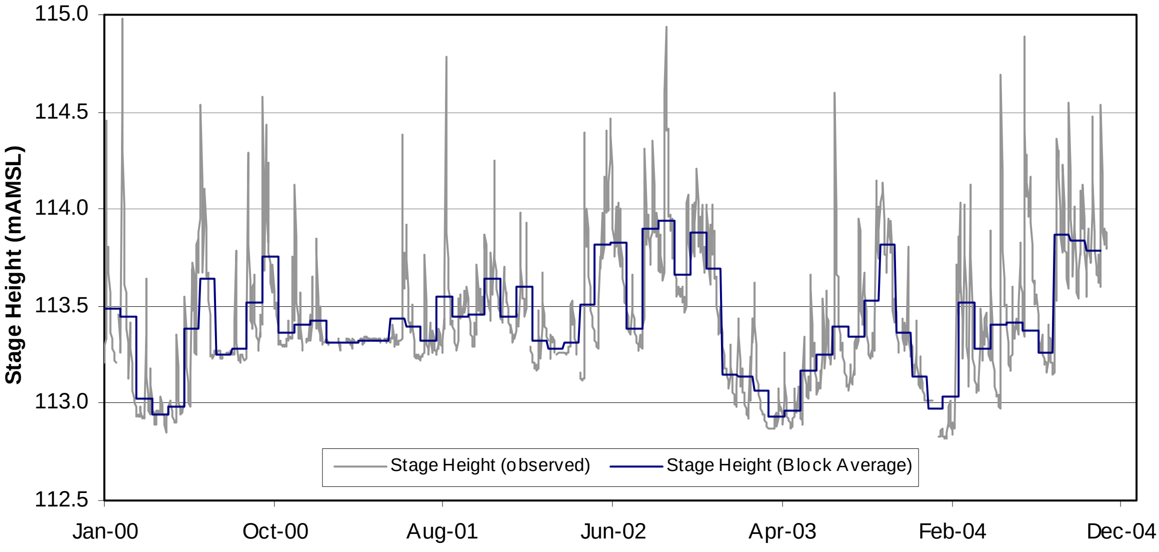
- **Figure 13. Model boundary conditions.**

Stage elevation is one of the main factors (along with bed conductance and adjacent aquifer transmissivity) 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, during model calibration the elevation was adjusted accordingly 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 1 January 2000 to July 2004. This data was block-averaged using time units identical to model stress periods (see Section 5.5) and the block average values were input into the model as transient river head data.

Sensitivity testing was undertaken on the block average lengths and no appreciable differences were observed in simulated groundwater levels with smaller or variable block lengths (see Section 7).

Figure 14 presents a time series graph showing the recorded stage height at Pyramid with block-averaged values corresponding to model stress periods.



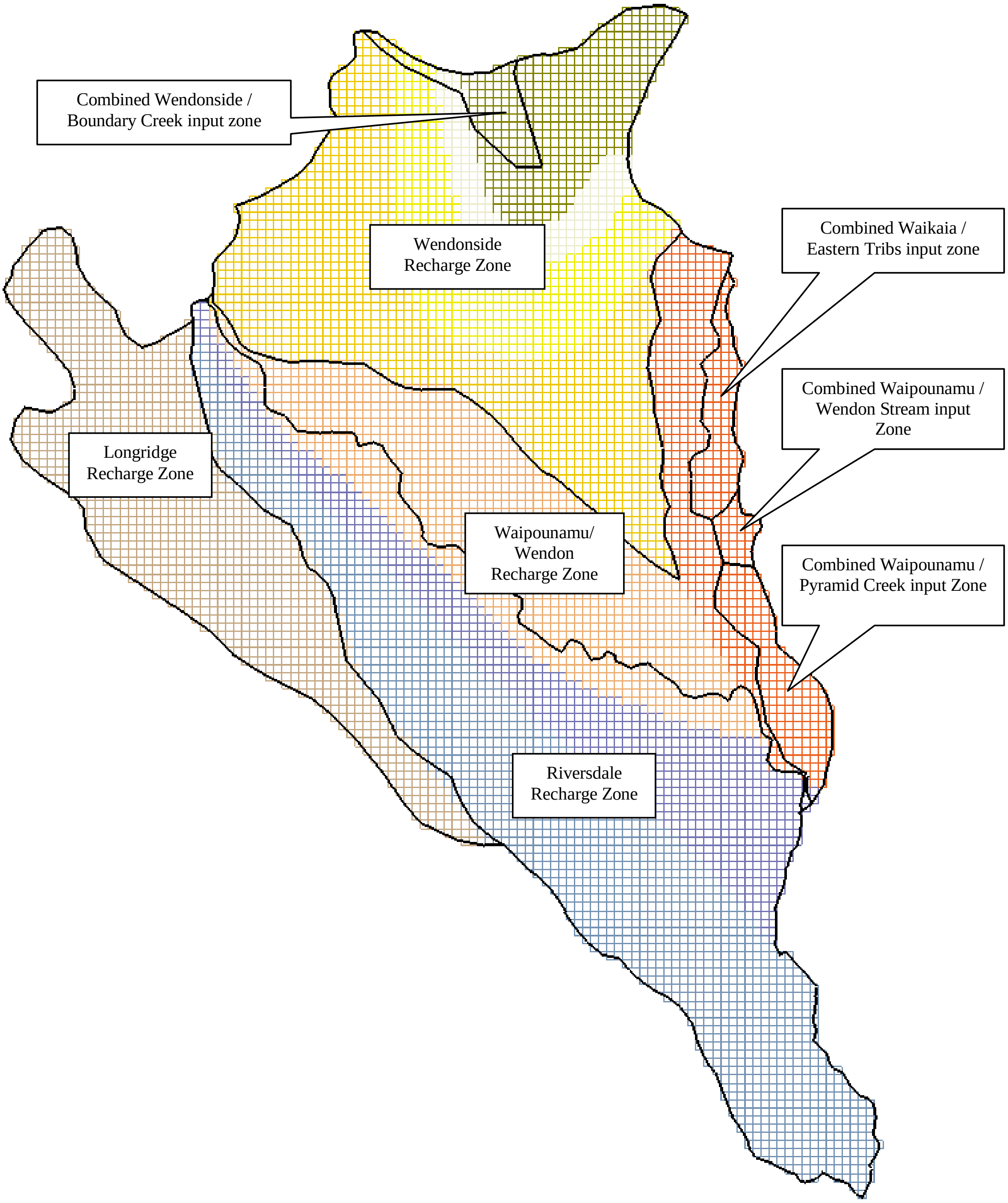
- **Figure 14. Pyramid Bridge stage height and block average values for model input.**

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.

