Appendix B – Preliminary Recharge Analysis

In order to provide a first approximation of groundwater recharge as a proportion of rainfall for the Aupouri aquifer region, a one-dimensional empirical analysis of groundwater movement versus rainfall was conducted for the bores monitored by NRC.

A smoothing technique was applied to daily rainfall data in order to remove the high frequency nature, and as such provide a more representative trace when matched to observed groundwater oscillations. This permits comparison of rainfall mass to changes in groundwater storage.

Daily rainfall was converted to monthly totals, and then two-month and three-month moving sums were computed. The moving sum calculated is for the respective period prior to the particular date under scrutiny. In this way, groundwater recovery can be attributed to the rainfall over the previous period.

In general, the bores show a delayed response to rainfall ranging from a few months to more than six months, depending on the depth to water table (extent of vadose zone) and aquifer hydraulic properties. The rainfall sum for the period leading up to a particular recharge event was calculated on a case-by-case basis, resulting in varying time lengths. In most cases the three-month moving sum rainfall value was used.

Figures B1 to B4 show bore hydrographs with two-month moving sum and three-month moving sum rainfalls. A plot of residual mass rainfall versus SOI index is also provided to aid in identifying the extremes in rainfall that can lead to phases of drought and groundwater recovery.

The bore hydrograph plots indicate numbered rainfall events delineated by dashed lines. Discrete analysis has been provided for each event by solving for groundwater recharge from the following equation:

$$\Delta WL = R \times Sy$$
$$\therefore R = \Delta WL \times Sy$$

where:

ΔWL = change in groundwater level (m),
R = groundwater recharge (m), and
Sy = specific yield (-) of the sands.

Various specific yield values have been applied at each location depending on the lithology indicated in borelogs and in reference to published values (Kruseman and de Ridder, 1994). Table B1 provides a comprehensive summary of this analysis, which indicates a high range in recharge coefficients ranging from 1.3% to 44.5%.

Because the analysis focuses on groundwater recoveries (i.e., following wet periods), the results will be biased towards the upper limits to the range in anticipated recharge coefficients. Some significant rainfall events do not even generate a recovery in groundwater levels, such as shown from 1990 to 1995 for Bore 207. These suggest that rainfall during this period was not sufficient or frequent enough to satisfy surface requirements such as soil moisture deficits and plant ET demands, or that aquifer discharge exceeds recharge. In this area surface requirements are likely to be much greater, as this bore is located in the middle of the Aupouri Forest (*Pinus radiata* plantation).

Table B1. Summary of groundwater recharge analysis.

Bore	Obs. No.	Sy (-)	ΔWL (m)	R (m)	Obs. Rain (m)	R (%)	Rmin (%)	Rmax (%)	Rmed (%)	Comments
81	1	0.20	0.96	0.19	2.69	7.2				Shows an attenuated response to
		0.25	0.96	0.24	2.69	9.0				rainfall consistent with lower
81	2	0.20	0.03	0.01	0.49	1.3				permeability materials.
		0.25	0.03	0.01	0.49	1.7				Also, located on edge of forest so
81	3	0.20	0.08	0.02	0.44	3.6				high ET impact from trees.
		0.25	0.08	0.02	0.44	4.5				Borelog indicates presence of iron
81	4	0.20	0.19	0.04	0.69	5.5				pans, clay and peat zones within
		0.25	0.19	0.05	0.69	6.9				20 m of the surface.
81	5	0.20	0.31	0.06	0.74	8.4				Approx. 22 m unsaturated zone.
		0.25	0.31	0.08	0.74	10.5				
81	6	0.20	0.57	0.11	0.78	14.6				
		0.25	0.57	0.14	0.78	18.2	1.3	18.2	7.0	
206	1	0.25	0.58	0.15	0.67	21.6				Shows a delayed groundwater
		0.30	0.58	0.17	1.67	10.4				response to rainfall of about
206	2	0.25	0.14	0.04	0.69	5.1				4 months.
		0.30	0.14	0.04	0.69	6.1				Borelog indicates very fine sands
206	3	0.25	0.30	0.08	0.56	13.4				from surface to about 16 mBGL.
		0.30	0.30	0.09	0.56	16.1				3 m of clay from 16 to 19 mBGL.
206	4	0.25	0.90	0.23	0.78	28.8				Approx. 12 m unsaturated zone.
		0.30	0.90	0.27	0.78	34.6	5.1	34.6	14.7	
207	1	0.25	0.10	0.03	0.67	3.7				Middle of forest.
		0.30	0.10	0.03	0.67	4.5				Shows recharge attenuation and
207	2	0.25	0.33	0.08	0.74	11.0				longer delays due to extent of vadose.
		0.30	0.33	0.10	0.74	13.3	3.7	13.3	7.8	Approx. 20 m unsaturated zone.
208	1	0.25	0.62	0.16	0.48	32.6				
		0.30	0.62	0.19	0.48	39.2				Eastern edge of forest.
208	2	0.25	0.95	0.24	0.67	35.5				Less impact from trees.
		0.30	0.95	0.29	0.67	42.6				Borelog indicates peat but no silt or
208	3	0.25	0.30	0.08	0.69	10.9				clay layers.
		0.30	0.30	0.09	0.69	13.0				Approx. 9 m unsaturated zone.
208	4	0.25	0.17	0.04	0.54	7.9				
		0.30	0.17	0.05	0.54	9.5				
208	5	0.25	0.49	0.12	0.74	16.6				
		0.30	0.49	0.15	0.74	19.9				
208	6	0.25	0.30	0.08	0.47	16.0				
		0.30	0.30	0.09	0.47	19.2				
208	7	0.25	0.69	0.17	0.78	22.1				
		0.30	0.69	0.21	0.78	26.5	7.9	42.6	19.5	
209	1	0.20	1.35	0.27	1.57	17.2				Higher proportion of peat and silts
		0.25	1.35	0.34	1.57	21.5				in lithological log than more
209	2	0.20	1.19	0.24	0.67	35.6				western piezos in forest transect.

