Rarangi Shallow Aquifer Sustainability Report

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Contents

Executive Summary

This report assesses the sustainability of existing and future allocation from the Rarangi Shallow Aquifer (RSA). A conceptual model of the RSA is presented, which is based on data that has been mostly gathered over recent years. The conceptual model has been used to develop a transient numerical groundwater model. This model has been calibrated to run for a three-year duration starting July 2002, a period for which suitable aquifer and surface water input data is available.

The calibrated model has been used to assess the aquifer response to different stresses. Three scenarios have been simulated, an extreme drought, an increase in allocation at the Wither Hills Vineyards Limited property, and predicted maximum future aquifer demand.

The key findings of the study are:

- Recharge to the RSA is entirely sourced from rainfall infiltration, together with some runoff from the Richmond Range. Recharge is highly variable from season to season, and year to year. During drier years, there can be prolonged periods when effective recharge is negligible.
- Wetlands and drainage networks play a pivotal role in the dynamics of the aquifer. Aquifer seepage to wetlands and artificial drainage networks accounts for 30 to 40% of annual recharge, a proportion that is equivalent to offshore flow. Wetlands and drainage networks are recharged by the aquifer when groundwater levels are high. They also play an important role in distributing water to southern areas of the aquifer during recharge events.
- The model predicts that existing aquifer allocation is sustainable for all stakeholders, and gives security of supply to WHVL for up to a 1 in 5 year dry event. The existing environmental thresholds ensure that domestic supplies are protected, and the natural character and health of wetlands will not be degraded.
- Simulations of increased groundwater allocation clearly show that the anticipated maximum demand is not sustainable for below-average recharge conditions. The limiting factors are the protection of domestic supplies and wetland sustainability rather than seawater intrusion. Drawdowns from pumping tend to be fairly localised. As a result, environmental effects depend on the abstraction’s proximity to domestic wells and hydrological boundaries.
- The localisation of effects makes the setting of an aquifer safe yield unpractical. To ensure security of supply of future groundwater applications, abstractions will need to be widely spaced throughout the aquifer. There is still groundwater available beyond its existing allocation if the adaptive management approach of setting appropriate environmental thresholds is continued.

1 Introduction

This study of the Rarangi Shallow Aquifer (RSA) has been commissioned by Marlborough District Council (MDC) in order to improve understanding of aquifer processes and stresses. To date, management of the aquifer has relied on an approach of adaptive management to mitigate the environmental effects of groundwater abstraction. However, little is known about the capacity of the aquifer to sustain existing or increased future demand. There is uncertainty about how the aquifer will cope with existing demand under different climatic conditions, particularly during drought years. There is also uncertainty concerning the aquifer's capacity to cope with the effects of land use on water quality.

Demand for water at Rarangi has accelerated considerably within the last five years or so. Prior to the turn of the century, Rarangi was a rural area with pastoral farming and a few coastal beach houses. The recent property boom with its demand for coastal residential property has prompted subdivision of all the coastal land at Rarangi. The timing of the property boom coincided with expansion of viticulture throughout the Wairau Plain. Much of the land at Rarangi that is suitable for viticulture has been developed within the last five years.

Expansion of viticulture and residential property has greatly increased demand for water in Rarangi. In 2003, the first application for consent to take water from the RSA for irrigation of the Wither Hills Vineyard Limited (WHVL) was heard (U021014). The application generated considerable concern within the residential community, and was followed in the press with emotive reports on the Rarangi "water war". The consent was granted for a limited volume and duration to test how the aquifer would perform under stress. An adaptive management approach was taken to limit adverse environmental effects. This involved the setting of threshold levels in monitoring wells along Rarangi Road to protect Pipitea Wetland and domestic wells. Abstraction is to be reduced by 50% when water levels in P28w/4329 or P28w/4330 reach 1.5m. Abstraction is to cease when either of these wells or P28w/4331 reaches 1.2m. An observation well was also drilled at the coastline to monitor seawater intrusion, which has a water level threshold of 0.2m.

Much of the difficulty with water availability at Rarangi arises from the absence of the Wairau Aquifer in the northern part of Rarangi. Properties to the south of Rarangi Road have access to water from the deeper Wairau Aquifer. The Wairau Aquifer pinches out north of Rarangi Road, so properties in this are reliant on the RSA for water supply.

2 Study Objectives

The objectives of this study are:

- To update the RSA conceptual hydrological model
- To develop a satisfactory calibrated numerical groundwater model
- To simulate and assess the environmental effect of current demand under drought conditions
- To simulate and assess the environmental impact of increased aquifer demand

3 Data Availability

3.1 Groundwater Levels

MDC maintains a network of groundwater monitoring wells along the Rarangi coastline (Table 1). The main purpose of the monitoring network is to provide early warning of seawater intrusion. The monitoring wells record continuous water level and conductivity data for the RSA. Values of critical head for three of the wells are also shown in Table 1. These are recommended minimum water levels to ensure that the saltwater interface does not contaminate domestic wells (PDP 2000, Wilson 2004).

Sentinel Well	Name	Start	Easting	Northing	Critical Head (m amsl)
P28w/1901	Golf Club	Feb-1989	2596730	5977430	-
P28w/3668	Hinepango	Nov-2000	2596082	5974387	0.2
P28w/3711	Bluegums	Jan-2001	2596266	5975193	0.3
P28w/4349	Rarangi North	May-2004	2597216	5977752	0.2

Table 1. Coastal sentinel wells established by MDC

In addition to the MDC sentinel well network, WHVL has established four groundwater level monitoring wells. These wells are required as a condition of consent U021014 to monitor sweater intrusion, and protect the Pipitea Wetland and domestic wells in the Clerveaux area. Continuous records are available for three of these wells from 17 March 2004 onwards.

Several wells in the area have manual records on a weekly basis (Table 2). These wells were monitored by MDC to improve understanding of the interaction between the RSA and the Pipitea Wetland. Water levels in P28w/4371 have also been monitored on a daily basis between November 2002 and April 2006. This monitoring was carried out by Clerveaux subdivision resident Brett Williams.

Well	Location	Easting	Northing	Start Date	End Date	Readings
P28w/3526	Lot 2, Edgewater	2595906	5975762	10/07/2003	23/06/2005	93
P28w/3486	Lot 74, Edgewater	2595729	5975842	19/09/2003	23/06/2005	92
P28w/3247	Blenheim Lifestyles	2595577	5974111	26/09/2003	23/06/2005	92
P28w/4298	Blenheim Lifestyles	2595539	5974011	5/05/2004	23/06/2005	59

Table 2. Existing monitoring record for RSA wells near Pipitea Wetland.

Aquifer-wide piezometric surveys have been undertaken by PDP for the WHVL application (PDP, 2003). These surveys were conducted in July 2002 and February 2003 to determine how the aquifer behaves during winter and summer conditions. The July 2002 survey was chosen as a starting point for the numerical model described in Chapter 5.

3.2 Rainfall

The only long-term rainfall record available for Rarangi is from Marshlands (2593973, 5972471). This record consists of daily rainfall totals from June 1925 to January 1989 when the station was decommissioned.

Recent rainfall records have been kept by Brent Williams, a resident of Clerveaux subdivision. Mr Williams has recorded daily rainfall totals at his property from March 2003 until April 2006. While there is no quality control on the data, it is the only information available for Rarangi Rainfall in recent years.

3.3 Stream Flow

There is little stream flow data available for the Rarangi area. The complete flow gauging record for Rarangi is shown in Table 3. Note that it is difficult to obtain a representative flow gauging of Pukaka Stream and Pipitea Wetland. This is because flow in these water bodies is largely influenced by stage in the Wairau Diversion, which varies with the tide as well as flow volume.

Site Name	Easting	Northing	Date	Flow (l/s)
Pukaka Stream upstream of quarry	2593239	5976719	9-Jun-04	173
			20-Jul-04	468
Pukaka Stream at Pembers Road	2593653	5975944	9-Mar-01	11
			18-May-04	496
			20-Jul-04	636
			27-Sep-04	275
			9-Nov-04	219
			8-Dec-04	153
			18-Jan-05	232
Pukaka Stream at Thomas Road	2593570	5973469	1-Feb-82	81
			18-May-04	461
			20-Jul-04	644
			27-Sep-04	350
			9-Nov-04	307
			8-Dec-04	201
			18-Jan-05	219
			9-Feb-05	99
Pipitea Wetland Outlet	2595403	5973769	18-May-04	2
			20-Jul-04	88
			27-Sep-04	43
			09-Nov-04	12
			08-Dec-04	1
			18-Jan-05	2
			09-Feb-05	0

Table 3. Flow gauging record for streams in the Rarangi area.

3.4 River and Wetland Stage

Continuous river stage data is available for the Wairau River Diversion. The record starts in 1968 and continues to the present. The recorder is located at the outlet to Pukaka Stream (2593609 5973359). The river is tidal at this point, with a daily variation of up to approximately 400mm. The tidal influence continues up the Pukaka Stream, and under low flow conditions can affect flow as far upstream as Thomas Road.

Wetland levels have been monitored on a weekly basis at flaxmill drive (2595450, 5974130) and south of Rarangi Road (2595737, 5975843). The record starts in September 2003 and finishes in June 2005.

The length of record for Pipitea Wetland stage is sufficient for an approximate relationship to be made with groundwater levels. Figure 1 shows the correlation between Pipitea Wetland stage and groundwater levels in the closest monitoring well, P28w/3668.

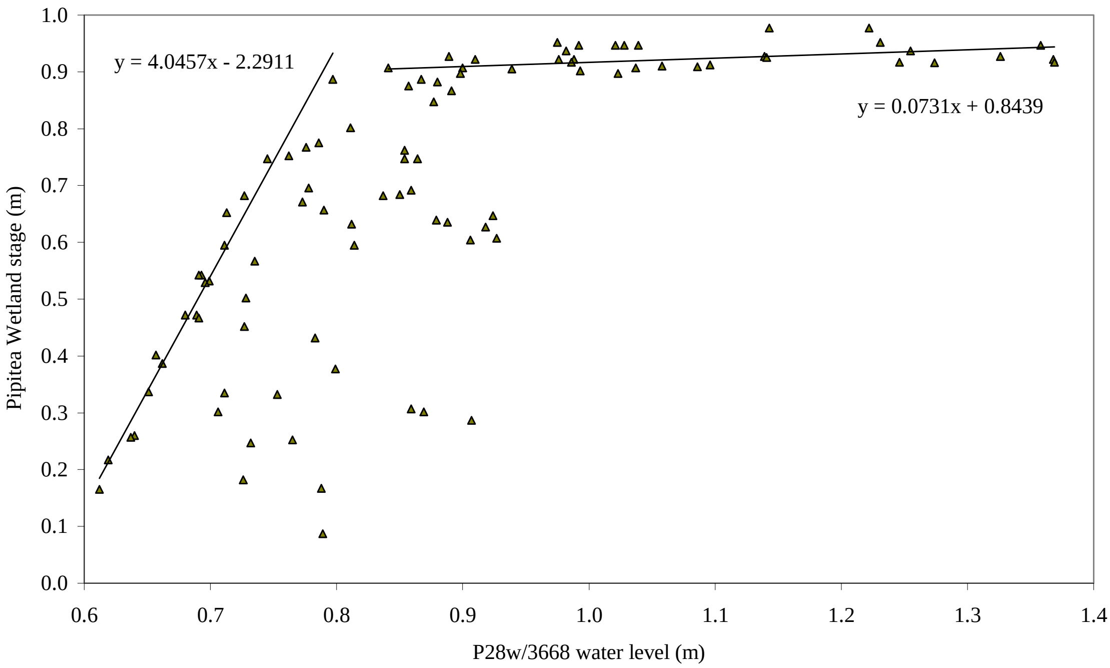

Figure 1. Relationship between Pipitea Wetland Stage and groundwater level in P28w/3668.

The relationship between the two sites has considerable scatter, particularly when water levels are low. The reason for this is that the wetland starts to pool at Flaxmill drive when water levels are below approximately 0.6m. Despite the evident scatter, the relationship is clearly bounded when water levels in P28/3668 are low. There is also an upper limit to wetland water levels, which is controlled by outflow to the Wairau Diversion. Trends have been drawn through these two bounds to give an approximate correlation between the two sites. There is an inflection point between the two trends where wetland stage starts to stabilise at about 0.9 mRL. Wetland stage can only be estimated with a high degree of confidence when water levels in P28w/3668 are above 0.95m RL, which is about 25% of the record.

Water Abstraction

Most abstractions within the RSA are for domestic supply. There is no data available for demand from domestic wells at this stage. Daily demand for smaller properties is estimated to be approximately 1 m^3/d. Larger properties, such as those in Edgewater Estate and Blenheim Lifestyles subdivision are likely to use slightly more, up to 2 m^3/d.

The largest abstraction in the RSA is the WHVL irrigation supply. This is also the only monitored abstraction from the RSA. A pulse-emitting water meter records the combined instantaneous abstraction rate from wells P28w/4246 and P28w/4249. The combined abstraction record for this well is shown in (Figure 2). During late spring and summer the consent is fully utilised, with demand reaching the consented maximum of 1,100 m^3/d on a regular basis.

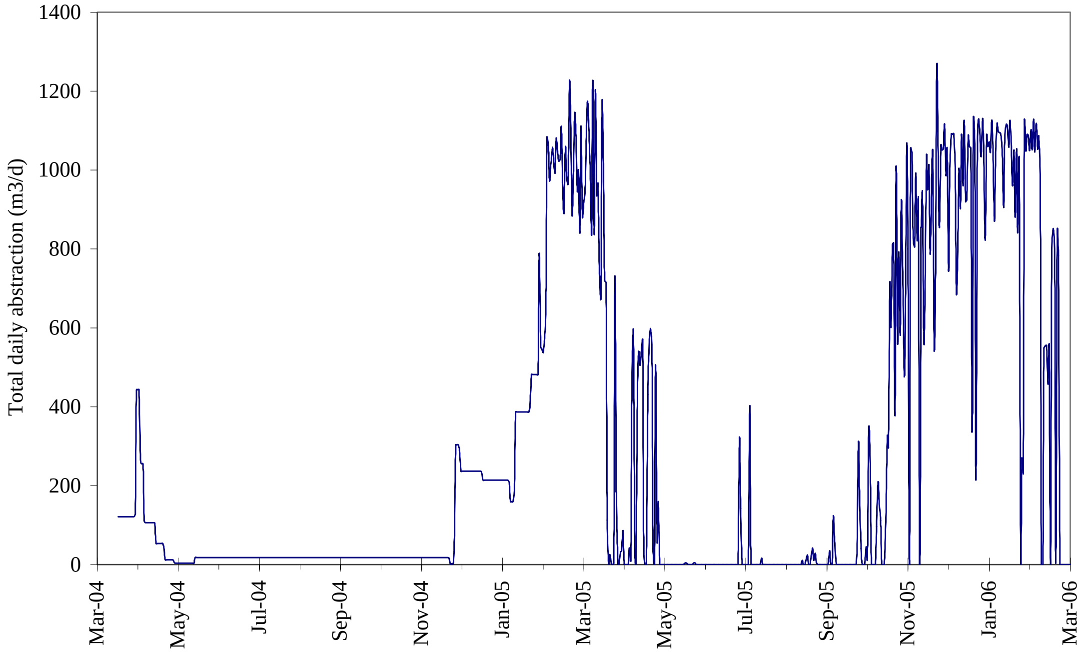

Figure 2. Total daily abstraction by Wither Hills Vineyards Limited.

The Rarangi Golf Club also abstract groundwater via a pond that intercepts the water table. The water is used for irrigating the greens. No abstraction data exists, however the limit for the consent is 1000 m^3/d. It is likely that approximately 500 m^3/d is used during the summer months.

3.5 Aquifer Properties

Aquifer properties are fairly well constrained due to the availability of pumping test results (Table 4). Much of the available data has been provided by PDP for the WHVL consent application.

The variety of geological environments present in the RSA suggests that aquifer properties should be highly heterogenous. Contrary to expectations, the results of aquifer tests show that hydraulic conductivity and specific yield values are fairly consistent from site to site. Hydraulic conductivity values have a standard deviation of only 71 m/d. Specific yield values have a standard deviation of 0.057. This low variability in aquifer properties suggests that the RSA is hydraulically homogeneous on an aquifer scale.

Note that the test results only characterise sandy and mixed sand and gravel units within the aquifer. Aquifer properties have not been obtained for peaty and clay-rich areas of the RSA. Hydraulic conductivities in these areas may be an order of magnitude lower than the sandy gravels. However, there have been no pumping tests performed to characterise these areas.

Pumped Well	Test date	Duration	Pumping rate (l/s)	Observation well	Transmissivity (m^2/d)	Hydraulic cond. (m/d)	Specific yield
P28w/3668	Sep-05	8 hours	4.4	P28w/1896	792	107	0.135
				P28w/1896	840	113	
P28w/0967	?	?	?	?	334	56	
P28w/4075	Jun-02	6 days	8.7	E1	403	130	0.110
				E2	432	135	0.150
				E3	461	200	0.185
				E4	418	199	0.168
				E5	403	224	0.140
				W1	547	252	0.087
				W2	547	274	0.160
P28w/4246	Sep-02	5 days	15.6	P28w/4242	282	49	0.280
				P28w/4251	331	58	0.050
				Q 40m Sth	504	88	0.070
				P28w/4244	518	90	0.080
				P28w/4249	648	113	0.070
P28w/4308	Apr-04	6 days	10.16	30m South	504	?	0.055
				PE	446	?	0.130
				PF	374	?	0.130
Mean Value					488	139	0.125
Median Value					461	122	0.130
Standard Deviation					145	71	0.057

Table 4. Summary of RSA pumping test data and interpreted aquifer properties.

4 Conceptual Hydrogeology

4.1 Geological Setting

The RSA is a shallow sandy coastal aquifer. Sediments that host the RSA are a sequence of prograding coastal gravels and sands with minor shell fragments deposited over the last 6,500 years. The thickness of these sediments ranges from about 10m along the coastal beach ridge to approximately 5m at Pukaka Stream.

Shallow marine silts and terrestrial clays of the Dillons Point Formation underlie the coastal sand sequence. This unit was deposited during a Quaternary marine transgression and regression phase that occurred in response to climatically driven sea level changes. The Dillons Point Formation is approximately 25m thick in the Rarangi area. The fine grainsize and large thickness of the Dillons Point sediments make it an effective aquitard for the deeper Wairau Aquifer. The western margin of the Rarangi coastal sediments is marked by the outcropping of the Dillons Point Formation to the west of Pukaka Stream.