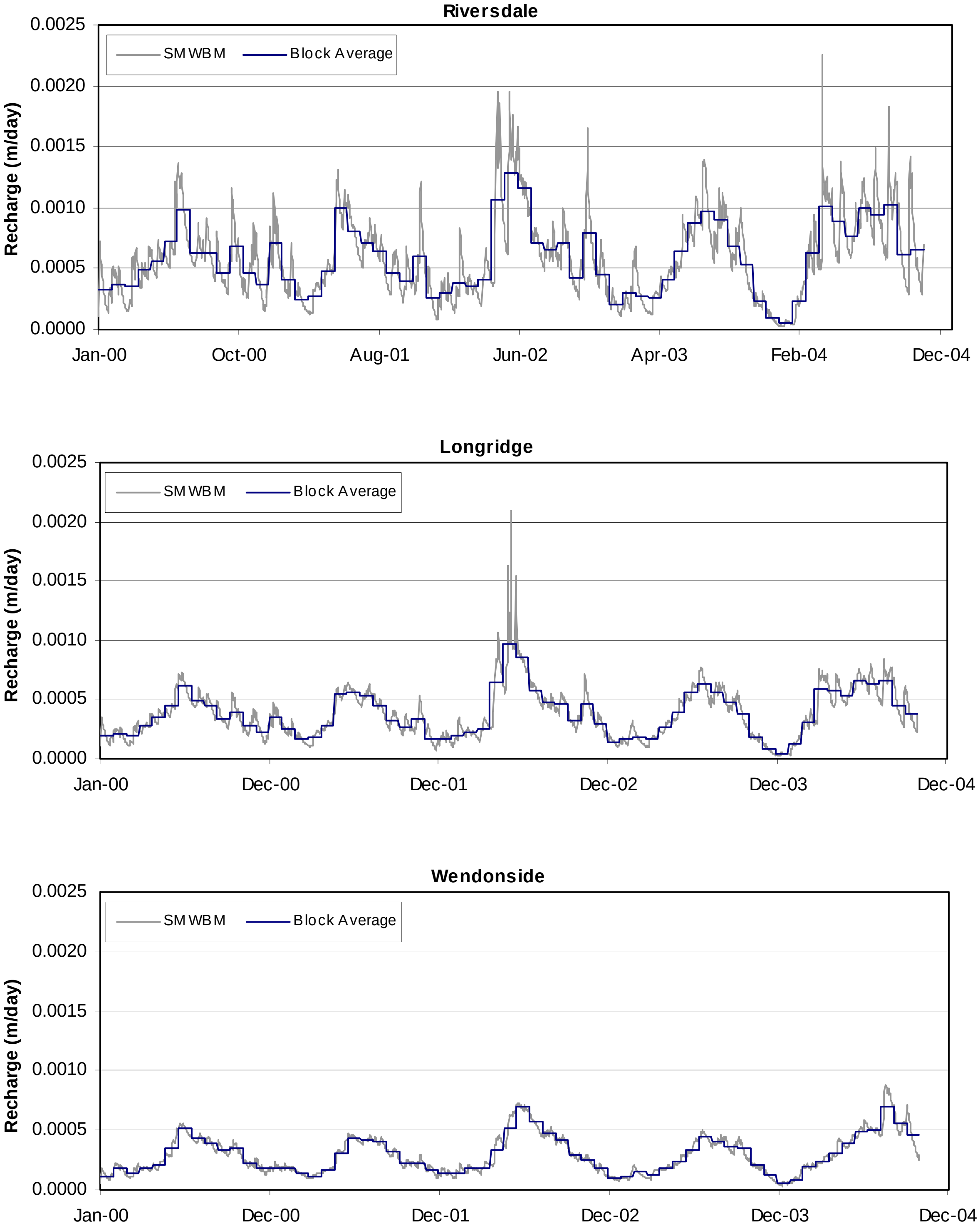
5.4.2 Rainfall Recharge

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 potential evaporation and transpiration (PET) losses are pre-conditioned or accounted for prior to the groundwater model.

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 groundwater zone zones (Riversdale and Waipounamu) and the less permeable Longridge, Wendonside and Wendon groundwater zones.



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



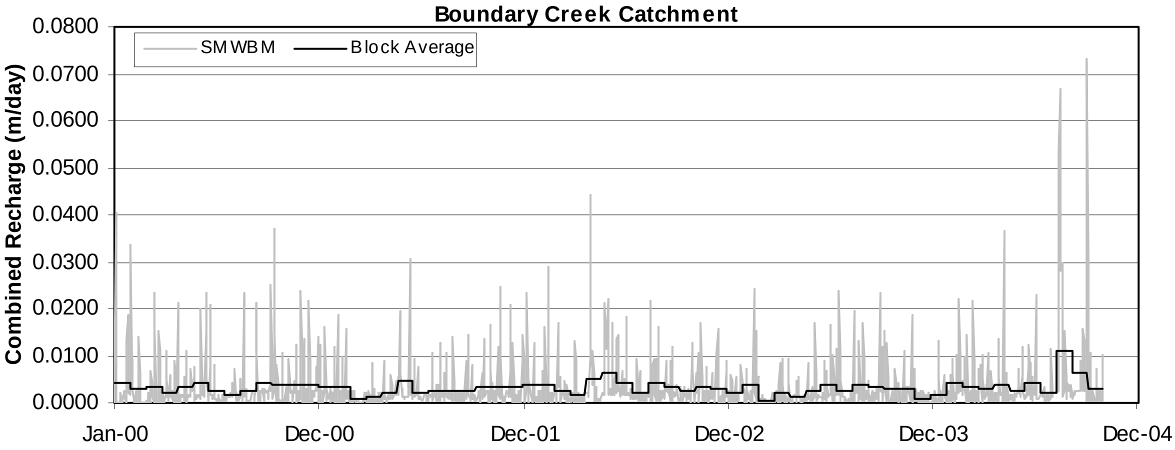
- **Figure 16. Area rainfall recharge input data.**