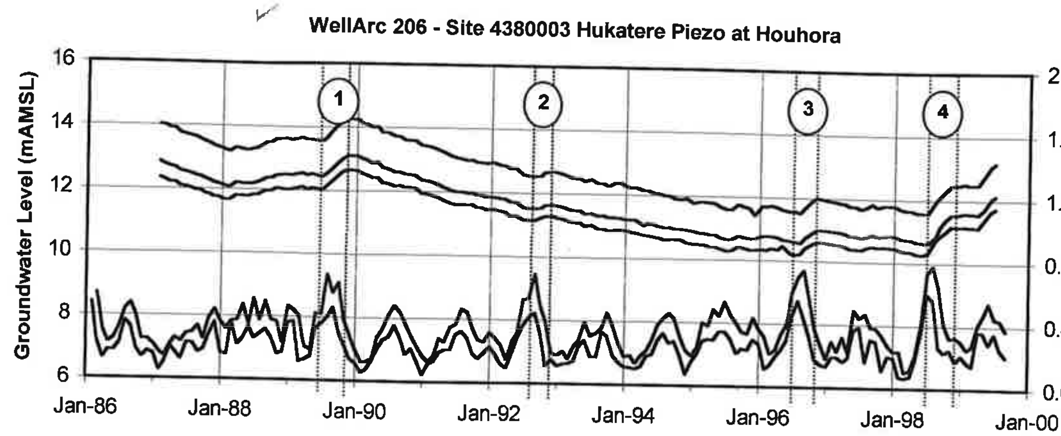
		0.25	1.19	0.30	0.67	44.5				However, rapid response to rainfall,
209	3	0.20	0.35	0.07	0.49	14.2				therefore high permeability
		0.25	0.35	0.09	0.49	17.7				(silt lenses probably only localised).
209	4	0.20	0.62	0.12	0.44	28.0				Possibly lower Sy overall than
		0.25	0.62	0.16	0.44	35.0				western piezos.
209	5	0.20	0.72	0.14	0.69	20.8				Peat Sy = 0.45
		0.25	0.72	0.18	0.69	26.0				Silt Sy = 0.10
209	6	0.20	0.14	0.03	0.46	6.2				
		0.25	0.14	0.04	0.46	7.7				Approx. 8 m unsaturated zone.
209	7	0.20	0.22	0.04	0.42	10.5				
		0.25	0.22	0.06	0.42	13.1				
209	8	0.20	0.75	0.15	0.54	28.0				
		0.25	0.75	0.19	0.54	35.0				
209	9	0.20	0.90	0.18	0.74	24.3				
		0.25	0.90	0.23	0.74	30.4				
209	10	0.20	0.40	0.08	0.45	18.0				
		0.25	0.40	0.10	0.45	22.5				
209	11	0.20	1.18	0.24	0.78	30.2				
		0.25	1.18	0.30	0.78	37.8				
209	12	0.20	0.74	0.15	0.55	27.1				
		0.25	0.74	0.19	0.55	33.9	6.2	44.5	25.2	
211	1	0.15	0.73	0.11	1.21	9.0				Shows an oscillatory response but
		0.20	0.73	0.15	1.21	12.0				low magnitude to the changes,
211	2	0.15	0.42	0.06	0.67	9.4				indicative of lower specific yield
		0.20	0.42	0.08	0.67	12.5				characteristics.
211	3	0.15	0.19	0.03	0.49	5.8				
		0.20	0.19	0.04	0.49	7.7				Borelog indicates 4 m of peaty silt
211	4	0.15	0.39	0.06	0.44	13.2				at surface.
		0.20	0.39	0.08	0.44	17.6				
211	5	0.15	0.60	0.09	0.69	13.0				Only slight delay in aquifer response
		0.20	0.60	0.12	0.69	17.4				to rainfall, suggesting well coupled
211	6	0.15	0.14	0.02	0.46	4.6				to surface.
		0.20	0.14	0.03	0.46	6.2				
211	7	0.15	0.27	0.04	0.42	9.7				Unsaturated zone only 2.7 m.
		0.20	0.27	0.05	0.42	12.9				
211	8	0.15	0.35	0.05	0.54	9.8				
		0.20	0.35	0.07	0.54	13.1				
211	9	0.15	0.52	0.08	0.74	10.5				
		0.20	0.52	0.10	0.74	14.1				
211	10	0.15	0.18	0.03	0.45	6.1				
		0.20	0.18	0.04	0.45	8.1				
211	11	0.15	0.75	0.11	0.78	14.4				
		0.20	0.75	0.15	0.78	19.2				
211	12	0.15	0.39	0.06	0.55	10.7				
		0.20	0.39	0.08	0.55	14.3	4.6	19.2	11.4	
226	1	0.25	1.50	0.38	2.99	12.5				Shows a very delayed and attenuated