The RSA host sediments were originally derived from the Wairau River, and have been deposited in the Rarangi area by longshore drift. The coastal origin of the sediments has created a distinctive geomorphology of paleo-beach ridges interspersed with swales. Many of the swales host permanent or ephemeral wetlands.

4.2 Aquifer Description

Peizometric surface maps of the RSA show that groundwater levels are highest along the foothills of the Richmond Range. Saturated thickness reaches a winter maximum of 7m in the central northern part of the aquifer. The minimum saturated thickness during the summer is approximately 3m, adjacent the Pukaka Stream.

A groundwater divide forms a central axis to the aquifer, running north-south just to the east of Neal Road. The piezometric surface slopes away from this central axis towards the three surface water bodies that bound the aquifer, Cloudy Bay, Pukaka Stream, and the Wairau Diversion. These three boundaries drain water from the aquifer, and dictate the direction of groundwater flow.

The significant implication of the observed piezometric pattern is that the aquifer is primarily recharged by rainfall and hillside runoff, with negligible inputs from the Pukaka Stream and Wairau Diversion. Results of oxygen isotope sampling indicate that average residence time in the aquifer is around five years (Stewart, 2004).

4.3 Recharge Sources

The dominant source of recharge for the RSA is from rainfall infiltration. The aquifer also receives catchment runoff from Richmond Range, which is routed into wetlands located along the foothills. The wetlands are more likely to act as conduits for hillside runoff during higher rainfall events. The bed conductance of these wetlands is estimated to be very low, as evidenced by their perched behaviour when groundwater levels are low. A pumping test has confirmed wetland bed conductance values to be consistent with a peaty wetland substrate (PDP, 2004b). Accordingly, the recharge potential of water stored in the wetlands during summer and autumn is likely to be small.

Other potential recharge sources are the Pukaka Stream and vertical leakage from the Wairau Aquifer. However, there is also no chemical evidence for any substantial groundwater mixing in the RSA having occurred (Wilson and Davidson, 2005). Oxygen isotope analyses also confirm that RSA groundwater has a proximal rainfall source (Stewart, 2004). If there is any vertical leakage through the Dillons Point Aquitard, the isotopes confirm that it does not significantly contribute to recharge.

Stream flow gauging results show that the contribution of recharge to the RSA from the Pukaka Stream is not significant. Table 5 lists the available concurrent flow gauging data for the Pukaka Stream and Thomas and Pembers Road. These gauging sites represent the northern and southern locations respectively where the Pukaka Stream enters and then exits the RSA.

Gauging Site	Date	Flow (l/s)	Flow gain/loss
Pembers Road	18-May-04	496	
Thomas Road		461	-35
Pembers Road	20-Jul-04	636	
Thomas Road		644	8
Pembers Road	27-Sep-04	275	
Thomas Road		350	75
Pembers Road	9-Nov-04	219	
Thomas Road		307	88
Pembers Road	8-Dec-04	153	
Thomas Road		201	48
Pembers Road	18-Jan-05	232	
Thomas Road		219	-13

Table 5. Available concurrent stream flow gauging data for the Pukaka Stream

The available gaugings show a general tendency for the Pukaka Stream to gain water between Pembers Road and the Diversion. The gain is likely to be caused by a combination of drain inflows and groundwater seepage. The occurrence of groundwater seepage is evident in the shape of the RSA piezometric surface, which shows the aquifer draining to the Pukaka Stream. Stream losses to the aquifer are restricted to summer months, when groundwater levels are low, although it is notable that these recorded losses are within the gauging accuracy of 8% of flow.

4.4 Rainfall

Isohyetal maps of the Wairau Plain indicate that rainfall increases northwards towards the Richmond Range (Rae, 1987). Mean annual rainfall over the RSA is likely to increase from around 800 mm/yr along the Wairau Diversion to 1200 mm/yr along the Richmond Range foothills. Rainfall in the Richmond Range just north of Rarangi is expected to be around 1400 mm/yr. Long term annual rainfall statistics for three sites located closest to Rarangi are shown in Table 6.

Site	Min	Max	Mean	Std.Dev.	Median
Marshlands	492	1045	771	138	781
Blenheim	404	1006	664	120	666
Ocean Bay	913	1977	1378	224	1387

Table 6. Statistics for total annual rainfall at Marshlands, Blenheim and Ocean Bay. The statistics are based on a calendar year.

Figure 3 shows the observed monthly rainfall variation at Marshlands. Mean monthly rainfall is about 65 mm over the entire record. There is a general trend of high rainfall from July to August, and a drier summer, particularly during February. It is notable that dry periods can occur throughout the year, as can wetter periods.

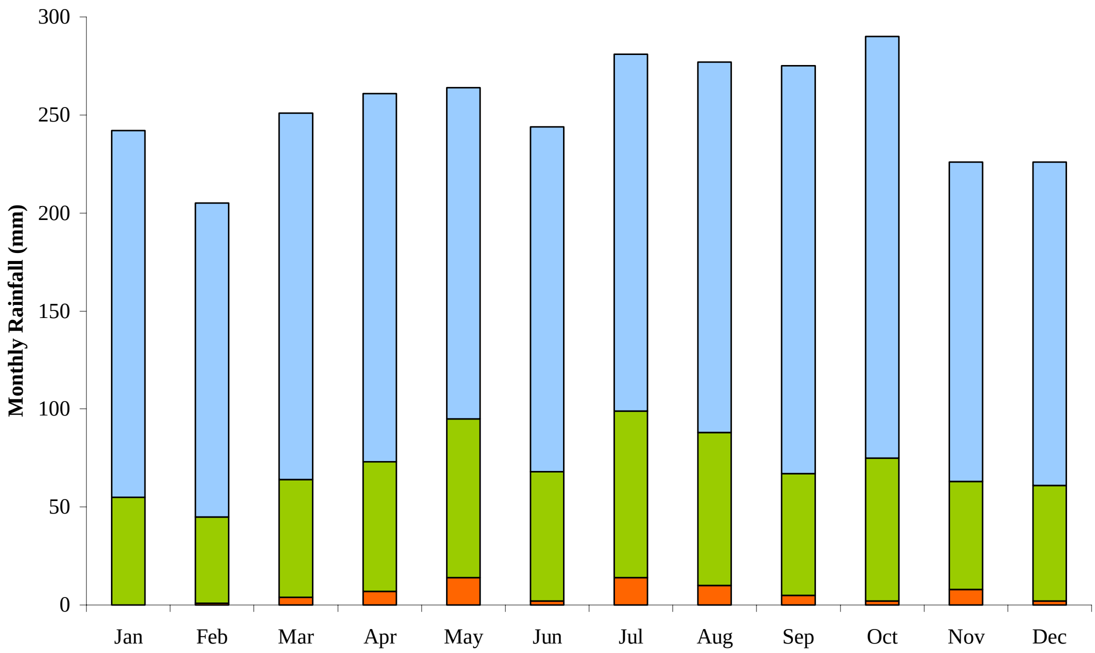

Figure 3. Minimum, mean and maximum monthly rainfall values for Marshlands.

The depth-duration curve for the Marshlands rainfall record shows that monthly statistics are skewed towards high rainfall events (Figure 4). While mean monthly rainfall is 65 mm, the median is only 58 mm, indicating that wetter months are more common than drier months (Table 7).

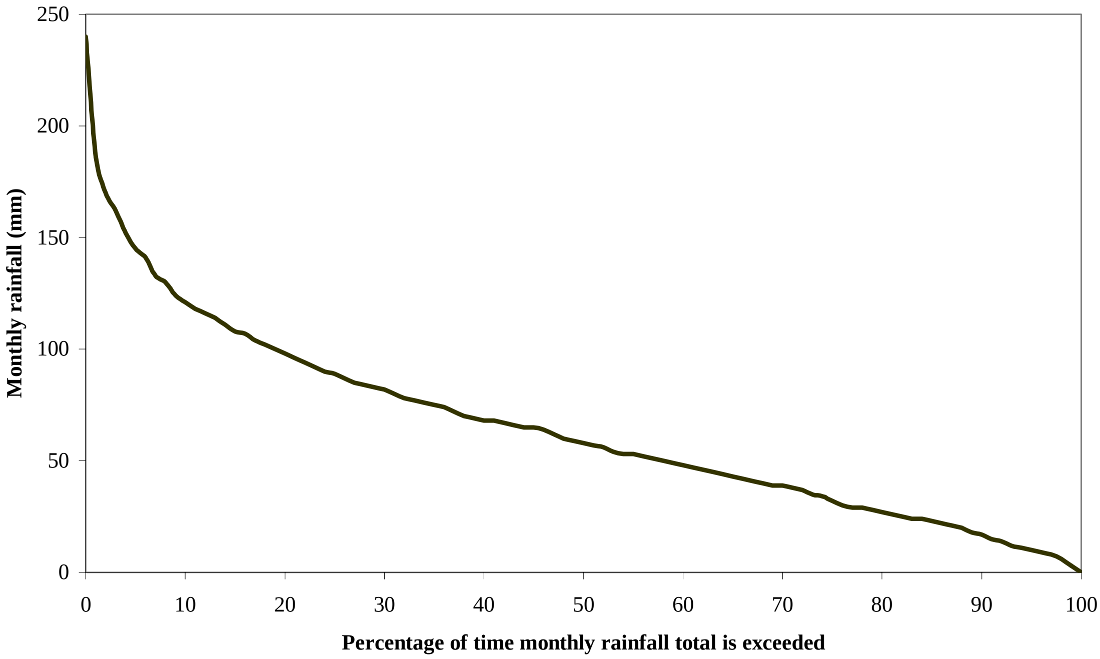

Figure 4. Depth-duration curve for monthly rainfall totals at Marshlands.

	0	1	2	3	4	5	6	7	8	9
0	240	186	170	162	152	145	141	133	130	124
10	121	118	116	114	111	108	107	104	102	100
20	98	96	94	92	90	89	87	85	84	83
30	82	80	78	77	76	75	74	72	70	69
40	68	68	67	66	65	65	64	62	60	59
50	58	57	56	54	53	53	52	51	50	49
60	48	47	46	45	44	43	42	41	40	39
70	39	38	37	35	34	32	30	29	29	28
80	27	26	25	24	24	23	22	21	20	18
90	17	15	14	12	11	10	9	8	6	3
100	0									

Table 7. Depth-duration data for monthly rainfall totals at Marshlands (mm)

4.5 Soils

The amount of rainfall that recharges the RSA is highly dependant on both rainfall intensity and soil hydraulic properties. Soils in the Rarangi area can be broadly classified into four soil series, as shown in Table 8. A map of soil units in Rarangi is shown in Appendix 1. The most widespread soil type is the Taumutu gravely silt loam, which is associated with sandy substrate. This soil has an extremely low water holding capacity, which allows rainfall to infiltrate more readily than other soils in the Rarangi area.

Series	Soil	Soil Type	Distribution	Profile Available Water (mm)
Taumutu	68b	Gravelly sandy loam	Widespread, dominant soil type	30
Waimairi	86	Peaty loam	Existing and drained wetlands	96
Taitapu	90	Silt loam	Pukaka Stream drainage area	63
Arapara	47a	Silt loam	Richmond Ranges	176

Table 8. Soil types and estimated hydraulic properties (based on NZLRI).

Note that the peaty Waimairi and Taitapu soils are more widespread than the present wetland distribution pattern. The reason for this is that prior to European settlement and associated widespread land drainage, wetlands were more extensive than they are now.

4.6 Wetland hydrology

Several wetlands and drains are distributed throughout the Rarangi area. Most of the wetlands are situated in topographic depressions, or swales, along the foothills of the Richmond Range. The Pipitea and Golf Links wetlands extend further southwards than most of the wetlands, and play an important role in distributing water through the aquifer.

The dynamics of the Rarangi wetland system is best understood if the wetlands are divided into two groups the northern wetlands, and the southern Pipitea wetland. An artificial drainage network connects these two wetland groups.

Northern wetlands

The northern wetlands are situated in topographic depressions adjacent to the Richmond Range where they receive recharge from hillside runoff. Some of the larger northern wetlands discharge into a series of artificial drains that have historically been excavated to create pastoral land.

Monitoring of groundwater levels by MDC has shown that there is a clear relationship between the aquifer and the northern wetlands when the hydraulic gradient is towards them. This indicates that the wetlands and aquifer are hydraulically connected during winter and spring.

During summer and autumn, when groundwater levels are low, the northern wetlands start to become perched above the aquifer because of their peaty substrate. A pumping test by PDP has showed that the bed conductance of the wetlands is low, which is consistent with the observed peaty wetland bed material (PDP, 2004b). It is unlikely that this peaty substrate regularly dries out completely over summer and autumn months, as evidenced by the presence of wetland plants such as *phormium tenax* and *kahikatea*.

Pipitea Wetland

The Pipitea wetland lies at the southeastern corner of the RSA, and discharges to the Wairau Diversion. The Pipitea wetland relies entirely on the RSA for its recharge, and supports a groundwater dependant ecosystem. Most of the recharge to Pipitea Wetland is provided by the artificial drainage network, which hydraulically links the wetlands with the RSA.

Monitoring of groundwater levels in and around the Pipitea Wetland was carried out between September 2003 and June 2005, to improve understanding of the relationship between the wetland and the RSA. The results of this monitoring are presented in Figure 6, together with water levels for P28w/4331.

The Pipitea North site shown on Figure 5 lies in a flax-filled depression to the east of P28w/3486. This part of the wetland is situated north of the confluence with the artificial drain inlet, and is topographically higher than the wetland at the confluence. Consequently, this northern branch of the wetland only contains standing water during winter months.

The monitoring record indicates that Pipitea Wetland is perched above the aquifer for most of the year. When groundwater levels are high, there is potential for groundwater to flow into the wetland either laterally, or vertically through the wetland substrate. However, recharge during these periods is likely to be greatly restricted due to the low conductance of the wetland substrate.

Note that the recession of the wetland at Flaxmill Drive is considerably steeper than the surrounding groundwater recessions. The reason for this is that a culvert was emplaced during construction of the Wairau Diversion stopbank to connect the Pipitea Wetland with the Diversion. This culvert drains the wetland and subsequently has a large role in lowering water levels in the RSA over summer months.

Artificial Drainage Network

The artificial drainage network north of Rarangi Road provides the bulk of recharge to the Pipitea wetland. When this network is fully saturated between Pipitea and the northern wetlands, the RSA has optimum potential to drain into the Pipitea Wetland. During summer and autumn, when groundwater levels are at their lowest, the inlet to Pipitea wetland becomes perched above the aquifer.

A seasonal progression in the degree of groundwater-surface water interaction that occurs in the drainage network is evident in the hydrograph response for well P28w/4331 (Figure 6). Monitoring by MDC has shown that water levels in this well show a clear relationship with water levels in the adjacent artificial drainage network that provides recharge to Pipitea wetland. This indicates that the bed conductance of the drainage network is high enough to enable a good hydraulic connection with the aquifer.

When water levels at P28w/4331 are above about 1.4m, the hydrograph shows a highly dynamic response to rainfall events. At this time, the artificial drainage network is saturated over its whole length, and in complete hydraulic connection with the RSA. Subsequently, the Pipitea wetland is hydraulically linked to the northern wetlands.

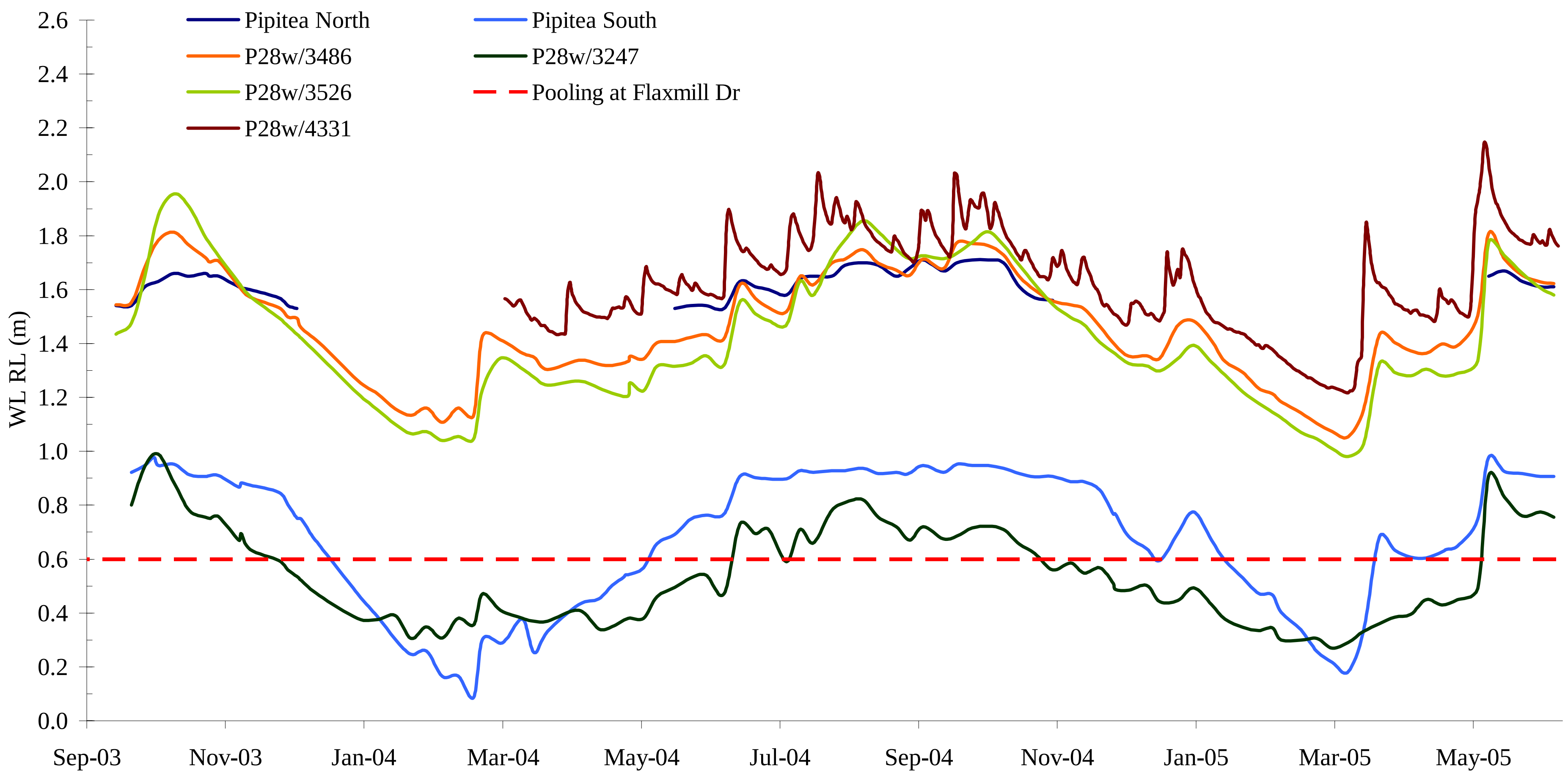

Figure 5. Hydrographs for Pipitea Wetland and nearby RSA wells.