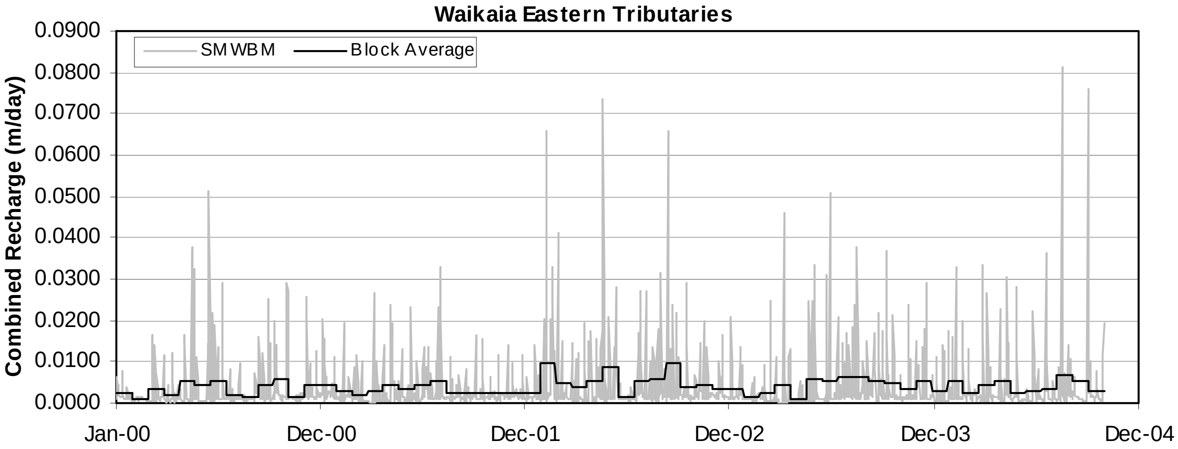
5.4.3 Recharge from Surface Runoff

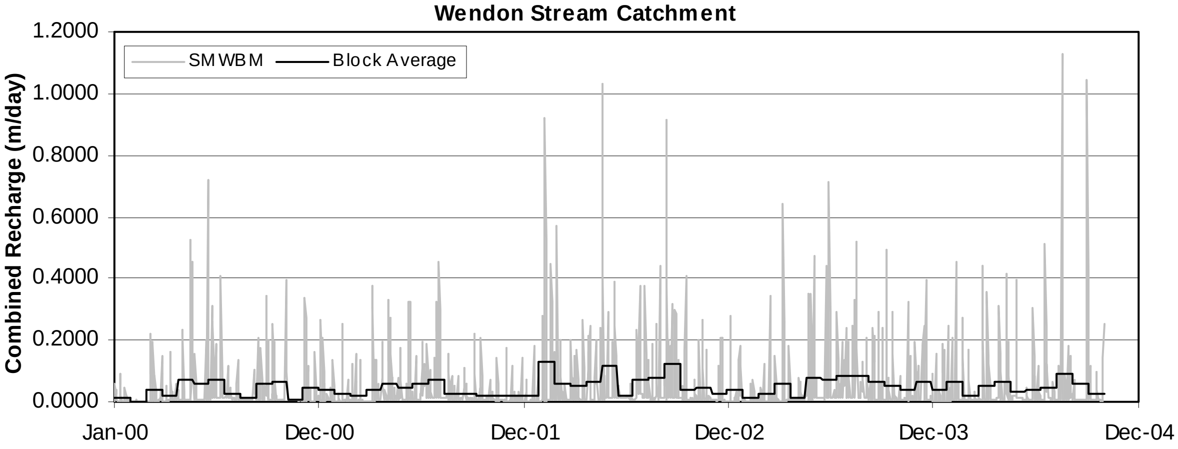
Runoff recharge inputs from the peripheral hard rock catchments were simulated using the SMWBM (see Section 4.2.3) and assigned to the appropriate portion of the model area. Daily average runoff volumes were then added to existing rainfall recharge values to produce a combined rainfall/runoff input for that part of the model domain. The location of the combined recharge polygons is marked in Figure 15.

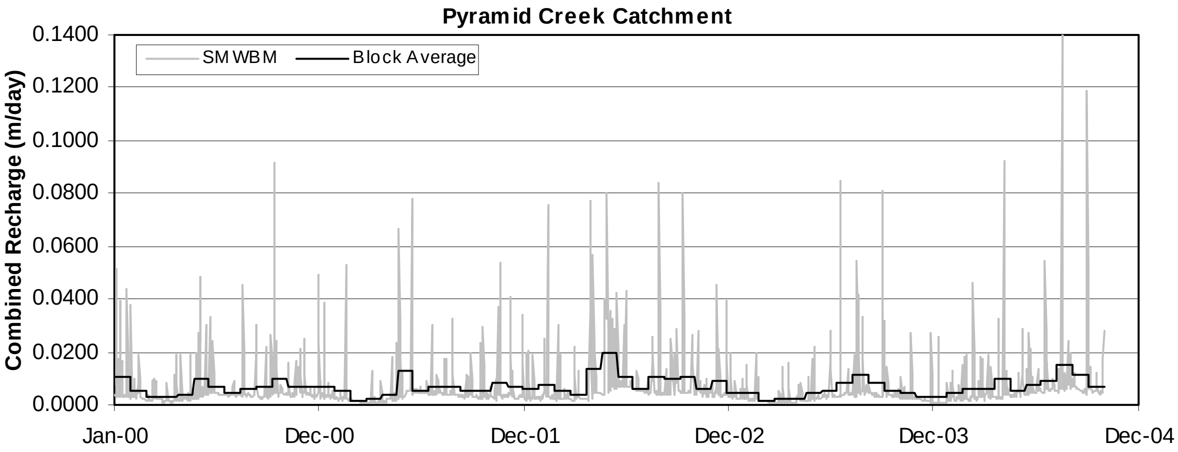
Hydrographs for areas with combined areal recharge and recharge from surface runoff are provided in Figure 17 so that a comparison can be made to Figure 16. It should be noted that differences in sub-catchment area and the ratio of areas to respective recharge portions of the model domain result in a range of up to one order of magnitude between the highest catchment input (Wendon Stream) and the lowest (Waikaia Eastern Tributaries).

Actual model water budgets showing total recharge for the model domain for a typical wet and dry period from the transient simulation are provided in Table 14.


Boundary Creek Catchment
SMWBM
Block Average
Combined Recharge (m/day)
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
Jan-00
Dec-00
Dec-01
Dec-02
Dec-03
Dec-04


Waikaia Eastern Tributaries
SMWBM
Block Average
Combined Recharge (m/day)
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
Jan-00
Dec-00
Dec-01
Dec-02
Dec-03
Dec-04


Wendon Stream Catchment
SMWBM
Block Average
Combined Recharge (m/day)
1.2000
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
Jan-00
Dec-00
Dec-01
Dec-02
Dec-03
Dec-04



- **Figure 17. Combined areal and runoff recharge input data.**

5.5 Model Stress Periods and Time Steps

Stress periods are temporal divisions of the model simulation (in transient mode) where stresses imposed on the model (e.g., rainfall recharge, river elevations, pumping, etc.) are held constant. Stress period length varies depending on the time frequency or scale of the physical process acting on the groundwater system. Due to computation limitations, there is often a compromise between stress period length and the number of stress periods and hence accuracy of the model simulation.

However, in contrast to surface water systems, groundwater systems generally respond relatively slowly to imposed stresses and it is therefore appropriate to use an average surface process to drive the modelled groundwater response. Stress period must however be sufficiently short to enable simulation of relatively short timescale recharge events.

For the purposes of this model, 28 day stress period lengths were defined from trial runs carried out to determine the most effective combination of length and total number of stress periods. Ultimately, the model was set up for simulations of 45 stress periods due to computational restrictions of MODFLOW 2000.

Timesteps are sub-divisions of model stress periods, required to facilitate smoother transition to a stable solution. Each stress period consisted of 3 timesteps. 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 readjustments 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 (1 Jan 2000) to present, however computational restrictions discussed above imposed a shorter run time than would ideally be used. As more observation data is available for the period after 2002, particularly the daily data from monitoring bores, the final model simulation period was moved forward to include the more recent data from May 2002 to October 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 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 18. Model starting conditions (mAMSL).**

5.7 Current Groundwater Abstraction

There are currently 35 bores that hold Resource Consents issued by Environment Southland to abstract groundwater in the model domain. At present resource consents are required for all groundwater abstractions in excess of 20 m^3/day which do not meet the requirements of Section 14, 3(b) of the Resource Management Act for reasonable domestic or stock use. 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.

A number of resource consents for pasture irrigation in the model domain have conditions which set a maximum daily abstraction rate as well as a maximum seasonal allocation. Depending on individual consent conditions, the maximum allocation restricts the duration over which the consent can be exercised at the maximum rate to between 80-100 days. This seasonal allocation reflects the decline in maximum demand during the shoulder periods of the irrigation season as evapotranspiration rates reduce and irrigation requirements correspondingly decline.

For the purposes of this exercise, groundwater consents were assessed as operation at their maximum daily abstraction 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

6. Model Calibration

The calibration of a numerical model is an iterative trial and error process that requires adjustment of model variables to achieve an equivalent model response to the measured field conditions. During calibration, the conceptual model is further refined as model responses are observed and model parameters are adjusted accordingly.

Steady state simulations involve a set of stresses that are held constant for the duration of the simulation (i.e., recharge, throughflow, pumping etc.). The model simulates to quasi-infinite time stopping when a stable solution is achieved, which occurs when the groundwater table and flow responses are in equilibrium with the stresses imposed on the model (i.e., model outputs equal model inputs).