When water levels at P28w/4331 fall below 1.4m, the hydrograph starts to lose its responsiveness, and the rate of recession increases. The reason for this is that the artificial drainage network becomes hydraulically disconnected from the northern wetlands, and also starts to disconnect from the aquifer. The degree of hydraulic disconnection increases further as water levels continue to fall, and the saturated area of the artificial drainage network decreases. This reduces the capture area for groundwater seepage that provides recharge to Pipitea Wetland.

When water levels at P28w/4331 fall further to 1.2m, the seepage interface between the RSA and the artificial drainage network recedes south of Rarangi Road. At this time, the drainage network is completely dry. Any further groundwater recharge to Pipitea wetland that may occur is restricted to seepage through the poorly conductive wetland substrate.

When the drainage network is completely dry, a significant rainfall event (at least 20mm/d) is required at this time to generate any recovery in groundwater levels at P28w/4331. The aquifer responds more rapidly to recharge in the vicinity of the artificial drainage network (P28w/4331) than more distant locations (P28w/4330, P28w/3711). This suggests that the artificial drainage network acts as a distributor of recharge to the aquifer. This observation also confirms that there is a good hydraulic linkage between the aquifer and the artificial drainage network.

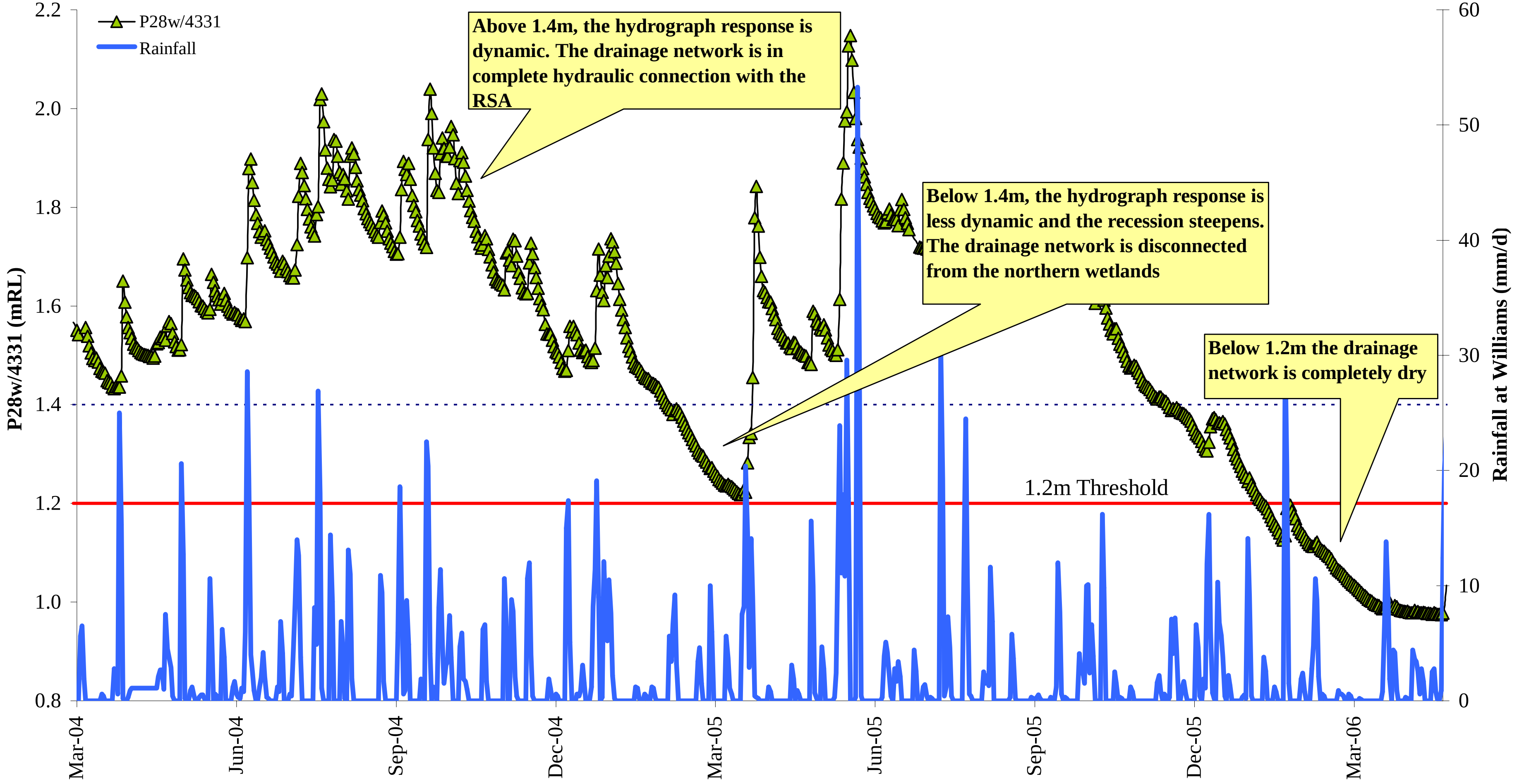

Figure 6. Hydrograph for P28w/4331 showing aquifer response to surface water dynamics

5 RSA Numerical Model

5.1 Model Design

The USGS finite difference numerical code MODFLOW (McDonald and Harbaugh, 1988) has been used to model the RSA. The RSA groundwater model has been developed using the Visual Modflow 3.1 graphical interface (Waterloo Hydrogeologic, 2003).

The model has been set up to run at weekly timesteps for 1075 days. The calibration period runs from 17 July 2002 to 25 June 2005. The starting date is set to coincide with an aquifer-wide piezometric survey conducted by PDP(2002). The finish date is constrained by availability of water level data for the Pipitea Wetland.

Initial heads for the transient model are based on a piezometric survey of the RSA conducted by PDP on 17 July 2002 (PDP, 2003). During later stages of the calibration process, the initial heads were set to the output heads of the previous run.

5.2 Model Domain

The numerical model consists of a single layer with 23 columns and 28 rows. Cell size for the majority of the model is 200m x 200m. Cell size around the model perimeter is 400m x 400m.

Topographical information is based on 10 ft contours surveyed by Vickerman and Lancaster in 1924. This survey only covers the southeast part of the RSA. Reduced levels on well collars have been used to supplement the topographic information. The basal surface of the aquifer has been constrained by bore log information. The data for both surfaces has been contoured using the Surfer package before importing into Visual Modflow.

The northern boundary of the model is well constrained by basement rocks of the Richmond Range, represented by inactive cells. The western, southern, and eastern boundaries are constrained by the Pukaka Stream, Wairau Diversion, and Cloudy Bay respectively.

Five types of flow boundary condition are incorporated into the transient numerical model:

- *Constant Head*: Simulates mean sea level in Cloudy Bay.
- *Recharge*: Inputs rainfall recharge data from the soil water balance model.
- *Evapotranspiration*: Used to simulate domestic water abstraction.
- *Stream*: Simulates flow in the Pukaka Stream, wetlands and associated drainage networks.
- *River*: Simulates changes in river stage in the Wairau Diversion.

The location of Constant head, stream, and river boundaries is shown in Appendix 2. Aquifer properties were initially assigned values consistent with pumping test results.

5.3 Recharge

A simple soil water balance model has been used to calculated aquifer recharge for each soil type. The soil water balance is calculated for each time step in a spreadsheet and imported into the Visual Modflow Recharge module.

The soil water balance used is a modified form of the method outlined in White et al (2003). Each soil unit is assumed to consist of a single homogenous horizon. Representative values of soil water storage capacity, or profile available water (PAW), used in the model are based on the New Zealand Land Resource Inventory (Landcare Research). Values of PAW used in the model are those given in Table 8.

The soil water balance is calculated at daily intervals as follows:

$$S_2 = S_1 + R_{eff} - AET$$

And if $S_2 < 0$, then $S_2 = 0$

If $S_2 > PAW$, then

Recharge = $S_2 - PAW$, and $S_2 = PAW$

Where:

S_1	Soil storage (mm) in week i-1
S_2	Soil storage (mm) in week i
R_{eff}	Effective rainfall. The first 2mm does not penetrate the ground.
AET	Actual evapotranspiration. Adjustments have been made to PET on a monthly basis to account for vegetation demand. Adjustments range from a factor of 0.1 in winter to 0.7 in summer. The model also reduces accounts for a reduction in AET when soil storage is low. If S_1 <0.5, AET is halved.
PAW	Profile available water (soil water storage capacity)

Recharge is only recorded when the soil water exceeds its storage capacity. The assumption has been made that each soil type is at storage capacity on the first day of the model. Results from the daily soil water balance model are totalled to give a weekly recharge rate for input into the numerical model. The distribution of recharge zones for different soil types is shown in Appendix 3.

Additional recharge is provided to the aquifer from hillside runoff along the northern margin of the aquifer. The same soil water balance model is applied to the hillside catchments, with runoff depth rather than drainage calculated. Factors have been applied to adjust the runoff depth with increasing rainfall intensity.

In Table 9 the average annual recharge values for different soils are compared to measured rainfall over the modelled time interval. As expected, the sandy soils allow the most infiltration of the four soil types, with nearly half of annual rainfall contributing recharge to the aquifer.

	(mm/year)	% of Annual Rainfall
Measured Rainfall	797	
Sandy Soil Recharge	376	47
Wetland Soil Recharge	305	38
Western Soil Recharge	335	42
Hillside Runoff	284	36

Table 9. Average annual recharge compared to rainfall for different soil types.

Figure 7 shows monthly rainfall totals at Rarangi for the duration of the model, compared to mean monthly rainfall for the lengthy Marshlands record. Conditions prior to the model start date were wet, with the month of June recording 113 mm at Blenheim research station.

The model starts during a particularly dry period, with negligible effective recharge occurring between August 2002 and May 2003. The six-month period starting December 2002 was the fourth driest on record at Blenheim research station with an occurrence probability of 0.86. This equates to a 1 in 12 year low rainfall event. The remainder of the model simulates mostly average to above average rainfall conditions.

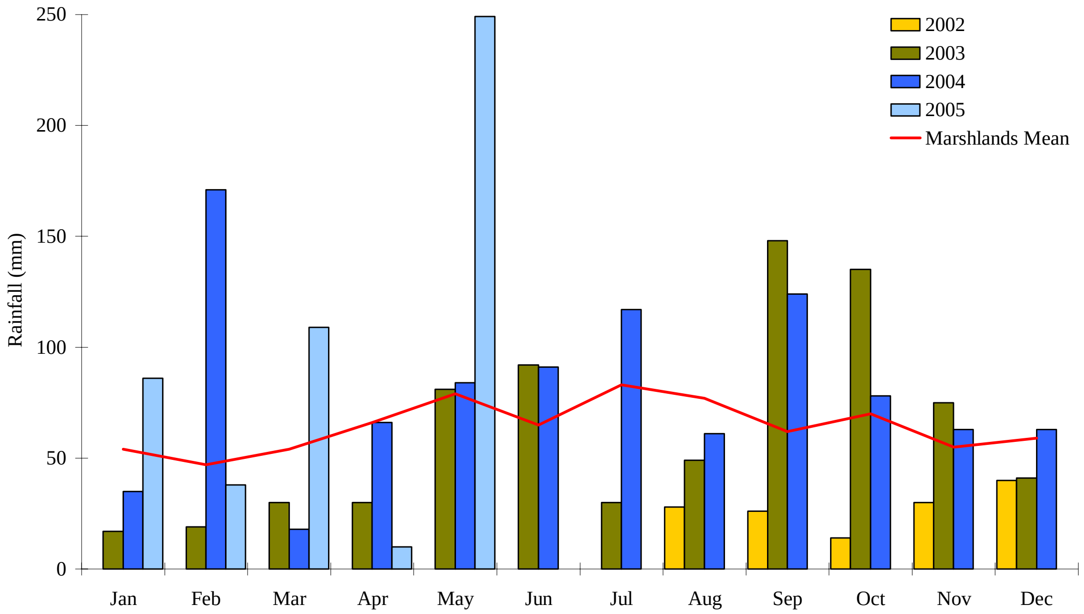

Figure 7. Monthly rainfall for the duration of the model compared to mean monthly rainfall for the entire Marshlands record.

5.4 Abstraction

Abstraction from the RSA has been simulated with both the Wells and Evapotranspiration packages. Larger, discreet abstractions have been modelled as pumping wells (Table 10). The WHVL wells make use of the available pumping record, which has been evenly divided between the two wells. The Golf Club pond abstraction is assumed to be a groundwater take with a peak seasonal demand of half the consented rate.

Wells	Name	Water Demand
P28w/0001	North Rarrangi Water Supply	60 m^3/d
Golf Pond	Golf links irrigation	500 m^3/d summer, 250 m^3/d shoulder season
P28w/4246 & 4249	WHVL	Variable, up to 572m^3/d per well

Table 10. Abstraction wells and demand used in the RSA model calibration

Smaller, more diffuse abstractions have been simulated using the Evapotranspiration package (Table 11, Appendix 4). Demand is based on the density of wells within a cell, and is dependent on property size.

ET Package	Model Cells	Demand (mm/yr)
Zone 1	Rarangi keyboard	90
Zone 2	Keyboard margins	45
Zone 3	Clerveaux	35
Zone 4	Blenheim Lifestyles, Edgewater Estate	15

Table 11. Estimated demand as simulated by the ET package during calibration.

5.5 Streams

The numerical model has four stream boundariess, the Pukaka Stream, Quarry drain, Pipitea Wetland, and the Golf Course wetland. These streams are divided into seven segments over 62 reaches or cells. The only water body where actual observations are incorporated in the model is stage in the lower Pipitea Wetland segment. All other parameters have had to be either fixed at constant values, or input as a synthetic time series.

The Pukaka Stream has few gauging observations available to use in the model. While gauging data show little in the way of gains and losses, Pukaka Stream has been modelled as a stream boundary, rather than a no-flow boundary representing a flow divide. The reason for this is that Pukaka Stream is considered to be important for aquifer drainage during times of high groundwater levels. Evidence for this is seen in the field, where there are numerous drains leading to the Pukaka Stream, including the Quarry Drain. These drains are typically full when groundwater levels are high during winter.

A rudimentary synthetic flow and stage record was developed for Pukaka Stream using a combination of rainfall data, stream gaugings, and groundwater levels. Catchment runoff was calculated using the Marshlands rainfall record and applying the soil moisture balance model for hillside runoff over the catchment area (2,245

Ha). This gives a flow record with unrealistically large fluctuations punctuated by periods with no flow. To overcome this, a 7-day moving average was used to smooth the data. The runoff record was then adjusted to fit stream gauging data at Pembers and Thomas Roads by linear regression. This synthetic flow record was inputted as inflow at the start of the stream segment above Pembers Road.

A second correlation was made between gauged Pukaka flow and stream depth (cross sectional area divided by width). Based on the limited available data, cotrrelation that best approximates the relationship is logarithmic. This correlation was applied to the synthetic flow record at Pembers and Thomas Roads to obtain a continuous variable stage record.

5.6 River Boundary

The River package has been used to model the Wairau Diversion. The river package simulates groundwater losses to the Diversion as a response to fluctuating river stage. The River package does not require river flow data as an input parameter. River stage at the western end of the Wairau Diversion has been modelled using data from the stage monitoring site at the Pukaka Stream confluence. The eastern edge of the Diversion at the outlet to Cloudy Bay has been set at sea level.

6 RSA Model Calibration

6.1 Calibration Process

The numerical model has been calibrated under transient conditions. A steady state model does not give a representative mass balance for the RSA because of the large fluctuations in recharge that occur though time.

The objective of the transient calibration was to enable simulation of the RSA under a variety of stresses such as reduced rainfall and increased groundwater demand. Model calibration was performed by manually adjusting aquifer conductivity, specific yield and bed conductance values. Calibration was achieved by achieving a satisfactory visual match between calculated and observed groundwater levels.

Once a satisfactory groundwater level fit was achieved, the model was verified by comparing calculated and observed stream flow values. The calibration process was repeated if stream flow values were considered to be poorly simulated.

Input values for river stage, constant head, recharge, evapotranspiration and pumping well parameters (metered and estimated) were considered to be well constrained by available data. Values for these parameters were not changed during the calibration process. However, the number of cells receiving hillside runoff was reduced considerably from the initial estimate. The reduction was made because of mounding in the northern part of the aquifer. Removal of the high groundwater levels in this area by altering aquifer or stream properties did not give a satisfactory calibration.

6.2 Calibration Results

Calibrated heads for observation wells in the RSA are shown in Appendix 8. Wells in the northern part of the aquifer are better simulated overall than those in the south. Wells at the southern part of the aquifer have higher calculated water levels than those observed. Least confidence can be placed in areas where the observation wells have the lowest heads above mean sea level.

The overall shape of the calibrated hydrographs is good, although some departures can be seen in the slope of recession curves. Improvements could be made to individual hydrographs by refining aquifer properties into smaller zones. This would be consistent with the likelihood of large hydraulic variability on a scale of tens or hundreds of metres. However, as there is no empirical basis for refining hydraulic properties, zones have been kept as large as possible to avoid inference.

In general, the some periods of the modelled hydrographs are not as responsive to land surface recharge as the observed hydrographs. This indicates that the soil water balance could be refined further. However, the poor hydrograph responsiveness to recharge may also be a reflection of the high spatial variability in rainfall at Rarangi.

Best-fit values for aquifer properties are shown in Table 12. The distribution of each hydraulic conductivity and specific yield zone is shown in Appendix 5 and Appendix 6 respectively. Calibrated values for hydraulic conductivity and specific yield agree very well with values obtained from pumping tests (Table 4). It has been assumed that each model cell is isotropic, having equal hydraulic conductivity in all three directions. In reality, this may not be the case. For example, there is likely to be preferential flow along beach ridges, and impeded flow along peaty areas. There is insufficient empirical knowledge of aquifer properties to justify the incorporation of anisotropic conductivity in each cell.