Transient simulations involve simulation of a timeseries discretised into a number of stress periods. Stresses are held constant for the duration each stress period.

As previously indicated the model calibration process for this project was an iterative process of steady state simulation to generate starting conditions for each transient simulation. This was followed by transient simulation and subsequent adjustment to model until model responses provided the best match to field observations.

In this modelling study, the objective of the calibration procedure was to provide the following:

- ***Piezometric head match* –** match model groundwater heads to observed heads for March 2003,
- ***River flux match (see*** Table 6***)*** – for April 2003
  - model river losses along the Mataura River between Ardlussa and the Riversdale bridge of approximately 118,000 m^3/day;
  - model river gains along the Waikaia River between Freshford Bridge Waipounamu Bridge Rd of approximately 268,000 m^3/day;
  - model river gains in the Lower Mataura reaches between Pyramid and Dillon Rd of approximately 174,000 m^3/day (with spring-fed stream input accounted for).

6.1 Model Water Budget

Table 14 presents model water budgets for the transient model calibration during typical “wet” and “dry” periods.

- **Table 14. Transient model water balance for a typical wet and dry period**

Source/Sink	Typical Wet Period June 13 2002	Typical Dry Period February 22 2003
Fluxes into Model (m^3/day)		
Recharge (areal)	359,724	116,610
Recharge (surface runoff)	17,628	5,714
River seepage to aquifer	291,322	278,191
Accessions from storage	64,458	149,627
Total In	733,132	550,142
Fluxes out of Model (m^3/day)		
Aquifer seepage to river	-484,943	-466,663
Aquifer seepage to drains	-110,643	-75,930
Bore abstractions	0	-65,663
Accessions to storage	-137,553	-7,553
Total Out	-733,139	-550,146
In – Out Discrepancy (m^3/day)	7	4
% Discrepancy	0.0009	0.0007

The information in Table 14 indicates that input from river seepage for both simulations is relatively consistent although a small decrease is observed for the dry period, a likely result of lower river flows typical of that time of year. The consistency of seepage inputs relative to recharge is evidence of its function as the primary water balance contributor for the model domain.

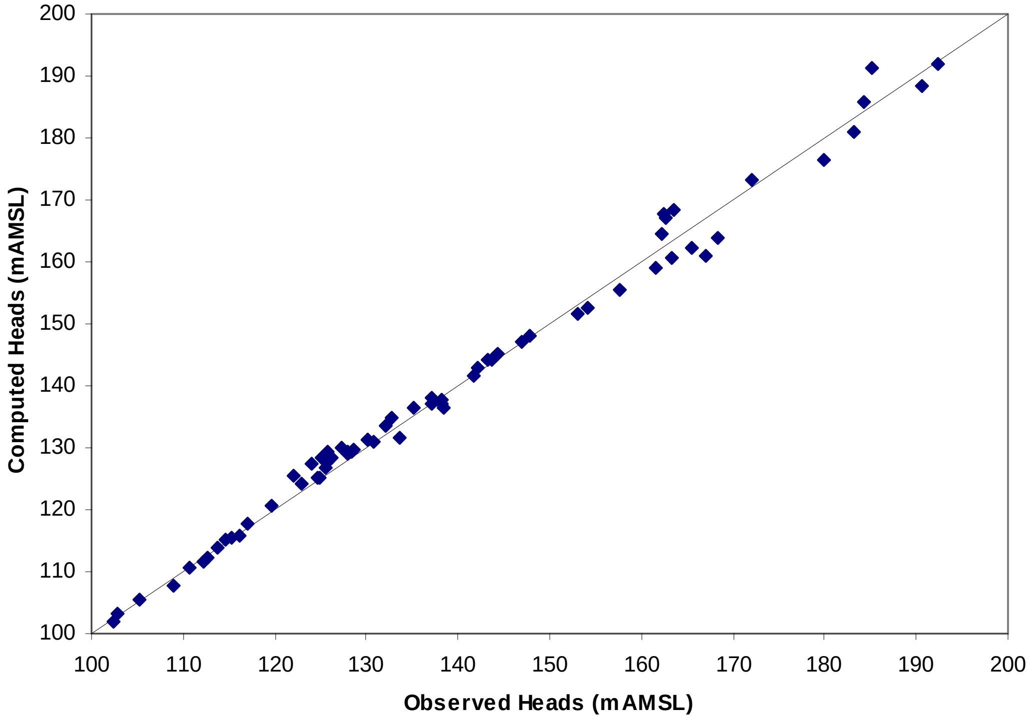
Output to river seepage is also similar for both scenarios indicating the presence of a relatively constant baseflow throughout the year, achieved during the dry period through the observed increased accession from storage and a reduction in seepage to drains, in addition to seepage input. The reduction in drain losses is likely to be due to low groundwater levels during summer, which decreases ground/surfacewater gradients, reducing flow across the interface.

Recharge inputs are reduced and abstraction volumes increase for the dry scenario as would be expected. Increased recharge inputs during wet periods effectively act to replenish storage deficits developed over summer.

This information indicates that the main controlling factor on aquifer water balance is river seepage to and from the aquifer. Seepage input from the upper reach of the Mataura River (Ardlussa to Riversdale Bridge) is likely to provide the main underlying base supply to the Riversdale groundwater zone, a significant input to the Waipounamu and Wendonside zones and a lesser input to the Wendon and Longridge zones.

6.2 Piezometric Head Match

Figure 19 shows the simulated steady state head condition across the model compared to measured groundwater levels at each bore recorded during the March 2004 piezometric survey.