Hydraulic Conductivity Zone	Area	Hydraulic Conductivity (m/d)		
1	Sandy gravels	130		
2	Peaty areas	110		
3	Offshore	30		
Specific Yield Zone	**Area**	**Sy**	**Eff Por**	**Tot Por**
1	Sandy Coastal	0.17	0.2	0.2
2	Central RSA	0.18	0.2	0.2
3	Peaty areas	0.11	0.2	0.2

Table 12. Best-fit aquifer properties for the calibrated RSA model.

Stream segment values used for model calibration are shown in Table 13. Values for steam and wetland beds are based on results of survey transects. Parameters for streams that incorporate variable stage and flow inputs are listed as “variable”. Modflow determines inflow values listed as “calculated” from outflow in the previous stream segment. Because most stream segment inputs are fairly well constrained, the calibration process was primarily involved altering bed conductance values.

Segment	Water Body		Stage	Bed top	Bed bottom	Width	Inflow	Kz
1	North wetland	Start	2.9	2.8	2.3	50	0	1
		End	2.3	2.2	1.7	5	Calculated	1
2	Artificial drain	Start	2.4	2.3	1.8	5	Calculated	1
		End	1.8	1.7	1.6	5	Calculated	1
3	Pipitea	Start	Variable	1.7	1.2	5	Calculated	1
		End	Variable	0.05	-1.0	15	Calculated	0.1
4	Upper Pukaka	Start	Variable	0.5	0.0	4.5	Variable	5
		End	Variable	0.45	-0.05	4.5	Calculated	1.5
5	Quarry Drain	Start	2.7	2.6	2.1	1	0	1
		End	1.0	0.9	0.4	2	Calculated	1
6	Lower Pukaka	Start	Variable	0.45	-0.05	4.5	Calculated	1.5
		End	Variable	0.2	-0.3	4.7	Calculated	5
7	Golf Wetland	Start	2.1	2.0	1.5	30	0	0.5
		End	1.8	1.7	1.2	5	Calculated	0.5

Table 13. Stream segments used in the RSA model and their calibrated properties.

6.3 Model Verification

Model verification was performed by comparing calculated and observed flows in Pipitea Wetland and Pukaka Stream. Modelled stream flows for Pipitea Wetland and Pukaka Drain are shown in Figure 8 and Figure 9 respectively. The hydrograph for Pipitea Wetland simulates the observed flow data closely, although the receding limb of the hydrograph is fairly sluggish.

The hydrograph for Pukaka Stream is not as responsive as gauging observations show. The modelled hydrograph could be improved with a more accurate catchment runoff model.

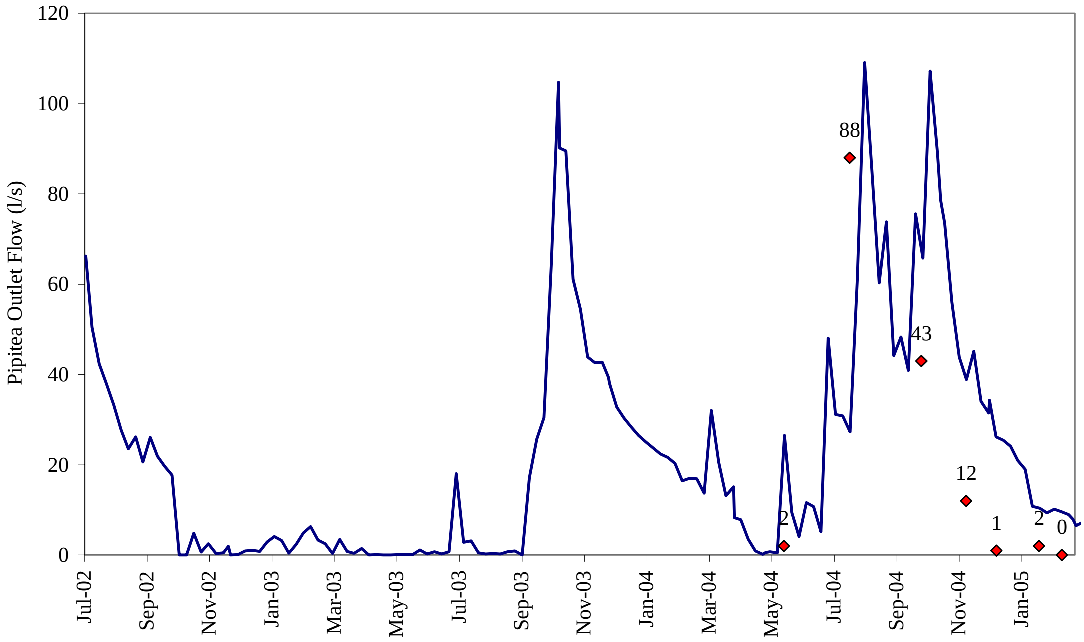

Figure 8. Modelled flow in Pipitea Wetland at the Wairau confluence. Gauging observations are plotted in red.

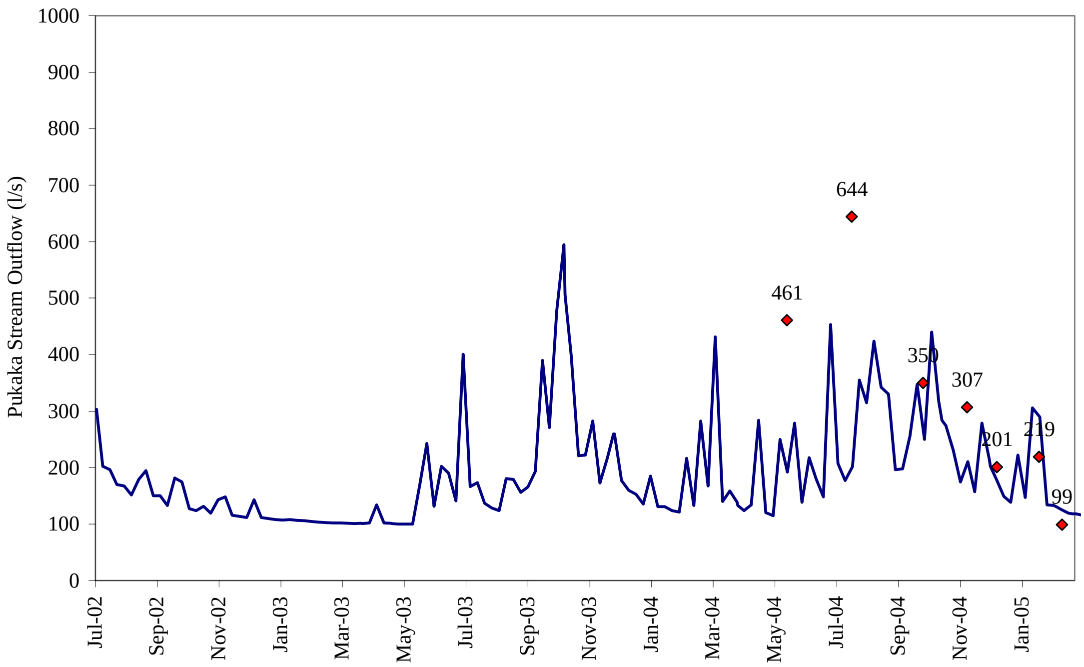

Figure 9. Modelled outflow in Pukaka Stream at the Wairau confluence. Gauging observations are plotted in red.

6.4 Mass Balance

The calibrated model mass balance is shown in Table 14. Note that Modflow treats storage as a separate reservoir from where water is released and recharged to the aquifer. Storage in represents water taken out of storage and put into the water. Thus a positive storage balance represents a net gain of water into the aquifer from storage.

Mass Balance (m^3/day)	**3-year average**	**2003 average**	**2004 average**	**Summer 2003**	**Summer 2004**	**Summer 2005**
Rainfall Recharge	14,695	14,801	18,149	0	5,979	1,589
Flow offshore	5,849	5,056	6,785	3,221	4,957	4,787
Loss to Pipitea and Pukaka	5,241	4,214	7,332	220	2,854	1,879
Loss to Wairau Diversion	4,020	3,808	4,581	1,714	2,675	2,190
Abstraction	422	335	387	605	635	1,298
Storage change	819	-1,394	901	5,737	5,143	8,559
Total Inputs	16,107	15,347	19,532	6,334	11,636	10,622
Total Outputs	16,125	15,353	19,567	6,357	11,636	10,627
Balance	-18	-5	-35	-23	0	-5

Table 14. **Mass balance for the calibrated RSA model. The summer period runs for three months of January to March each year.**

The annual and summer inputs and outputs balance well. As expected, rainfall recharge and stream losses are highly variable. For example, stream flows are strongly affected by the lack of effective recharge during summer 2003. Overall, aquifer loss to surface water bodies accounts for 30 to 40% of annual recharge.

The storage balance can also be highly variable through time, particularly on a seasonal basis. During summer months when recharge volume is low or negligible, the aquifer relies heavily on storage as a water source.

6.5 Calibration Statistics

The absolute mean head residual for the calibrated model is 0.23m for a total of 4020 observations. The largest residual means are calculated at coastal monitoring well P28w/4349, and the southern wells P28w/4298 and 3247.

The standard error for all 4020 observations is less than 2%. This gives a sufficiently accurate calibration for the model to be used for simulations with confidence.

Well P28w/-	Max. Residual (m)	Residual Mean (m)	Std Error (%)	RMS (m)
1901	-0.42	0.05	0.9	0.17
4298	0.86	0.15	1.2	0.27
4329	0.95	0.08	1.9	0.36
4330	0.89	0.05	1.9	0.35
4331	-0.67	-0.08	1.3	0.25
3471	0.82	0.01	1.3	0.24
3486	-0.63	-0.05	1.3	0.24
4349	-0.98	-0.40	1.9	0.53
3247	0.78	0.15	1.7	0.34
3526	0.66	0.02	1.2	0.22
3711	0.59	0.09	1.1	0.23
3668	-0.52	-0.02	1.1	0.21
All Observations	**-0.98**	**0.01**	**0.5**	**0.30**

Table 15. Calibration statistics for all time steps in the RSA transient model.

6.6 Discussion

The calibrated hydrographs show the aquifer's response to a range of dry and wet conditions. An important aspect of the calculated hydrographs is the response of the aquifer during summer and autumn 2003. The modelled hydrographs for this period provide information at a time when there is little monitoring data available inland of the MDC coastal monitoring wells. This was a particularly dry period with minimal effective recharge and only minor groundwater abstraction (abstraction by WHVL was negligible prior to December 2004). Consequently, the hydrographs at this time give the best available approximation of the aquifer's response to drainage under natural conditions.

Rainfall at Blenheim for a six-month duration starting December 2002 is estimated to have an occurrence probability of 0.86, or a 1 in 12 year low. The model predicts that environmental thresholds set on wells P28w/4329, P28w/4330 and P28w/4331 would have been reached during this period. These thresholds apply to the WHVL consent, and are shown as horizontal red lines on the hydrographs displayed in Appendix 8. Dashed red lines indicate a 50% reduction in abstraction, whereas solid red lines indicate a cease in abstraction.

Apart from a brief period where water levels reached the same thresholds in April 2005, is no significant impact on wetlands or domestic wells for the remainder of the model duration. Winter 2003 onwards is representative of normal to wet conditions with an annual probability of occurrence.

It is evident from the calibrated hydrographs that the existing aquifer allocation provides security up to a 1 in 5 year low rainfall event. Pumping restrictions would not be required under these conditions. During drier years, restrictions are necessary to protect drawdown around wetlands and domestic wells. As a result, security of supply is compromised for more extreme dry events.

7 Model Simulations

7.1 Introduction

MDC has requested that the calibrated model be used to simulate three scenarios:

1. *Extreme drought*. The purpose of this simulation is to determine how the aquifer would respond to drought under the calibrated allocation.
2. *WHVL full allocation*. This simulation specifically studies the effect that an abstraction of 3270 m^3/d for 100 days would have on nearby monitoring wells.
3. *Full aquifer demand*. This scenario assesses aquifer sustainability if groundwater were allocated to meet expected maximum future demand.

Results for these three scenarios are presented in this section of the report.

7.2 Drought Scenario

The calibrated model has been run to assess the response of the aquifer at its existing allocation to an extreme dry event. To simulate drought conditions, land surface recharge to the aquifer has been reduced. Other boundary conditions such as stream stage and flow have not been altered from the calibrated model. This makes the simulation simple to set up and run, although aquifer drainage to Pukaka Stream and the Wairau Diversion are underestimated. Accordingly, the simulation results give a conservative scenario for aquifer response to drought.

To simulate the aquifer's response to drought, the driest observed conditions were simulated. The driest conditions observed in the Marshland rainfall record occurred during the 1957-1958 hydrological year with only 403 mm of rainfall. The return period of that event is 42 years using the GEV distribution.

The 2000-2001 year was the driest recorded at Blenheim. The return period of that event was 1 in 54 years. The Marshlands rainfall record does not include this event because the station had been decommissioned in 1989. An event analysis of the Marshlands record indicates that a 50-year low rainfall event at Rarangi is equivalent to an annual total of 395 mm.

To approximate the driest historically observed conditions, the rainfall record for the 2003 calendar year was adjusted by a percentage to give a total rainfall of 395 mm. This allows a comparison to be made between water levels under drought and observed conditions.

The scenario simulated is a summer followed by a dry winter. The effect of reduced recharge on aquifer water levels is represented by yellow lines on the aquifer hydrographs in Appendix 8. Note that abstraction by WHVL commenced in late 2004, which is after the simulated drought period.

The simulation predicts that observation wells located in the northern part of the aquifer are more affected by drought conditions than those near the Wairau Diversion. This is because under dry conditions, the aquifer gradually loses available storage to its boundaries. The hydraulic gradient to the aquifer boundaries is greatest in the northern part of the aquifer where water levels are highest.

There is no flow in the Pipitea and Golf Club wetlands for the duration of the drought.

The extent of pooled water within the wetlands is uncertain. It is clear from the hydrographs that thresholds are required on monitoring wells to protect wetlands during dry years. P28w/4331 falls well below its observed record in response to the dry winter, and breaches the 1.2m threshold for most of the period between February 2003 and May 2004. A similar, although less drastic, response is predicted in P28w/4329 and P28w/4330.

No leakage in from the constant head boundary occurred in this simulation and water levels in the coastal sentinel wells remained above their thresholds. This indicates that the limiting factor on the existing allocation is the preservation of domestic supply and wetlands.

7.3 Full WHVL allocation

A second simulation has been run to assess the environmental effect of raising the WHVL abstraction from 1100 m^3/d to 3270 m^3/d. The modelled scenario assumes that abstraction is evenly partitioned between wells P28w/4318 (MQ) and P28w/4249 (Q6) at a constant rate of 1635 m^3/d for 100 days, starting 1 December each year. No threshold conditions are applied to the pumping schedule. The simulation uses the same boundary stream and recharge conditions as the calibrated model.

Effect on neighbouring wetlands

Two thresholds have been set to protect wetlands, at P28w/4331 and P28w/4074. Maximum predicted drawdowns for these wells are 250mm and 160mm respectively. The model predicts a transgression of the 0.8m threshold at P28w/4074 for a period of three weeks in Autumn 2003.

Figure 10 shows the predicted drawdown at P28w/4331 in terms of duration below the 1.2m threshold. The model predicts that the 1.2m threshold is transgressed in 2004 and 2005, which were years with close to average rainfall totals. During 2003, a particularly dry year, the drawdown at P28w/4331 is so great as to render the consent inoperable for most of the irrigation season.

Effect on neighbouring properties

The model predicts drawdown at the monitoring wells installed to protect domestic wells as follows:

P28w/4329 up to 480 mm

P28w/4330 up to 650 mm

Water levels in both wells are rapidly drawn down to the 50% cutoff threshold. This takes between 16 and 81 days depending on the observation well and the water level at the beginning of the irrigation season. P28w/4330 drops to the 50 % threshold each year, and would greatly restrict operation of the proposed abstraction.

Three observations are important to bear in mind when observing the relationship between pumping effects and the threshold values. Firstly, increased pumping steepens the hydrograph recession, which means that the threshold is reached more rapidly. Secondly, water levels continue to decline after pumping has ceased, until a significant recharge event occurs. When pumping does cease, the hydrograph recedes at its natural rate after a period of storage replenishment in the area of drawdown. The natural rate of hydrograph recession is not as steep than as pumping recession curve. In other words, the effect of pumping is to displace the natural recession curve downwards due to the removal of aquifer storage. Thirdly, water level recovery upon recharge is more sluggish because of the additional storage loss of storage. Considerably more recharge is required to recover groundwater levels than if no pumping had taken place.

The implication of these three observations is that the existing thresholds of 1.5 m (50% cutoff) and 1.2 (100 % cutoff) are sufficient for the current allocation of 1100 m^3/d, but are not sufficient to protect domestic wells at a higher pumping rate. When pumping at 1100 m^3/d, the 1.5m threshold is reached relatively late in the season, and water levels will not fall much below 1.2m after pumping has commenced. A higher pumping rate causes the hydrograph to reach the first threshold earlier in the season, and to remain below it for considerably longer unless there is a major recharge event. Furthermore, because the threshold would be reached earlier in the season, water levels have the potential to fall well below the 1.2m threshold after pumping has ceased. In dry years this would compromise the operation of domestic wells in Clerveaux Estate. To protect the domestic wells at the increased pumping rate of 3270 m^3/d would require the setting of higher thresholds for these two wells.

Potential for seawater intrusion

The mass balance for the model indicates that no reversal of flow across the constant head boundary occurs in response to the proposed abstraction. The model predicts drawdown in the MDC coastal monitoring wells as follows:

P28w/4349	up to 25 mm
P28w/4332	up to 100 mm
P28w/3711	up to 70 mm

The resulting water levels remain above the recommended thresholds for seawater intrusion for all sentinel wells.

Note that drawdown in coastal sentinel wells south of Rarangi Road is greater than in sentinel wells to the north. The reason for this is seen in the shape of the piezometric surface (eg PDP 2003, figure 3), which shows mounding of groundwater in the northern central part of the aquifer. This means that there is more available groundwater storage between P28w/4318 and the northern coastline than there is between P28w/4249 the southern coastline. As a result, the area of coastline at greatest risk from the proposed pumping is in the vicinity of Millennium Rock.

While it does not appear that seawater intrusion is likely to be caused by the proposed abstraction, the degree of drawdown observed is largely dependent on groundwater levels at the start of the irrigation season. If there has been a dry winter and spring, groundwater levels at the coast will be considerably lower than normal, and there will not be the available storage to buffer the effects of abstractions. A pumping duration longer than 100 days would also further increase the drawdown at the coast. For these reasons it is important that the threshold on well P28w/4332 remain as a safeguard, although this level is unlikely to be reached if the thresholds on wells P28w/4329 to 4331 continue to apply.

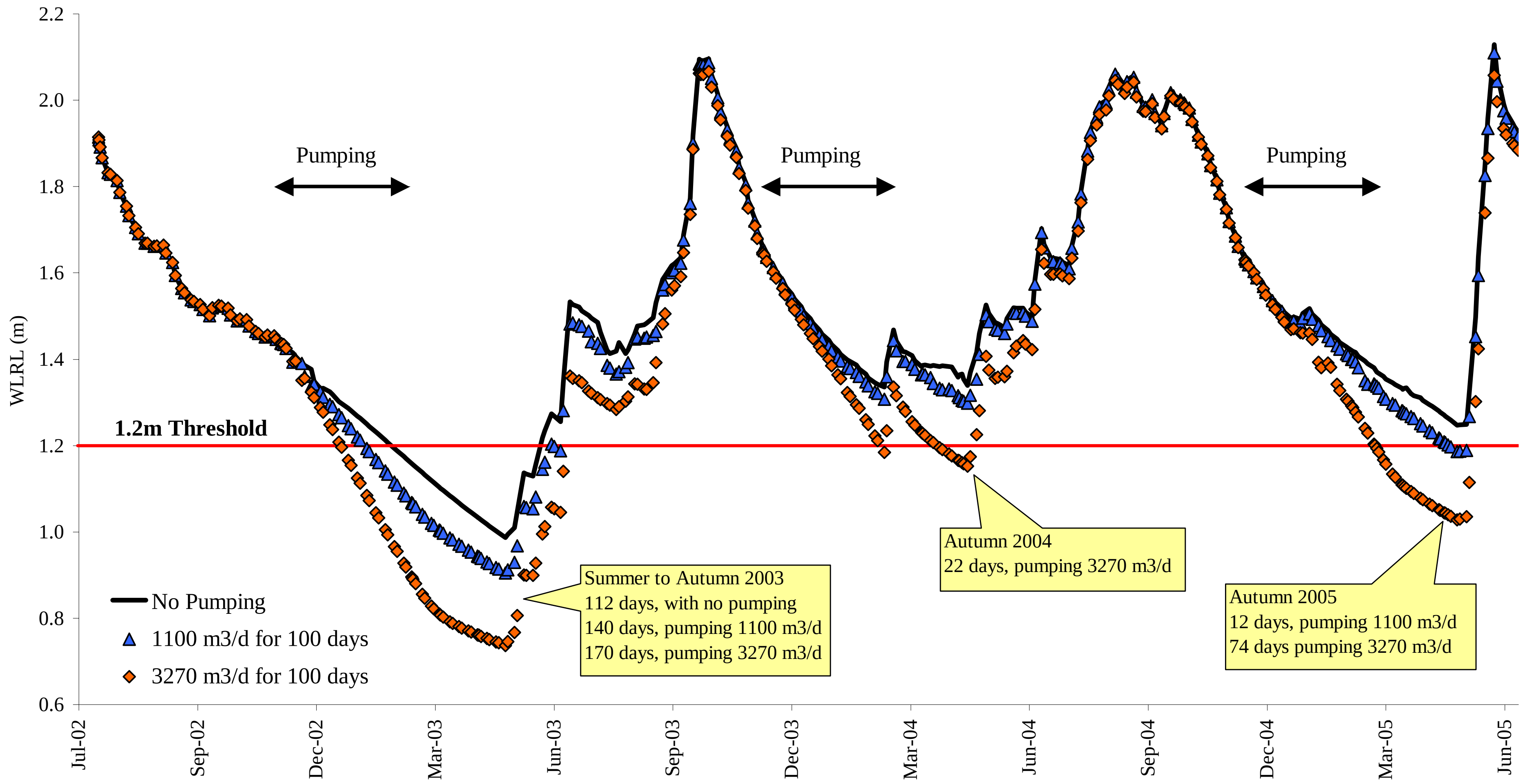

Figure 10. Hydrograph showing predicted drawdown at P28w/4331 in terms of duration below the 1.2m threshold.

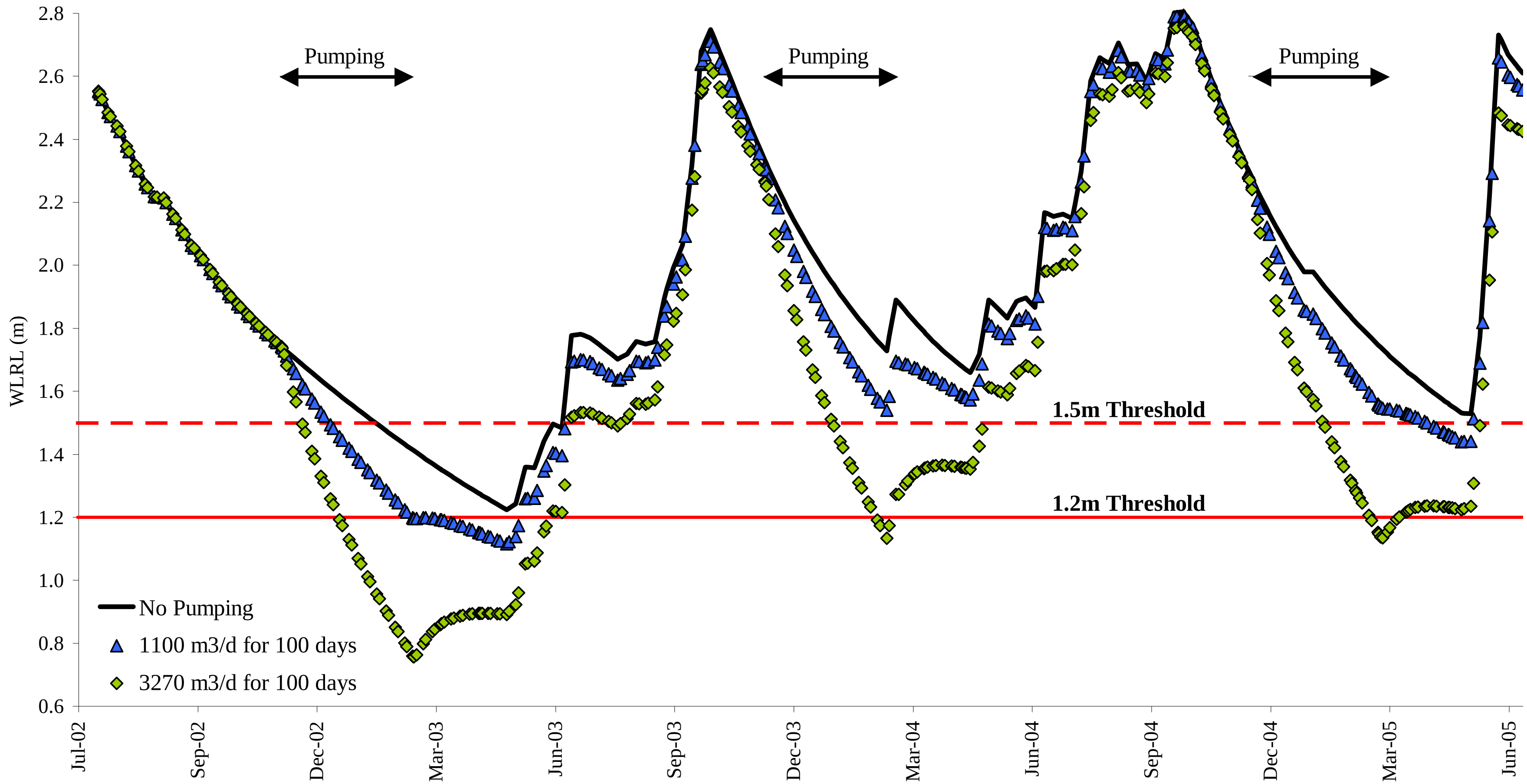

Figure 11. Hydrograph showing predicted drawdown at P28w/4331.

7.4 Full Aquifer Demand Scenario

A third simulation was carried out to assess the sustainability of the highest potential demand on the aquifer. The simulation uses the same boundary stream and recharge conditions as the calibrated model. Increase in demand is simulated by an increase in abstraction rate and duration from pumping wells (Table 16).

Wells	Name	Demand (m^3/d)
P28w/0001	North Rarangi Water Supply	60 m^3/d, constant
Golf Pond	Golf links irrigation	1000 m^3/d 1 Dec to 31 March, 500 m^3/d 1 month shoulder season
P28w/9999	Edgewater drinking supply	70 m^3/d, constant
P28w/4249 & 4318	WHVL	3270 m^3/d distributed equally at 1635 m^3/d per well for 150 days starting 1 November

Table 16. Wells and abstraction rates used in the RSA full demand simulation.

An increase in residential land use has been assumed, with full residential development on all Edgewater Estate and Awarua Farms properties. Increased demand for domestic supply was simulated by increasing the area covered by ET Zone 4 (Appendix 7). Abstraction from the golf course and ET Zone 4 is separated into a shoulder season (November and April) and a peak season (December to March). All other demand rates are constant. Thresholds have not been applied to the WHVL wells for the purpose of this simulation.

The predicted impact of high water demand on groundwater levels is represented by the blue lines on hydrographs in Appendix 8. It is evident that the peak effect of pumping on water levels in all the observation wells is considerably greater than the effect of an extreme drought. The rate of water level recession caused by the removal of storage is more rapid than the recession rate observed during natural drainage in a dry period. The effect of abstraction is to steepen the hydrograph curves away from their natural recession rate.

At the end of the irrigation season when abstraction ceases, the slope of the recession curve eventually recovers to its natural rate after an initial delay period. The delay is caused by the loss of storage in the cone of depression around abstraction wells. This water needs to be recharge by the surrounding aquifer before recovery can take place. Once the recession rate returns to its natural state, water levels continue to decrease at their natural rate. Recovery of water levels at the end of summer only occurs when there is significant aquifer recharge. It is encouraging to see the high degree of hydrograph recovery predicted for each simulated winter period. However, if peak demand was superimposed on the simulation for an extreme drought year, it is clear that thresholds in coastal sentinel wells would be triggered.

Predicted drawdown beyond the existing allocation is shown in Table 17. Drawdown effects are greater in the northern part of the aquifer where projected demand is greatest. Water level thresholds for P28w/4329, 4330, 4331 are transgressed each year. The 0.8m threshold for P28w/4074 is transgressed in April 2003. It is clear that increased groundwater demand will impact severely on domestic wells at Clerveaux estate, and wetland levels throughout the Rarangi area.

Well P28w/-	Predicted maximum additional drawdown (mm)	Lowest simulated water level (m)
3471	280	0.86
4329	650	0.73
4330	830	0.51
4331	400	0.59
4332	140	0.37
4074	170	0.67
1901	65	0.49
4349	20	0.25
3711	80	0.41
3668	35	0.30

Table 17. Minimum water levels and maximum drawdown as predicted at selected observation wells for the peak demand simulation.

The mass balance for the full demand simulation is shown in Table 18. The main departures from the calibrated mass balance are the reduction of groundwater flow to surface water bodies, and the large increase in storage demand during the irrigation season.

The predicted reduction in flow offshore is relatively small. No inflow to the aquifer from the constant head boundary occurs, so there is been no direct effect on the saltwater interface. This is consistent with the minimum predicted water levels in the coastal sentinel wells, which remain above threshold values.

	3-year average	2003 average	2004 average	Summer 2003	Summer 2004	Summer 2005
Rainfall Recharge	14,700	14,419	18,311	0	5,900	1,414
Flow offshore	5,650	4,735	6,626	3,155	4,954	4,643
Loss to Pipitea and Pukaka	4,464	3,299	6,326	125	2,006	1,303
Loss to Wairau Diversion	3,972	3,708	4,546	1,716	2,666	2,168
Abstraction	1,805	1,807	1,783	4,040	4,058	4,056
Storage change	1,174	-882	961	9,050	7,775	10,753
Total Inputs	16,530	15,063	19,823	9,612	14,350	12,682
Total Outputs	16,546	15,076	19,831	9,597	14,358	12,684
Balance	**-17**	**-12**	**-8**	**15**	**-8**	**-2**

Table 18. Mass balance for full aquifer demand simulation.

The high demand scenario places great stress on the aquifer during the dry 2003 summer. Even if abstractions are managed with thresholds emplaced to limit aquifer drawdown, water levels around wetlands and domestic supplies are substantially lowered. The reason for this is that the thresholds are reached earlier in the season as a result of more rapid removal of storage. Also, the increased recession rate caused by high demand extends the duration that water levels are low. If the current thresholds continue to apply, there will be long periods of times (weeks) when little to no abstraction could occur during dry years.

Conclusions

The existing groundwater allocation for the RSA provides security of groundwater supply to all abstractions for approximately 1 in 5 years. During drier events, water levels reach recommended threshold levels that protect domestic wells and Pipitea Wetland. Pumping restrictions are enforced when this threshold is reached, and the security of supply for irrigators is compromised.

Modelling simulations indicate that the aquifer will not be able to provide for existing demand for all irrigators during extremely dry years without the retention of appropriate environmental thresholds. Limiting factors are the preservation of wetlands, and maintenance of water levels for residential wells. With appropriate thresholds in place, the existing allocation will continue to be sustainable.

Simulations of predicted maximum aquifer demand induce large drawdowns during summer periods. Environmental thresholds are reached earlier each irrigation season, and also more frequently. In addition, the duration that water levels remain below the thresholds is extended, and water levels recede to lower levels because of the additional removal of aquifer storage.

Accepting the existing aquifer thresholds, increased groundwater allocation becomes a balancing act of increased volume verses security of supply for the irrigator. Increased allocation results in decreased security of supply to existing operations because environmental thresholds are reached more frequently. Increased allocation also increases the potential risk of compromising domestic supplies along Rarangi Road during dry years. The reduction in seepage wetlands will adversely affect their natural character, and may lead to long-term damage of flora and fauna.

At this stage, seawater intrusion is not a limiting factor on existing or potential groundwater allocation. This suggests that there is still potential to increase groundwater abstraction beyond its existing allocation. However, available storage in the aquifer is not large, and the environmental effects of pumping at Rarangi tend to be very localised. Further allocation, particularly in the south and east, could easily reverse the flow balance offshore during drought years.

An increase beyond the existing aquifer allocation could only be environmentally sustainable if future abstractions are spread at distance throughout the aquifer. Further allocation would also require adaptive management in the form of appropriate environmental thresholds.