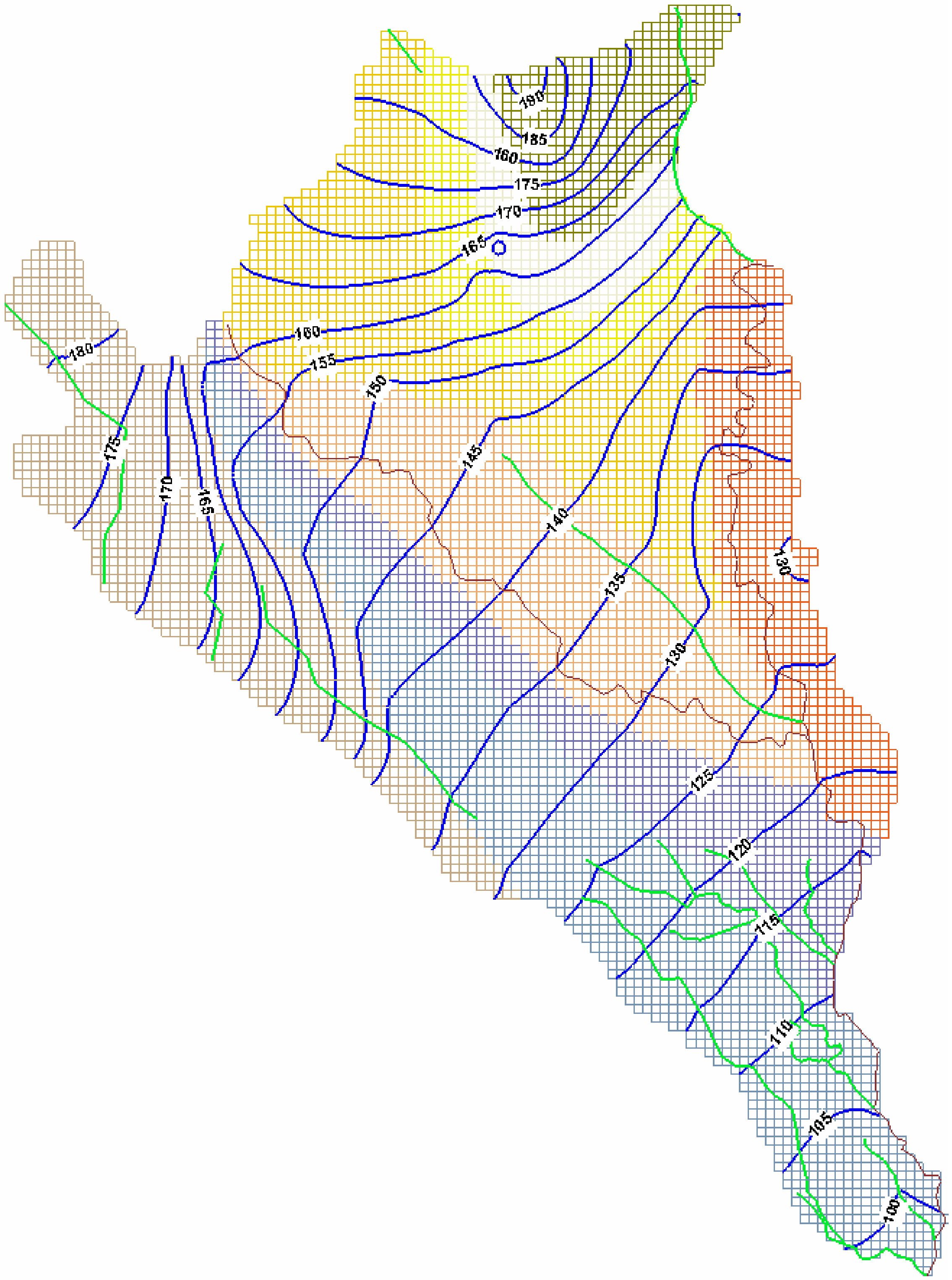
- **Figure 19. Simulated steady state heads versus observed heads.**

The chart demonstrates that there is a very good match between head magnitude in the model and in the field, which gives confidence that the model set-up is reasonably representative of actual conditions. This is tested and demonstrated with greater rigour through the transient calibration outputs.

Figure 20 provides the simulated piezometric surface for March 6 2004. Comparison to Figure 7 indicates that simulated heads generally reflect observed heads across the majority of the model domain. Exceptions to this occur at the following locations:

- Along the model boundary where no-flow conditions may inhibit simulation of natural hydraulic conditions, such as the southwest Longridge and northwest Wendonside margins
- Areas where hydraulic conductivity changes may produce poor simulation of natural conditions, such as the 130m contour at Wendonside/Waipounamu/Wendon boundary.

- Areas where monitoring bore coverage is not sufficient, reducing accuracy of piezometric plots used for model comparison (NW Longridge)
- Inputs from the Wendon Stream combined recharge zone are likely to have produced the additional 130 m contour line at that location. However, there are no observation bores in that area and it is possible that seepage inputs from the Wendon Stream may indeed naturally produce this feature.



- Figure 20. Simulated piezometric surface plot for March 6 2004.

Figure 21 provides bore hydrographs for each observation used during the transient calibration process.

- **Figure 21. Transient calibration hydrographs.**

  (See A3 attachment at rear)

Analysis of the graphs in Figure 21 shows that modelled groundwater fluctuations closely simulate observed data for the majority of observation bores. A lesser correlation is observed for bores F45/0167 (Riversdale), F44/0006 (Longridge), and F44/0139 (Wendonside). A number of attempts were made to achieve the observed heads for these locations, however this was not possible without affecting correlation for other bores or using unrealistic material parameters. It is considered likely that the observed heads represent either a perched water table (F44/0139 and F44/0006) or are the result of the influence of local geological formation anomalies (F45/0167).

In terms of overall amplitude and phase of response, the Upper Mataura (F44/0055 and F44/0044) and central area (F44/0181, F44/0350 and F45/0167) bores, along with F44/0018 in Wendonside show very good to very correlation with observation data. This indicates that defined model hydraulic parameters are likely to be within the range needed to approximate observed conditions, allowing close simulation of natural responses to aquifer stresses and storage changes. However, although a desirable response was achieved in general, fluctuations on the scale recorded by daily data loggers were not attained. Attempts were made which involved altering stress period length and using variable stress periods based on both river stage and recharge components, but these proved ineffective.

The simulated mass balance for the system is good, illustrated by stable hydrograph profiles (i.e not following a rising or declining trend) for all bores. This is consistent with the close input – output volume comparisons provided in Table 14 and is a further indication that model parameters employed have produced a reasonable representation of the natural aquifer system

6.3 River Flux Match

Table 15 provides the river flux calibration match. Observed fluxes are taken from the April 11 2003 flow gauging (see Table 6), whilst model values are taken from timestep 74 (April 5 2003) which is the stress period time step nearest to the gauging date.

- **Table 15. Model river flux match**

River Reach	Observed Fluxes (m^3/day)	Model Fluxes (m3/day)
Upper Mataura River		
Mataura River from Ardlussa to Riversdale Bridge	117,936	107,706
Mataura River from Riversdale to Waikaia Confluence	199	-47,148
Total Flow on Upper Mataura	118,135	60,558
Waikai River		
Waikaia River from Freshford to Waipounamu Bridge Rd	*-268,075*	-137,192
Waikaia River from Freshford to Upstream of Confluence	-36,953	-92,309
Total Flow on Waikaia	-305,028	-229,501
Confluence Section		
Mataura from Riversdale to Pyramid minus Waikaia input	-11,863	-247,612
Lower Mataura River		
Total Flow on the Lower Mataura	-174,182	-98,989[1]

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

Despite numerous attempts, it was not possible to simulate observed river fluxes without disrupting the overall heads correlation. However, through manipulation of riverbed conductance it was possible to achieve an approximate correlation for the reach from Ardlussa to Riversdale.

As discussed in Section 5.4.1 recent gauging data indicates that there are negligible river gains between Riversdale and the Waikaia confluence and significant gains on the Waikaia below Waipounamu Bridge Rd. This proved impossible to replicate given the data available, though river conductance manipulation again enabled closer approximation than that achieved in earlier model runs. Also discussed in Section 5.4.1 is the likely influence of palaeotopography on groundwater flow in the area. It is considered that a pinching out of aquifer saturated thickness beneath Waipounamu could account for observed river fluxes as this may encourage preferential groundwater flow toward the Waikaia in that area.

The model is under reporting river gains on the Waikaia upstream of Waipounamu Bridge Rd and on the Lower Mataura, which also includes inputs from the Riversdale spring-fed streams. This is likely to be related to poor simulation of fluxes in the confluence section detailed above, as river stage heights, river and streambed elevations, and groundwater levels are also relatively well defined for these reaches.

In summary, the current level of understanding of hydrogeological conditions in the Mataura-Waikaia confluence area is likely to be the main source of inaccuracy in the present model. Supplementary field investigations in this area are likely to be required to facilitate future model development.

7. Model Sensitivity Analysis

A formal statistical analysis of model sensitivity was not performed. However, various tests were carried out during the course of the model calibration to determine the sensitivity of model response to various parameter changes.