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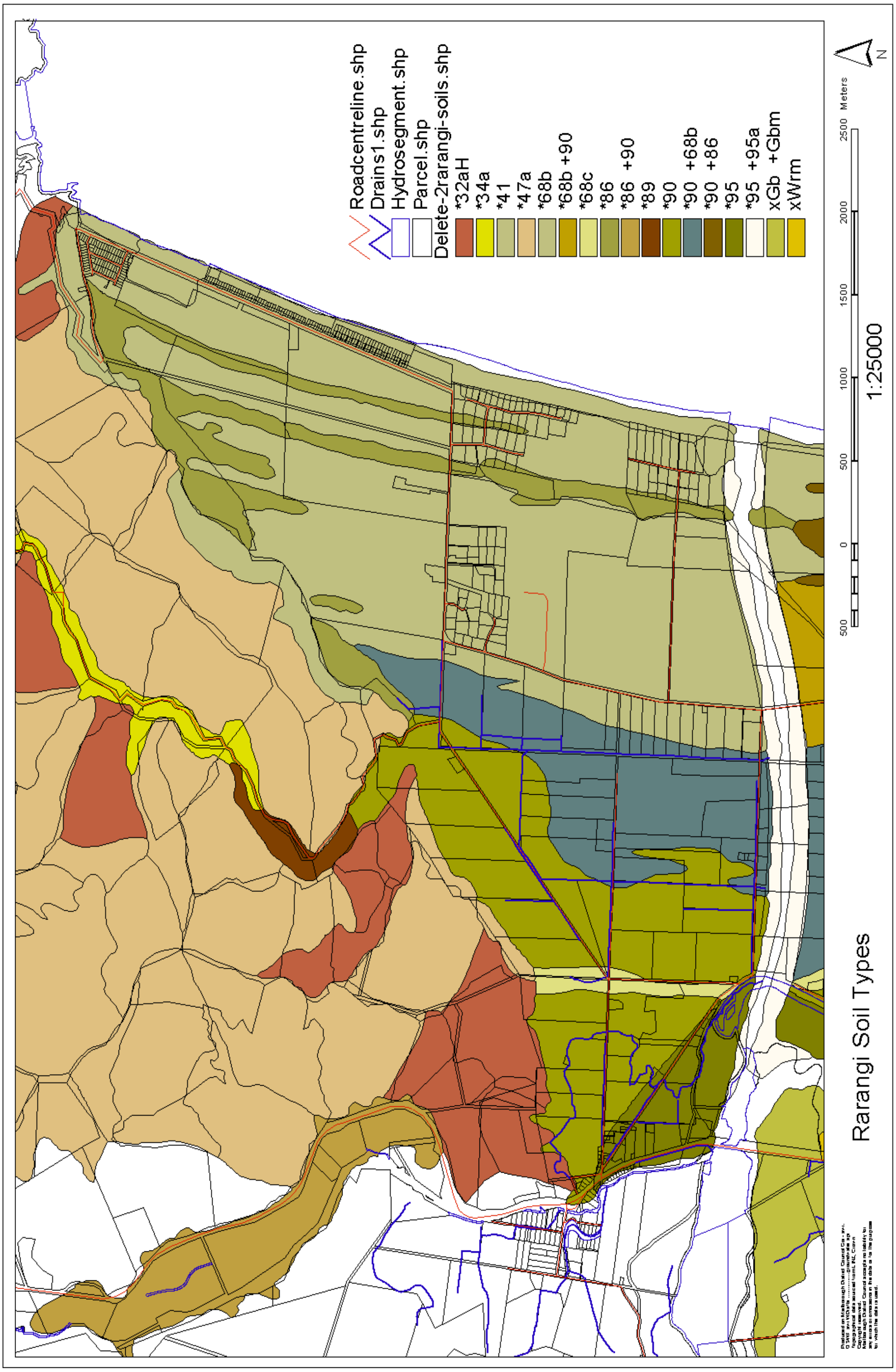
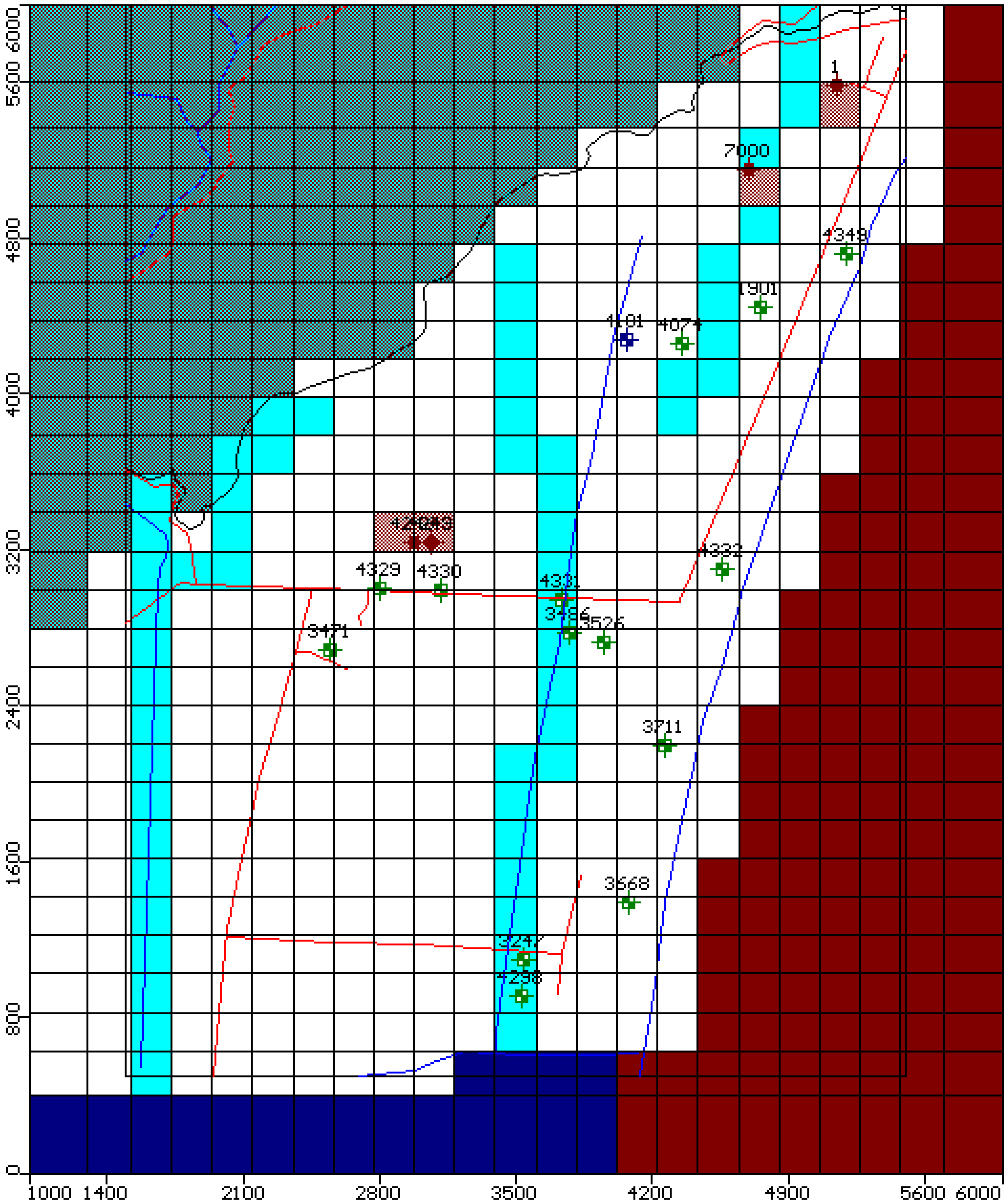
Appendix 1. Map of soil units in Rarangi



Appendix 2. RSA Numerical Model Boundaries



Key to Model Boundaries

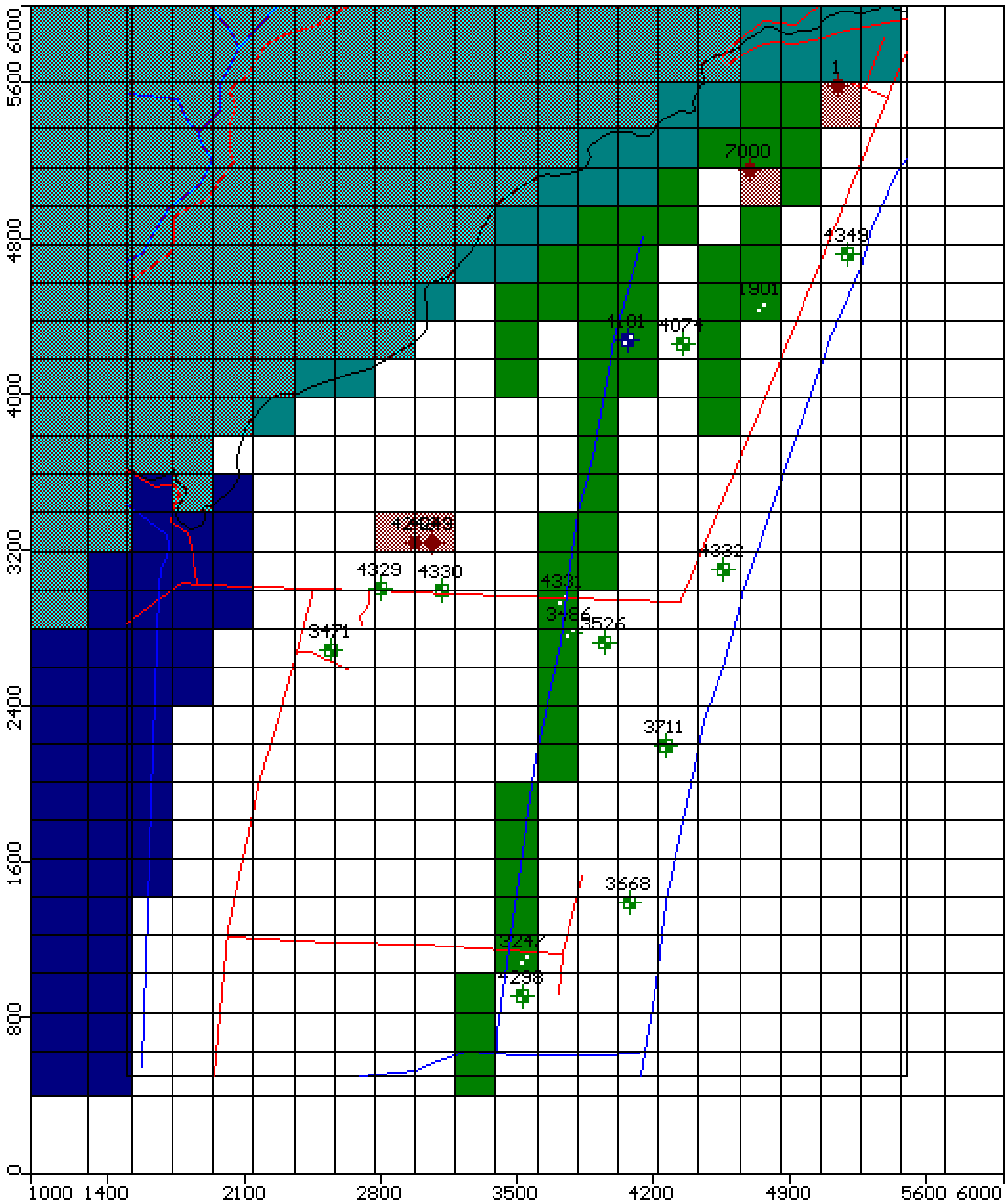
Red: Constant Head

Dark Blue: River

Light Blue: Stream

Grey-blue: No Flow

Appendix 3. RSA Numerical Model Recharge Zones



<u>Key to Recharge Zones</u>

White: Sandy soils, average of 310 mm/year

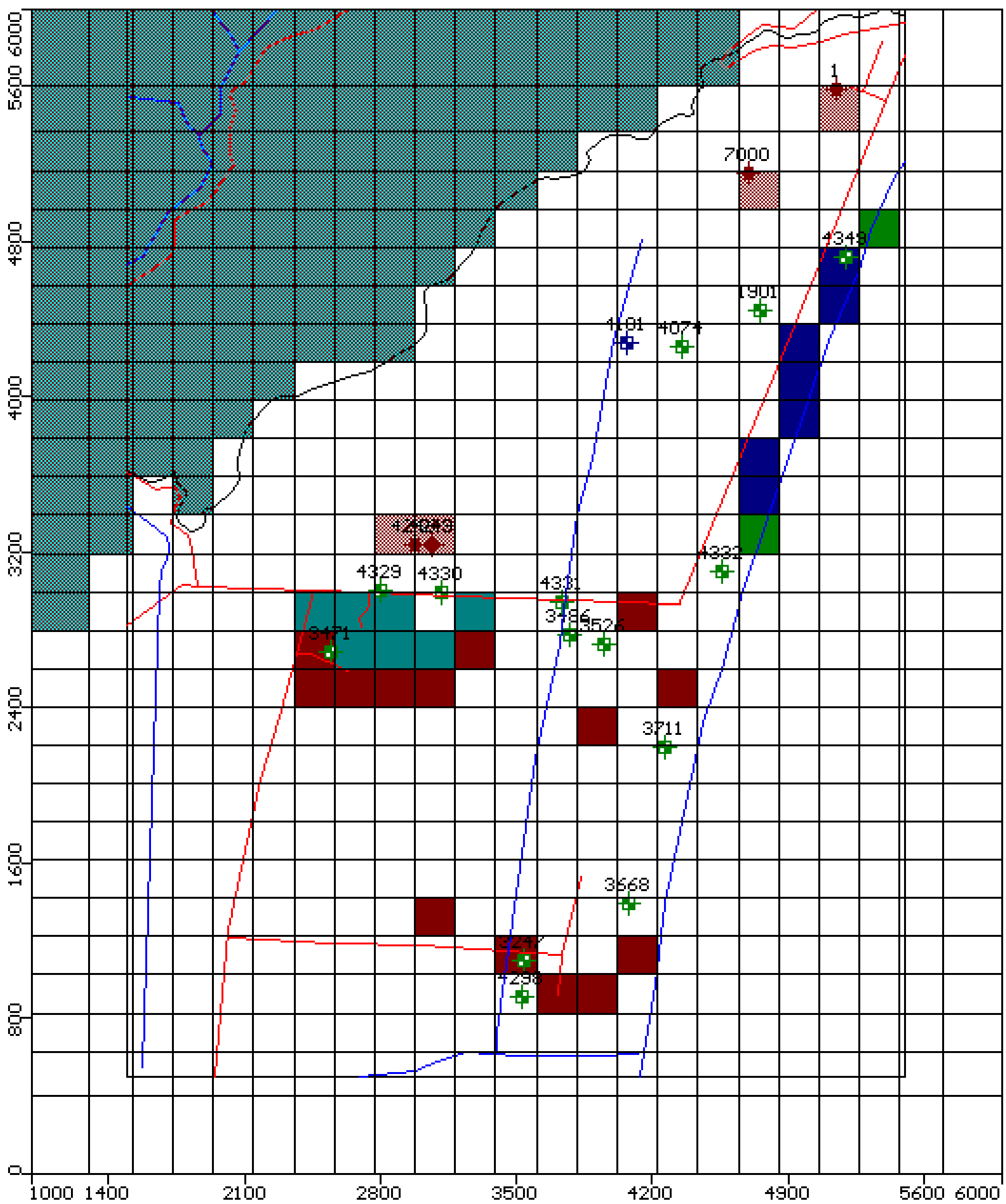
Blue: Western soils, average of 279 mm/year

Green: Wetland soils, average of 310 mm/year

Teal: Hillside runoff, average of 586 mm/year

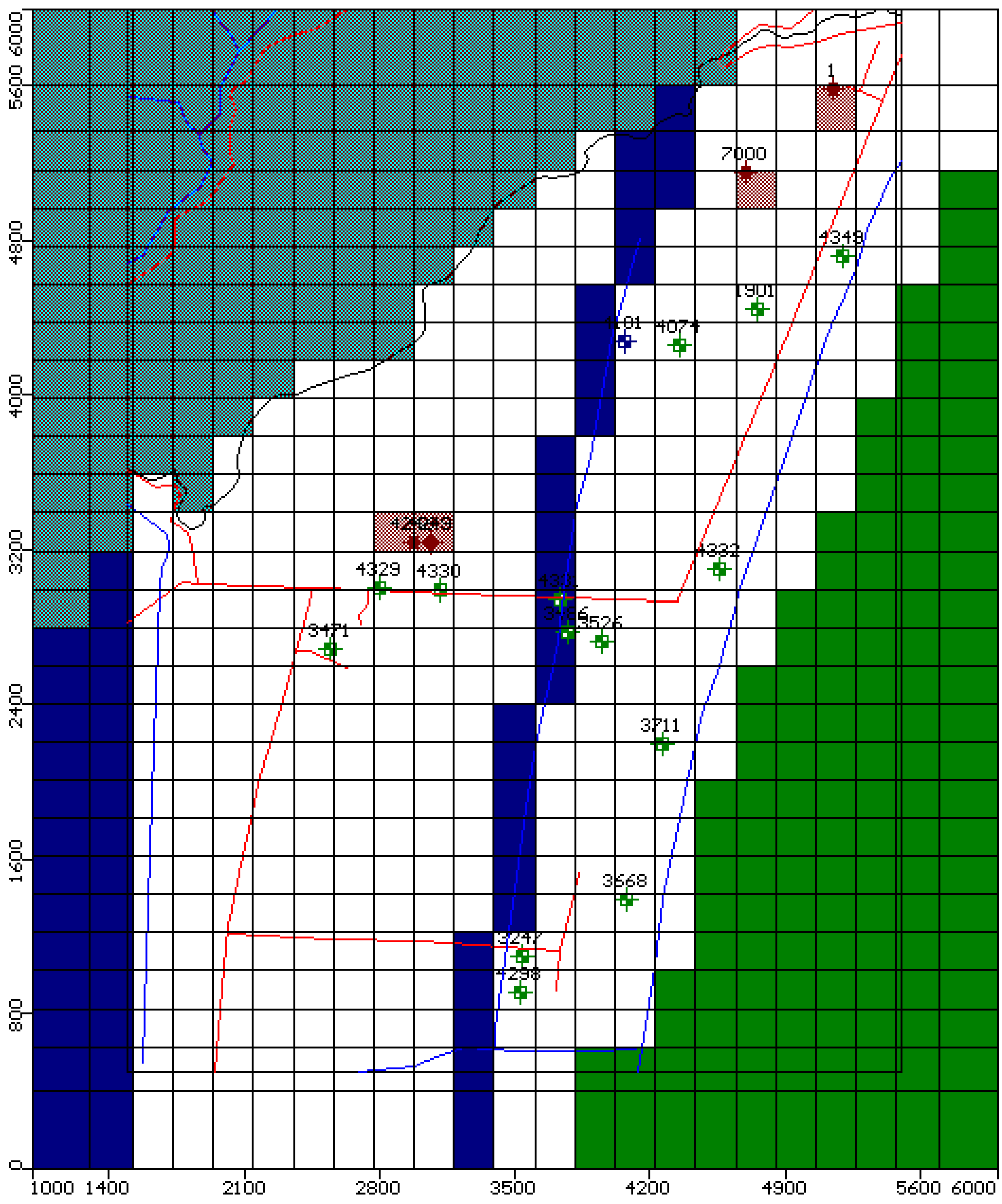
Grey-blue: No Flow

Appendix 4. RSA Numerical Model Pumping Wells and ET Zones



Key to Evapotranspiration Zones	
Blue:	90 mm/year
Green:	45 mm/year
Teal:	35 mm/year
Dark red:	15 mm/year
Grey-blue:	No Flow