Overall, the model is significantly more sensitive to hydraulic conductivity than any other parameter. This is due to the extremely high hydraulic conductivity values evident in the Waipounamu and Riversdale groundwater zones. The high test values that have been determined for predominantly the Waipounamu and Riversdale aquifers, and to a lesser degree the remaining lower terrace alluvial aquifers. The result of this is that slight changes in recharge and specific yield have very little impact on simulated heads and fluxes.

The model is reasonably well-constrained by river and drain boundary conditions, which in the case of the river boundary can act as both sink and source, while the drain can only act as a sink to groundwater. The model is reasonably responsive to changes in both river stage elevation and riverbed conductance, however, since the likely range in river stage is relatively small, feasible changes in this parameters do not have great effect. However, changes in river and drain bed conductance can have a marked effect on both head and fluxes in the adjacent aquifer.

Trials conducted with varying recharge indicated that a 30% reduction in recharge required only a 10-15% reduction in aquifer permeabilities to compensate. The model is considered less sensitive to recharge due to the significantly greater volumes of seepage input to the system through the Mataura River.

Sensitivity tests were undertaken to determine appropriate conductance values for the various rivers. For the Mataura River, flow gains, river stage and adjacent groundwater levels are reasonably well defined. A number of combinations of conductance values for the river arcs were trialed before a reasonable head match was achieved whilst also reproducing approximate river to aquifer flux. For example, bores F44/0055 and F44/0040 have groundwater levels that are approximately 2 – 4 m below the river stage elevation immediately adjacent. Initially, to achieve the vertical head difference conductance in adjacent arcs was adjusted accordingly, with too higher values reducing the vertical gradient between river and aquifer and too low a conductance value increasing the separation distance. However, to also achieve simulated river losses in the Upper Mataura reach, the whole reach had to be considered as one requiring conductance to be raised upstream of the two bores and lowered down stream. For drains, a similar response to changes in conductance was observed, although the model was limited by lack of certainty with respect to drain bed elevations. Changes in drain conductance had a significant impact on heads in the lower part of Riversdale as would be expected.

Modelled head fluctuations are not particularly sensitive to changes in stress period length. Trials were conducted where the model stress periods were shortened around fresh or flood events within the Mataura River. However, no significant difference was observed in aquifer responses with the finer time discretisation. This may have been a function of the models' computational restrictions (i.e., there was a requirement to minimise timesteps to compensate for the greater number of stress periods).

8. Model Limitations

The following provides a list of model limitations, which identify areas where additional work could be undertaken to improve the accuracy of the model. The model limitations need to be considered when applying the model in a predictive or scenario testing sense, so that the model outputs are utilised appropriately with adequate qualification where required.

- ***Areal recharge*** **-** the SMWBM used to simulate the catchment water balance and groundwater recharge for the groundwater model has been calibrated to a single soil moisture probe at Riversdale. Field testing of model parameters such as soil porosity, infiltration rates and sub-surface drainage rates at sites in upper terrace locations would improve conceptual understanding of recharge inputs to these areas. Additionally, consideration of a catchment runoff experiment over a few hectares within the lower (Riversdale, Waipounamu and Wendon) and upper terraces (Longridge and Wendonside) would provide critical details with respect to the partitioning of rainfall between surface runoff, ET losses and recharge.
- ***Flow gauging and river/aquifer fluxes***
    - The quantity of river gains or losses along respective reaches formed the main model calibration parameters, as the model is most sensitive to changes in these fluxes. The model is well constrained by gauging data along the majority of the Mataura and Waikaia rivers, however information is limited for the reaches around the confluence with only one recent data set available.
    - It was not possible to simulate observed fluxes on the confluence reaches, indicating that the model is poorly conceptualised in this area with respect to groundwater flow partitioning from Wendonside to Wendon and Waipounamu aquifers, and continued flow into the rivers. Inaccuracies in river-fluxes around the confluence are also likely to be the source of under-reported gains on the Waikaia and Lower Mataura (see Table 15). Continued regular gauging and additional field-testing would enable improvements to the model water balance in the confluence area to better reflect gain/loss under variable aquifer thickness, river elevation and aquifer permeability conditions.
- ***River and streambed conductance values*** – Experiments should be set up in conjunction with analytical checks using Bruce Hunt’s streambed depletion method to help validate the calibrated model parameters, especially in Waikaia catchment and spring-fed streams.
- ***Riverbed elevations*** – are not certain at the confluence and for immediately adjoining reaches. A survey of these reaches would enable more accurate simulation of topographical controls on problematic river fluxes in this area.
- ***Hydraulic properties*** – as indicated in the report, there is limited hydraulic conductivity data coverage and reliability. Further field testing would enable validation of calibrated parameters.

9. Summary & Conclusions

Significant groundwater development has occurred over the past 2 to 3 years through the middle reaches of the Mataura catchment. This development has led to a significant focus on both the sustainability of the groundwater resource and potential cumulative streamflow depletion effects. The key driver for this is compliance with statutory allocation limits imposed by the Mataura River Water Conservation Order, which was established to protect the significant fishery and angling amenity values within the catchment.

Significant flow losses and gains are recorded in various reaches of the Mataura River upstream of Gore reflecting the considerable interaction between the river and adjacent unconfined fluvial-glacial riparian aquifers. These aquifers are typically of restricted lateral extent and characteristically exhibit relatively high permeability. In addition to river recharge, the riparian aquifers also receive recharge from direct rainfall infiltration and throughflow from aquifers underlying remnant Quaternary terraces (upper terraces) along the valley margins.

Prior to 2001 limited information existed to quantify the hydrogeology of the mid-Mataura catchment. Information that has subsequently become available through resource development and environmental monitoring has been used to develop a regional scale groundwater model of the mid-Mataura catchment (Northern Southland Groundwater Model) with the end objectives being to assess the sustainable abstraction limits and to provide a tool to compliment analytical assessments of cumulative streamflow depletion.

A preliminary steady state model was developed in 2003 incorporating just the Riversdale and Longridge aquifers (SKM, 2003). This model provided some useful insights into the functioning of the aquifer systems and sensitivity of various parameters. However, application of the model as a resource management tool was limited by a number of significant data gaps, including lack of control on river and spring fed stream levels and real time piezometric data for transient calibration.

To address limitations of the initial model, Environment Southland initiated a targeted data collection program. Concurrent with this, work began to extend the model to incorporate the Waipounamu, Wendon and Wendonside aquifers, situated between the Mataura and Waikaia Rivers to the north of Riversdale. The model was then prepared and data series were input for transient calibration.

The unconfined aquifers are bounded at the lateral extents and beneath by hardrock aquifers that are thought to have limited hydraulic interaction due to their considerably lower permeabilities.

Aquifer hydraulic characteristics appear to conform to that expected according to river valley geomorphology, with permeabilities greatest beside the river reflective of the higher energy depositional environment and overall younger age. Permeabilities are lowest on the upper terraces due to increased silt and clay contents reflective of glacial outwash accumulation.

Although the aquifers modelled are generally unconfined systems, their hydrodynamic functioning was not as straight forward as first thought. The model development process helped redefine the conceptual understanding of the aquifer systems, with the following key features of interest identified:

i) presence of spring fed streams perched above the local groundwater table downstream of spring starting point (i.e., streams have no further interaction with the model);

ii) multiple perched water tables within the upper Quaternary terraces (impossible to simulate with typical saturated water table model such as MODFLOW);

iii) requirement to input stream fed recharge on the upper terraces adjacent to the foothills of the Wendonside and Waipounamu aquifers in order to simulate close to the measured groundwater levels (i.e., the model under-predicts head levels without this side-flux recharge);

iv) spatially distributed hydraulic test results appear to be not entirely representative of bulk aquifer transmissivities due to a) undulating base of aquifer topography or variable saturated thickness, and b) thin saturated aquifer in places, which makes testing difficult and test results particularly unreliable;

v) Mataura and Waikaia river gains in reaches immediately upstream of the confluence indicate preferential groundwater flow from Wendonside through the Wendon aquifer into the Waikaia River. This may be the result of reduced aquifer saturated thickness beneath Waipounamu due to pinching out of the quaternary gravels, which may be related to palaeotopography;

vi) river gains and losses account for by far the greatest inputs and outputs of the aquifer system, with rainfall recharge a relatively insensitive parameter in comparison.

Because the model is relatively insensitive to area rainfall recharge, river gains and losses at respective reaches became the primary model calibration target and because these are readily quantifiable, the model can be considered reasonably well defined. Knowledge of the model hydraulic properties effectively became a calibration parameter with test results and typical publicised data for the materials forming reasonable parameter bounds. Therefore, the model under transient calibration has provided a more realistic understanding of aquifer hydraulic properties than could be achieved through field-testing alone.

The transient model developed is considered an appropriate tool for scenario testing and comparison of relative responses. However, various limitations have been indicated and these should be considered during application of the model.

10. References

Sinclair Knight Merz, July 2003. Riversdale Aquifer Management Zone: Preliminary Sustainable Yield Assessment. Prepared for Environment Southland.

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 groundwater zone 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.

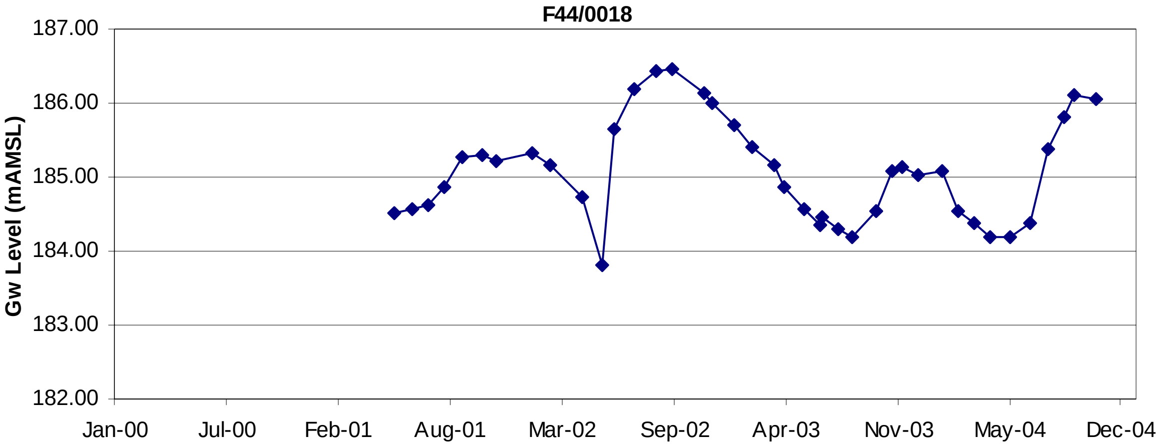
Has no effect in this application of the model as we are only interested in infiltration and percolation to groundwater, not the discharge of groundwater to surface water bodies.

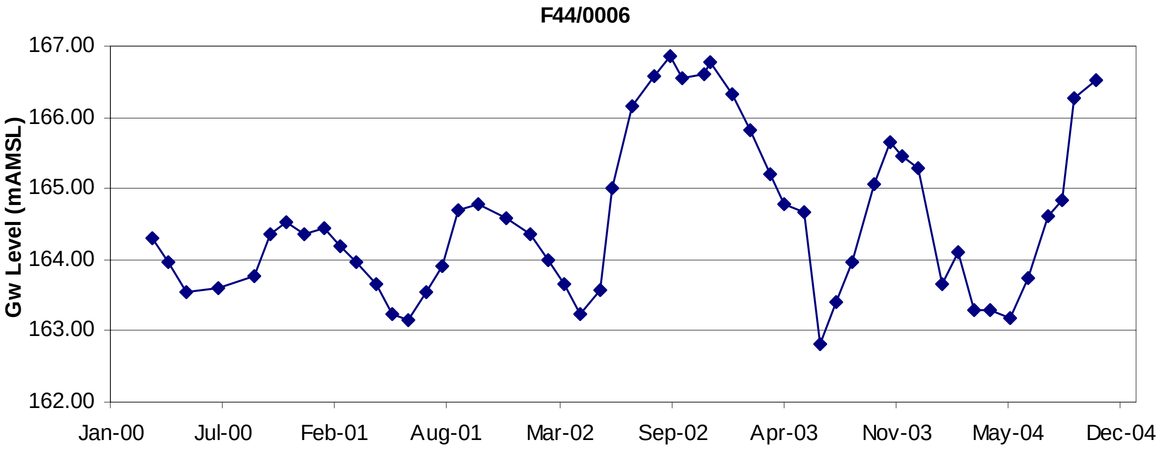
- **Table A1. SMWBM parameters used for catchment modelling**

Catchment/Groundwater Zone	ST	FT	AL	Zmax
Riversdale/Waipounamu	75	1.5	0.1	10
Longridge	100	1	0.1	5
Wendonside/Wendon	125	1	0.1	2.5
Boundary Creek	50	0.5	0.1	1.5
Waikaia Eastern Tributaries	50	0.5	0.1	2
Wendon Stream	50	0.5	0.1	2
Pyramid Creek	125	1	0.1	5