Appendix 5. RSA Numerical Model Hydraulic Conductivity Zones



Key to Hydraulic Conductivity Zones

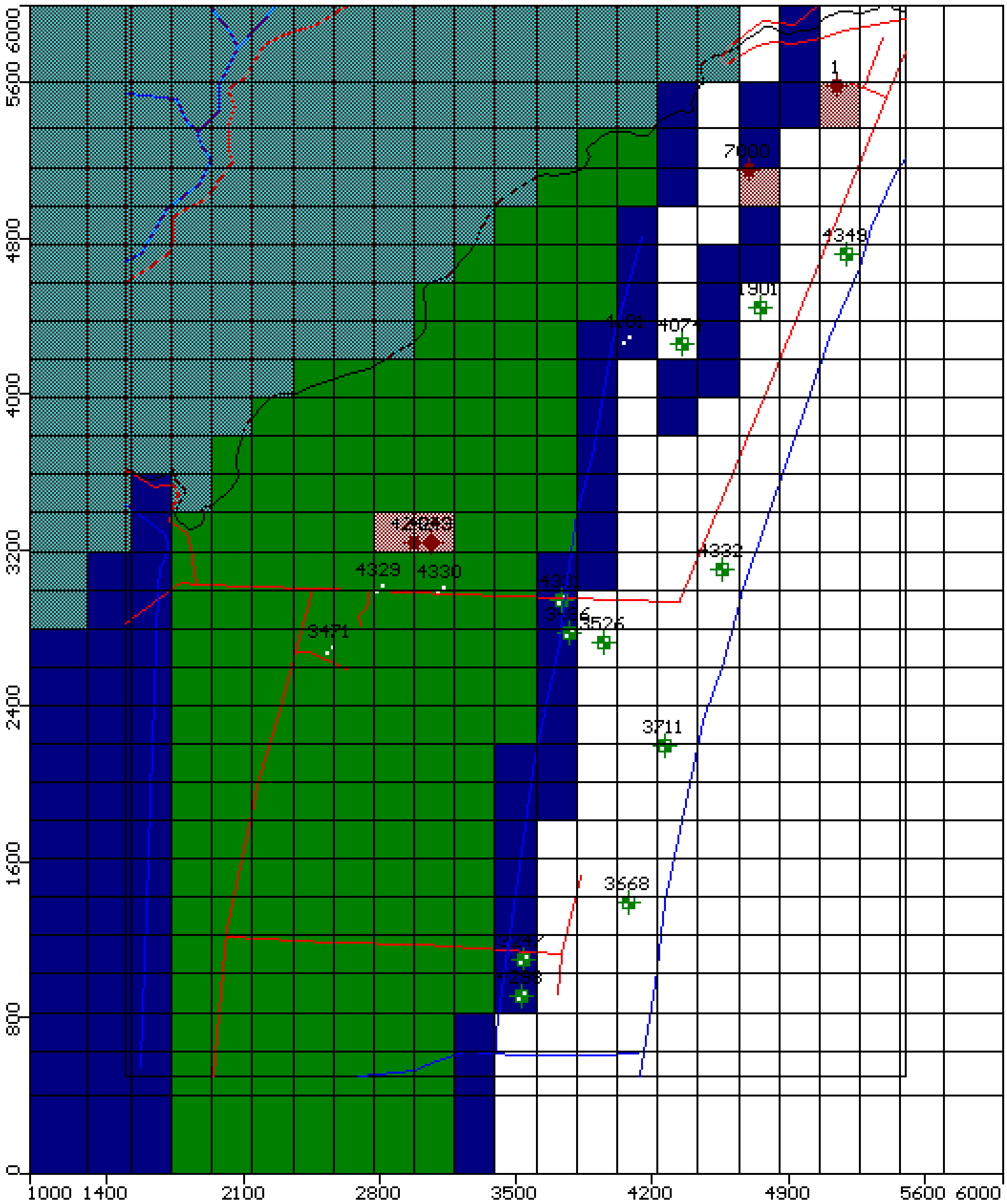
White: 120 m/d

Blue: 100 m/d

Green: 20 m/d

Grey-blue: No Flow

Appendix 6. RSA Numerical Model Specific Yield Zones



Key to Specific Yield Zones

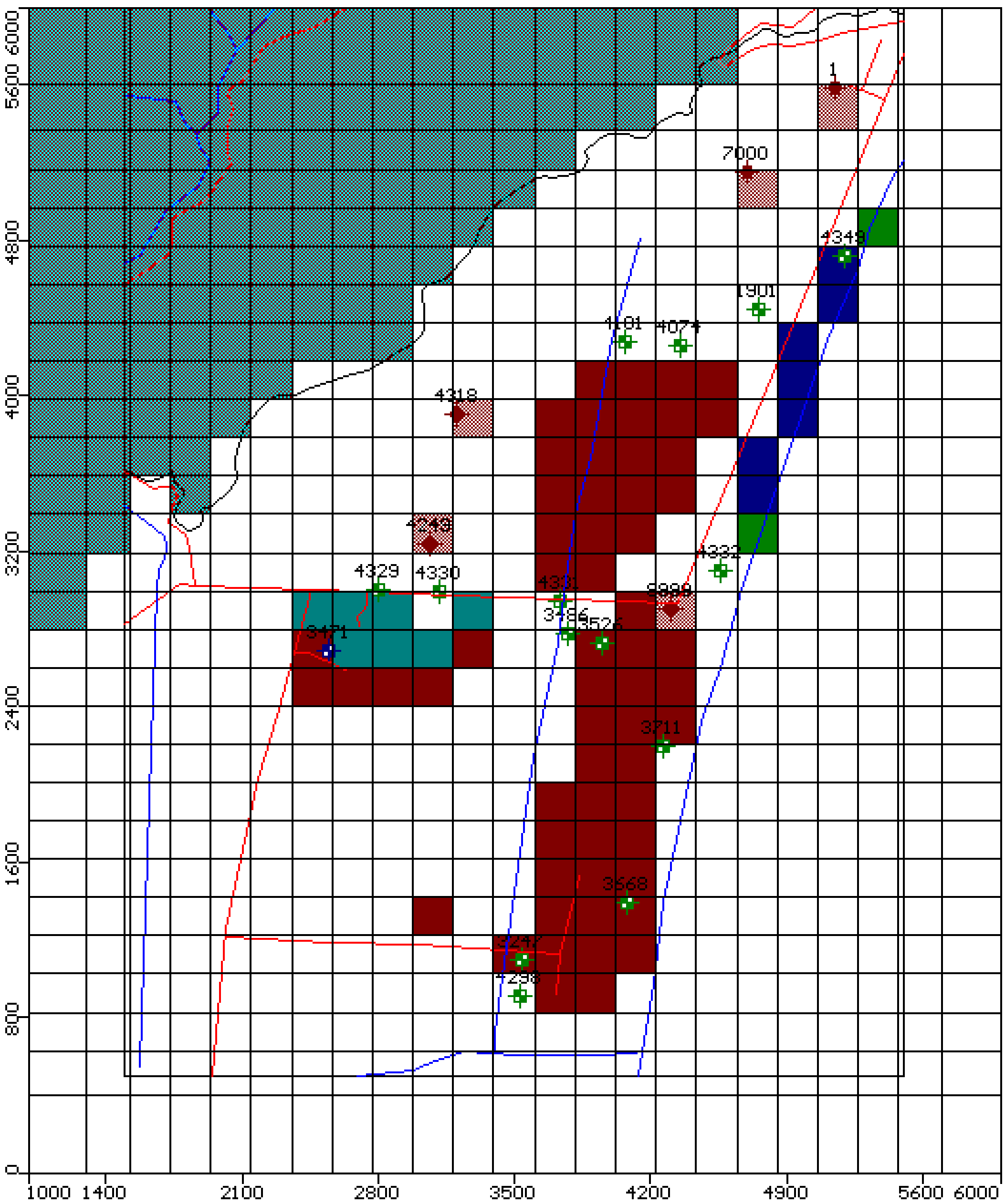
White: 0.16

Blue: 0.13

Green: 0.15

Grey-blue: No Flow

Appendix 7. Full Demand Scenario Pumping Wells and ET Zones



Key to Evapotranspiration Zones

Blue: 90 mm/year

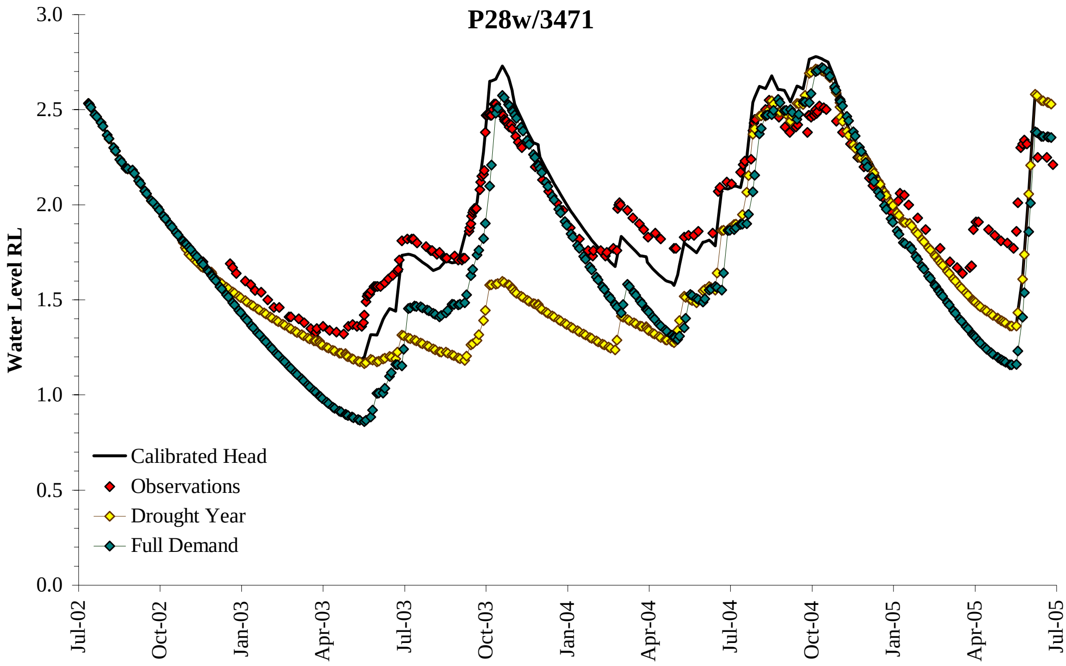
Green: 45 mm/year

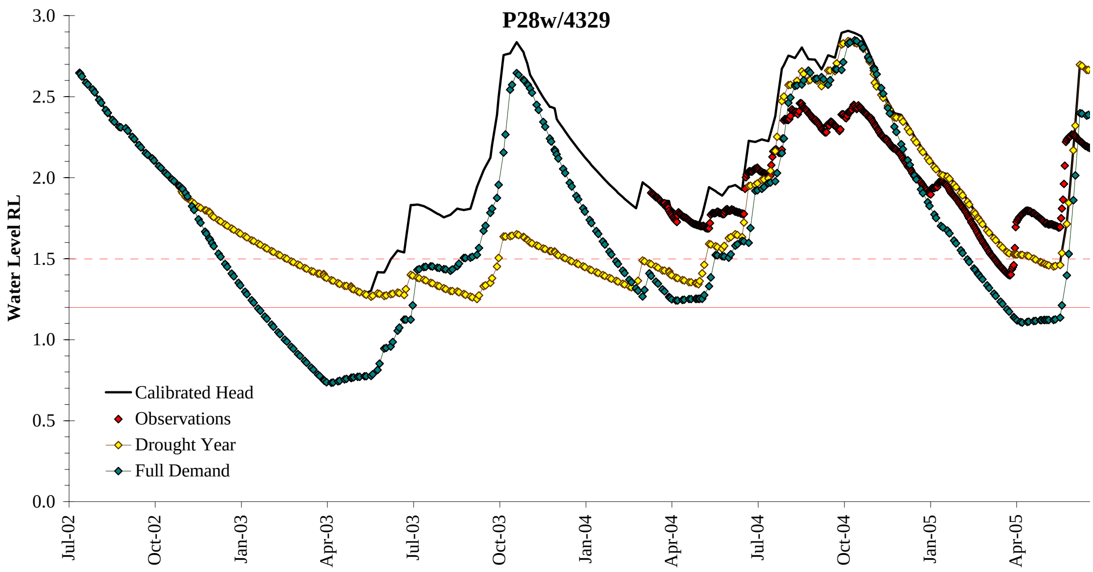
Teal: 35 mm/year

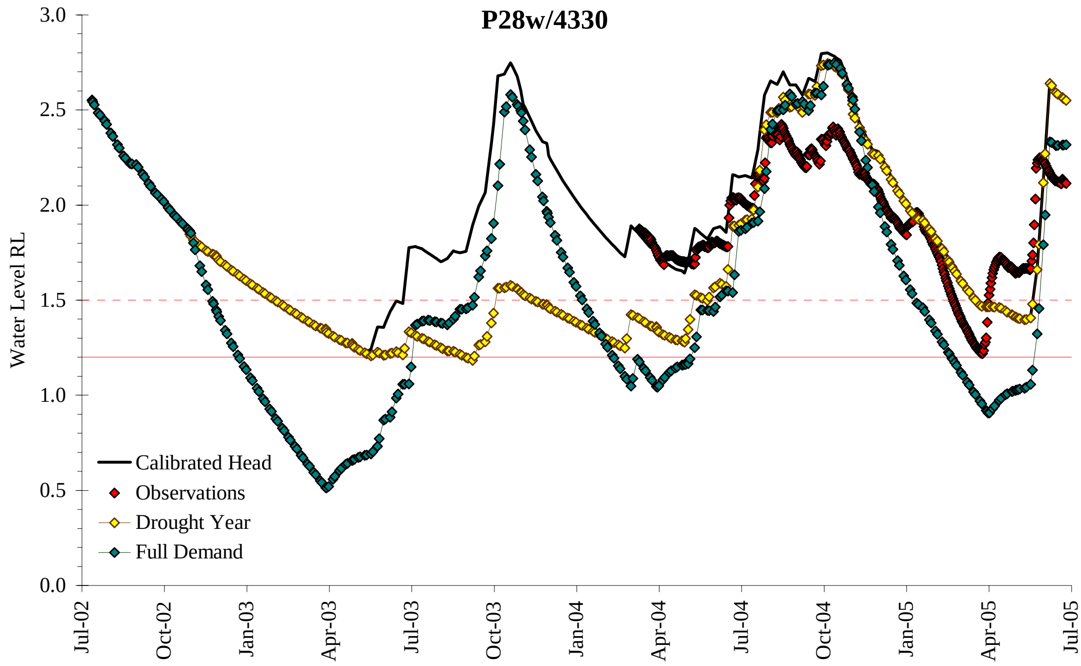
Dark red: 30 mm/year Dec-Mar, 15 mm/year Nov & April