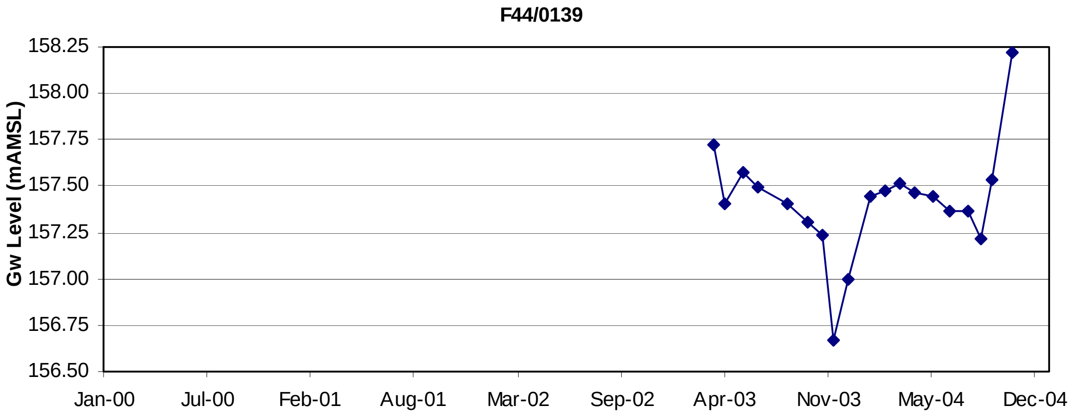
Appendix B Observation Bore Hydrographs

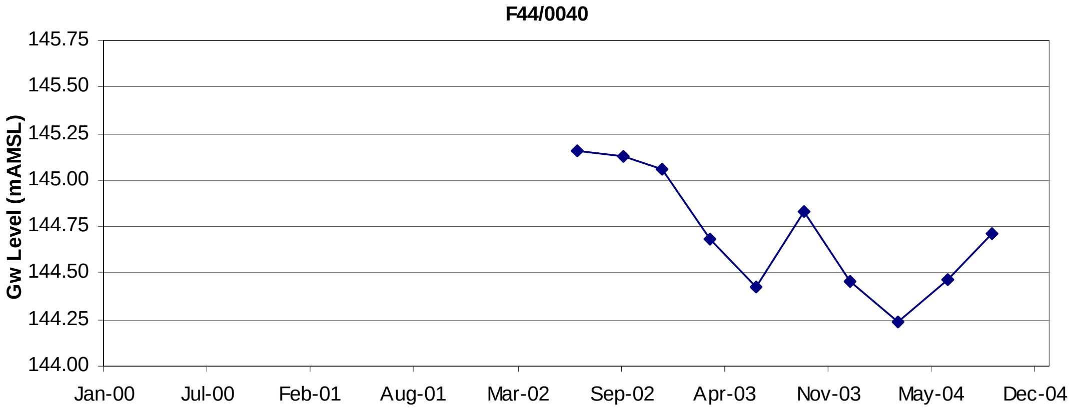
B.1 Bores in Upper Terrace Locations

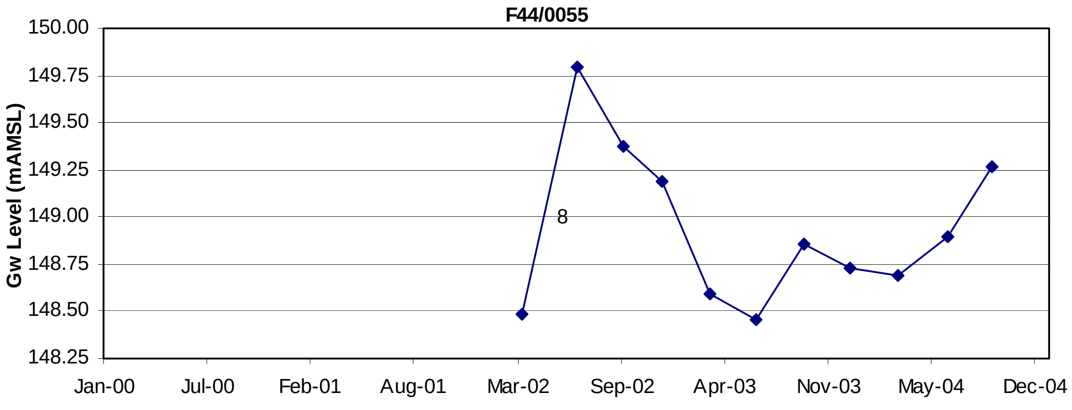


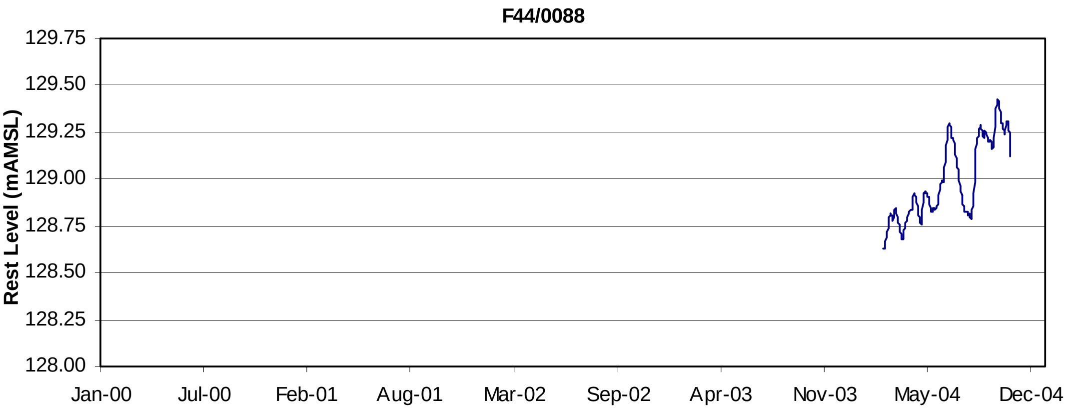


B.2 Remaining Bores








F44/0088
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129.50
129.25
129.00
128.75
128.50
128.25
128.00
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Feb-01
Aug-01
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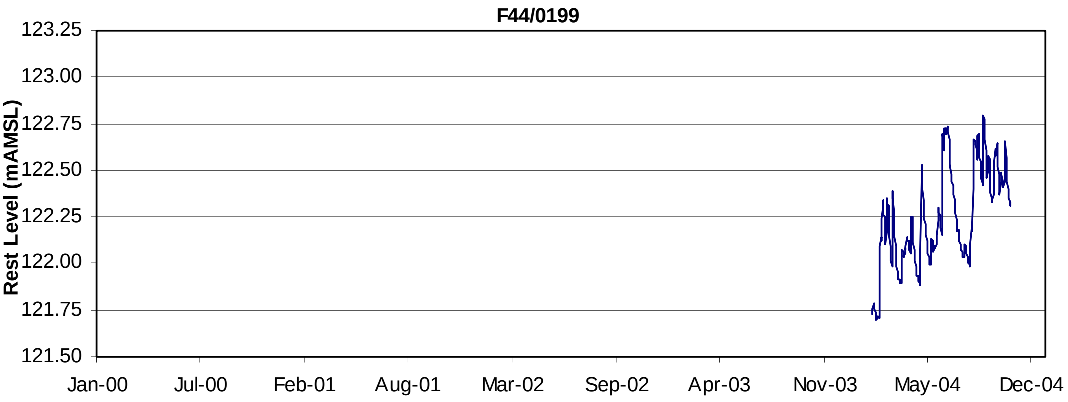
Sep-02
Apr-03
Nov-03
May-04
Dec-04


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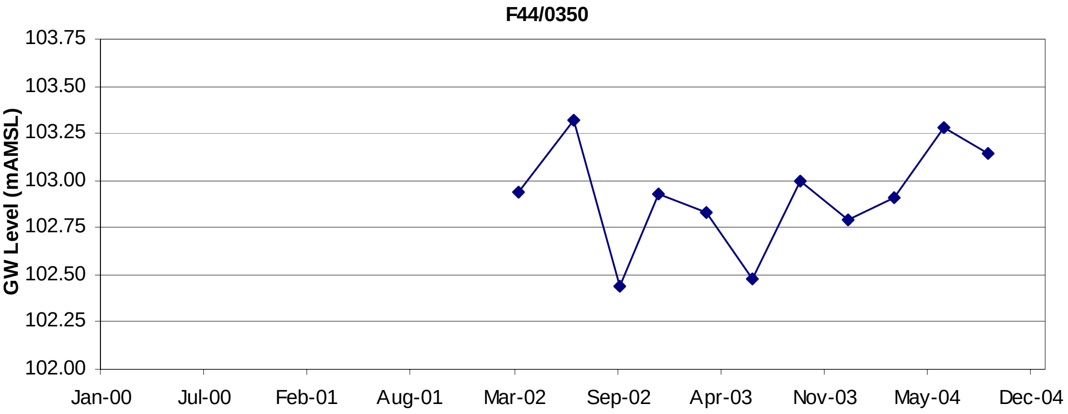
121.75
121.50
Jan-00
Jul-00
Feb-01
Aug-01
Mar-02
Sep-02
Apr-03
Nov-03
May-04
Dec-04


F44/0350
GW Level (mAMSL)
103.75
103.50
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