Grey-blue: No Flow

Appendix 8. RSA Numerical Model Calibration Plots



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Water Level RL
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Calibrated Head
Observations
Drought Year
Full Demand
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
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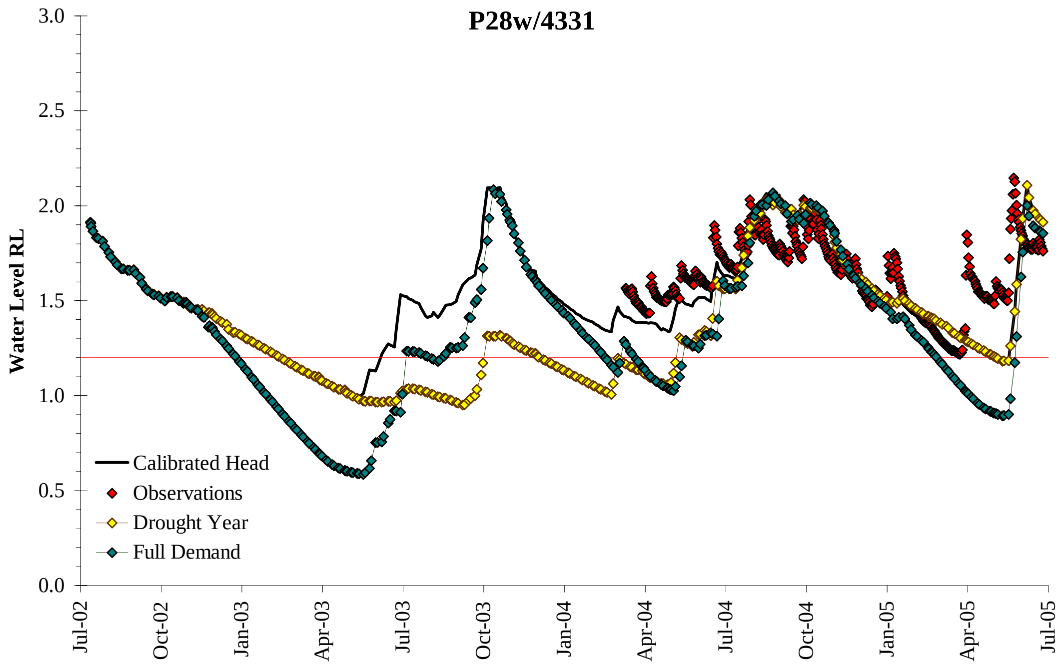
Oct-04
Jan-05
Apr-05
Jul-05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2.0
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1.0
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0.0
Calibrated Head
Observations
Drought Year
Full Demand
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
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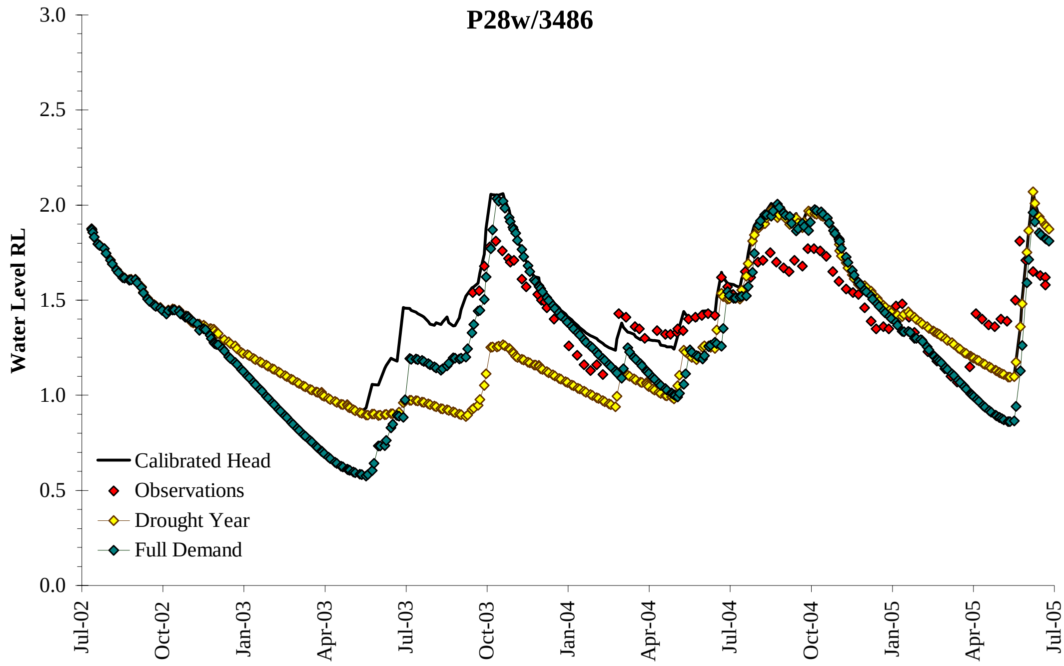
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05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1.0
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Calibrated Head
Observations
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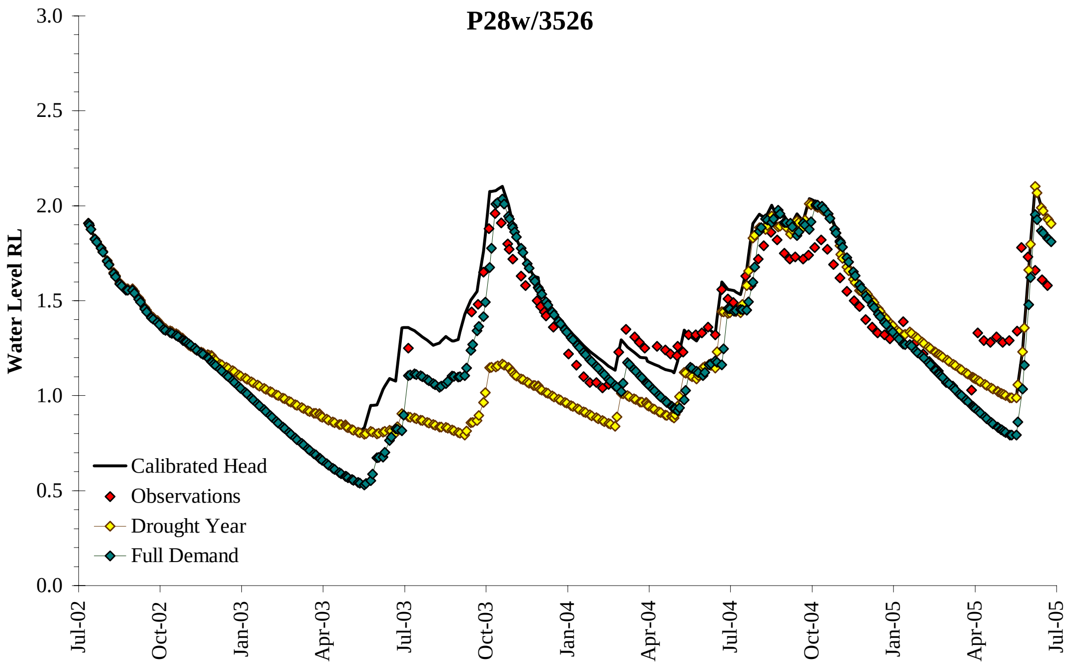
Full Demand
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05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1.0
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0.0
Calibrated Head
Observations
Drought Year
Full Demand
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
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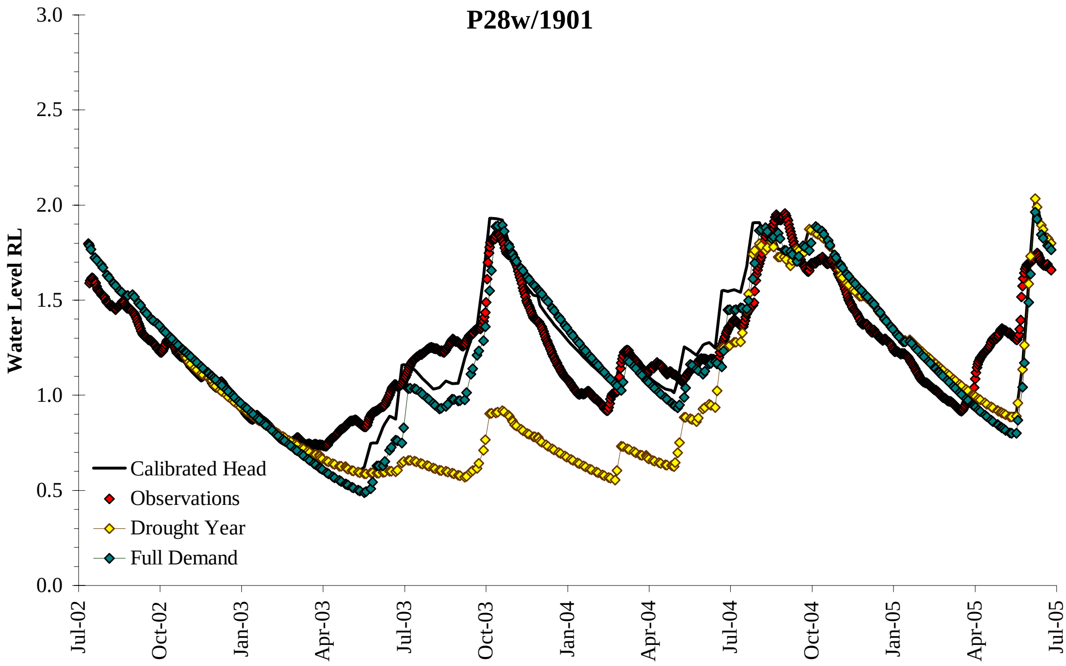
Jan-05
Apr-05
Jul-05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0.0
Calibrated Head
Observations
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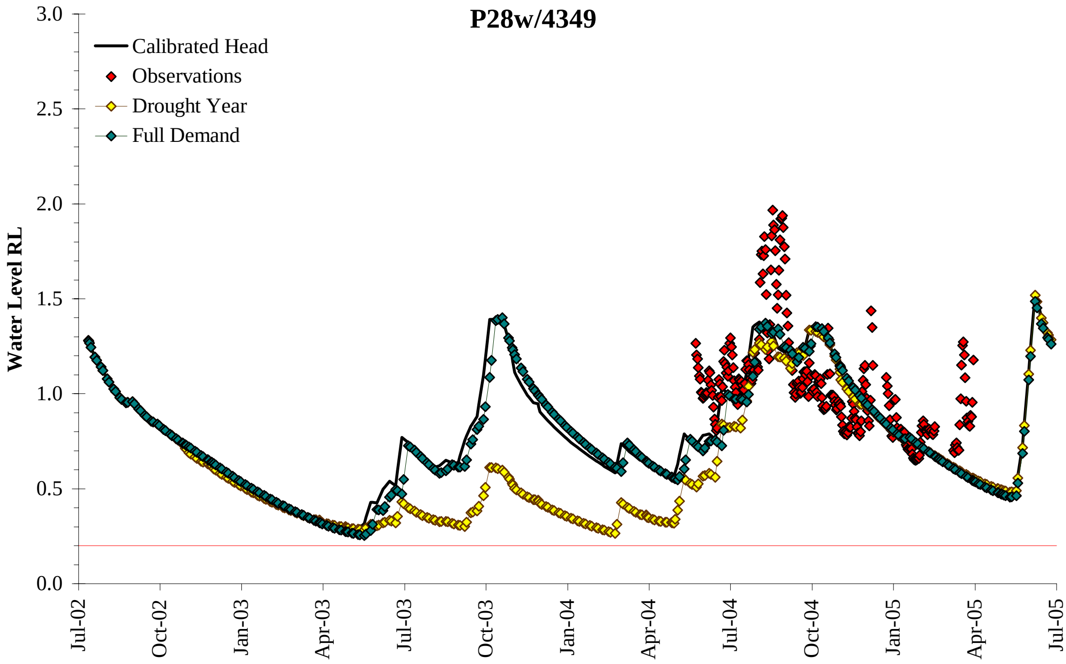
Jan-05
Apr-05
Jul-05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Observations
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Full Demand
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Oct-02
Jan-03
Apr-03
Jul-03
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Jan-04
Apr-04
Jul-04
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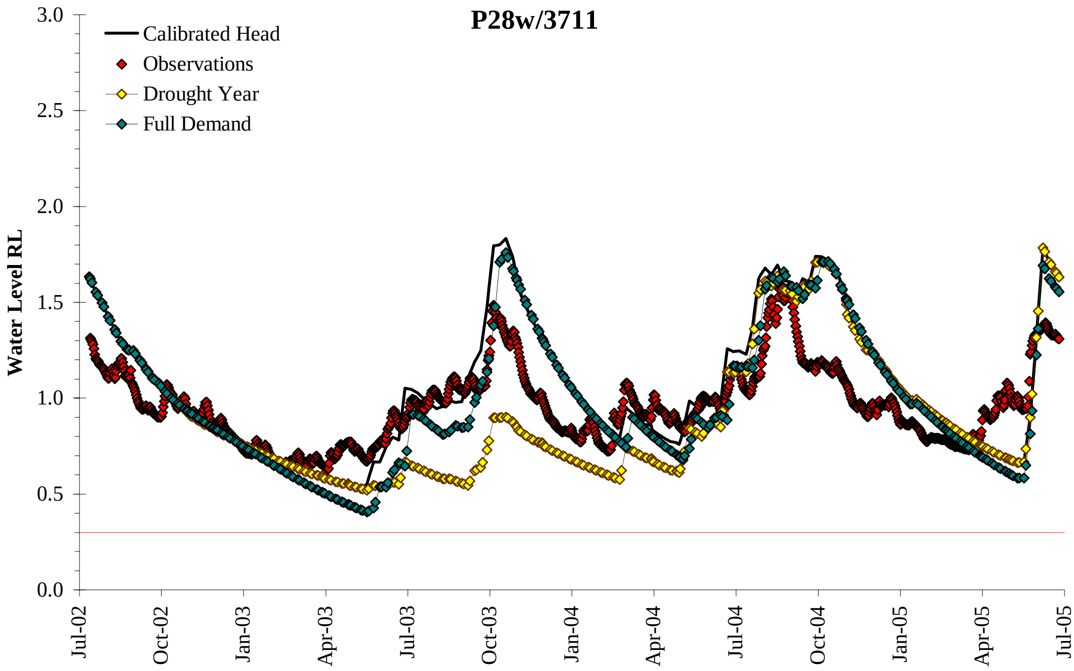
Jan-05
Apr-05
Jul-05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Drought Year
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Oct-02
Jan-03
Apr-03
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Oct-03
Jan-04
Apr-04
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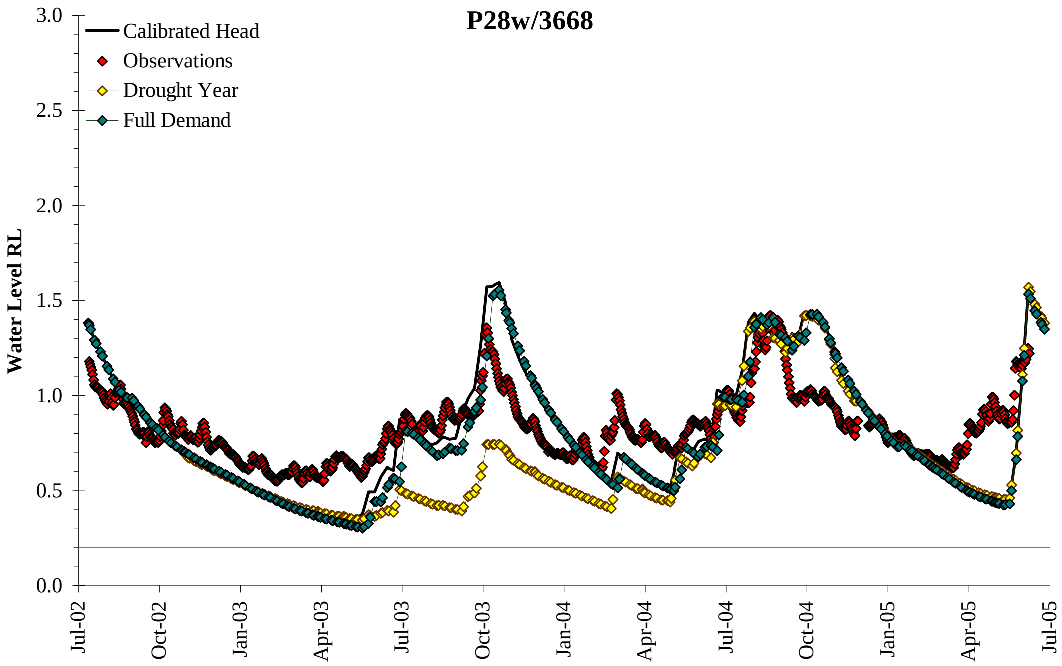
Jan-05
Apr-05
Jul-05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Observations
Drought Year
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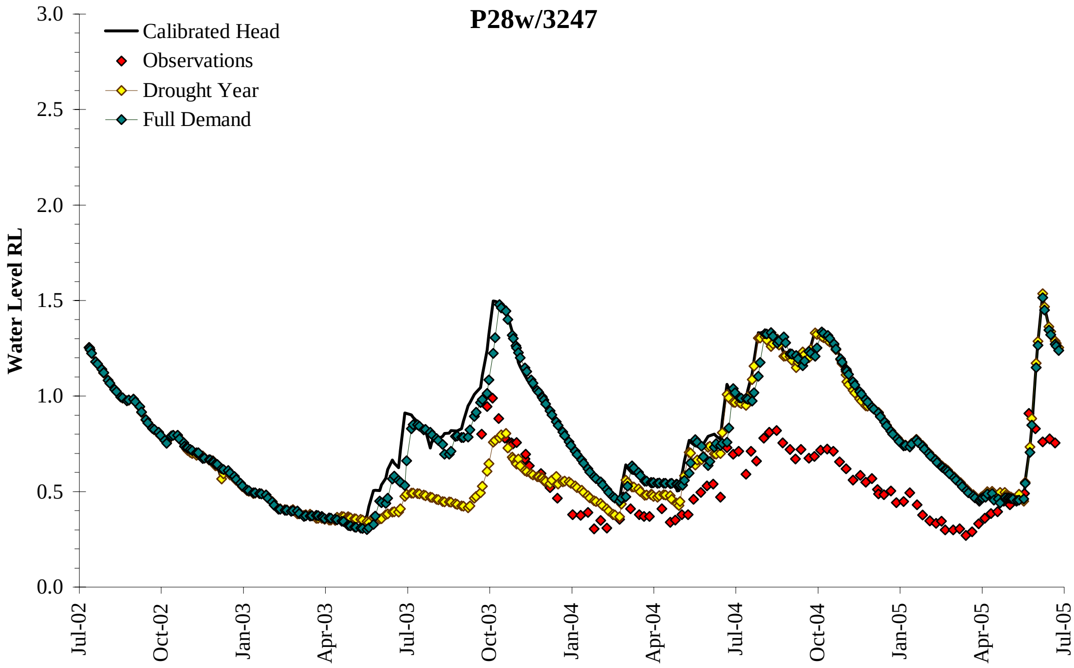
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05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Observations
Drought Year
Full Demand
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0.0
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
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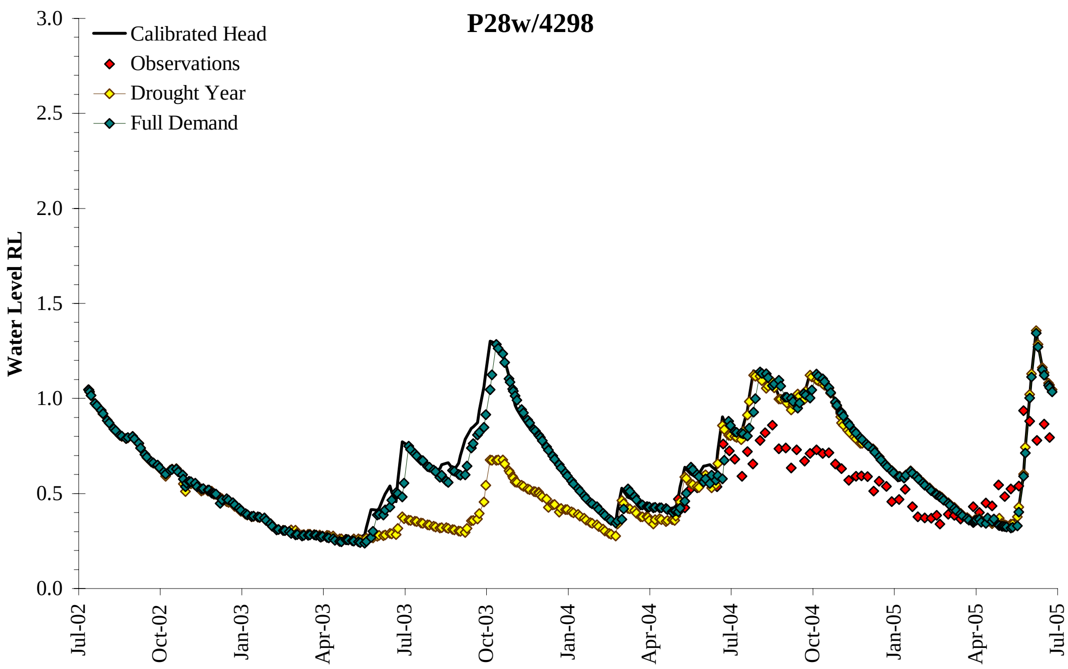
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05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Calibrated Head
Observations
Drought Year
Full Demand
Water Level RL
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2.0
1.5
1.0
0.5
0.0
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05

Appendix 9. RSA Transient Model Calibration Datasheet

Model Domain

Grid	28 rows by 23 columns 200m x 200m cells, with a 400m perimeter
Layers	Single layer, variable surface elevations
Inactive Cells	Richmond Range
Time steps	Weekly
Duration	1075 days from 17 July 2002 to 25 June 2005

Boundary Conditions

Constant Head	Cloudy Bay, 0m amsl
Stream	Pukaka: variable inflow, start and end stages, Kz=5 m/d Quarry Drain: 0 inflow, const. start and end stages, Kz=1 m/d Pipitea wetland: 0 inflow, const. start and variable end stage, Kz=1 to 0.1 m/d Golf Wetland: 0 inflow, const. start and end stage, Kz=0.5 m/d
River	Wairau Diversion, variable start and constant end stage at mean sea level, Kz=1 m/d
Recharge	Sandy (Taumutu) variable, 310 mm/year average Wetland (Temuka) variable, 310 mm/year average Western (Motukurara) variable, 279 mm/year average

Properties

The model has been calibrated to be consistent with observed aquifer properties. Pumping tests have shown hydraulic conductivity to be 50 to 125 m/d. Specific yield is expected to be between 0.05 and 0.28.

Conductivity	Three zones where Kx=Ky=Kz 1-Majority T of model domain: 120 m/d 2-Pipitea and Pukaka areas: 100 m/d 3-Offshore: 20 m/d
Storage	Sandy Coastal: Sy=0.16, Eff. porosity=0.2, Total porosity=0.2 Central (Neal Rd to Pipitea): Sy=0.15, Eff. porosity=0.2, Total porosity=0.2 Peaty areas: Sy=0.13, Eff. porosity=0.2, Total porosity=0.2

Demand

Demand is simulated in two ways. Pumping wells are used to simulate large, discrete abstractions. More dispersed (residential) abstractions are simulated by the evapotranspiration package.

Pumping Wells

Golf Club Pond	Three seasonal rates, winter =0 m^3/d, summer= 500 m^3/d, shoulder season =250 m^3/d
P28w/0001	North Rarangi water supply, const. 60 m^3/d
P28w/4246 & 4249	Wither Hills Vineyard. Variable pumping rate, based on water meter records. Up to 572 m^3/d per well

Evapotranspiration

Rarangi Beach	Constant 90 mm/yr
Beach margins	Constant 45 mm/yr
Clerveaux	Constant 35 mm/yr
Miscellaneous	Includes Clerveaux margins, Blenheim lifestyles and Edgewater Estate. Constant 15 mm/yr