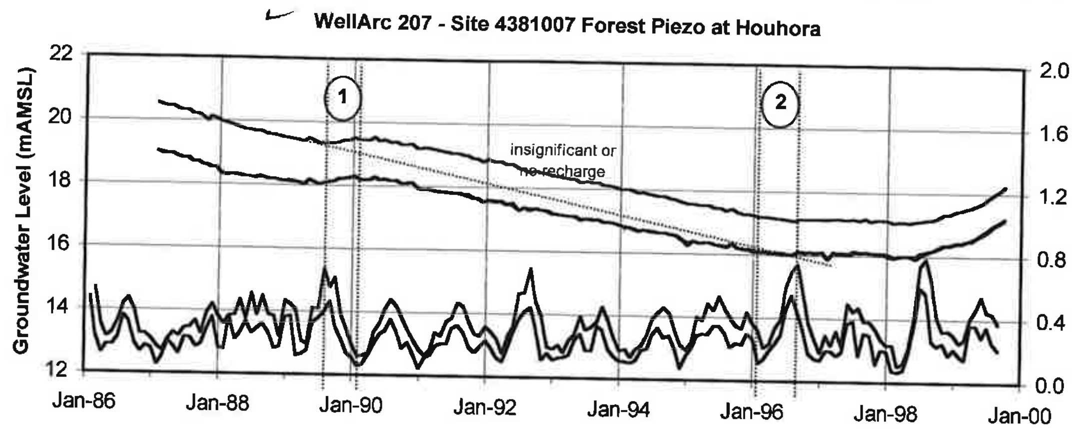
		0.30	1.50	0.45	2.99	15.0				response. Borelogs indicate presence
226	2	0.25	0.05	0.01	0.69	1.8				of major peat band 7 m thick from
		0.30	0.05	0.02	0.69	2.2				12 to 17 mBGL.
226	3	0.25	1.35	0.34	5.23	6.4				
		0.30	1.35	0.41	5.23	7.7	1.8	15.0	7.1	
227	1	0.25	2.34	0.59	2.99	19.6				see bore 226
		0.30	2.34	0.70	2.99	23.5				
227	2	0.25	0.26	0.07	0.69	9.4				
		0.30	0.26	0.08	0.69	11.3				
227	3	0.25	0.52	0.13	2.51	5.2				
		0.30	0.52	0.16	2.51	6.2				
227	4	0.25	0.58	0.15	0.78	18.6				
		0.30	0.58	0.17	0.78	22.3	5.2	22.3	10.3	

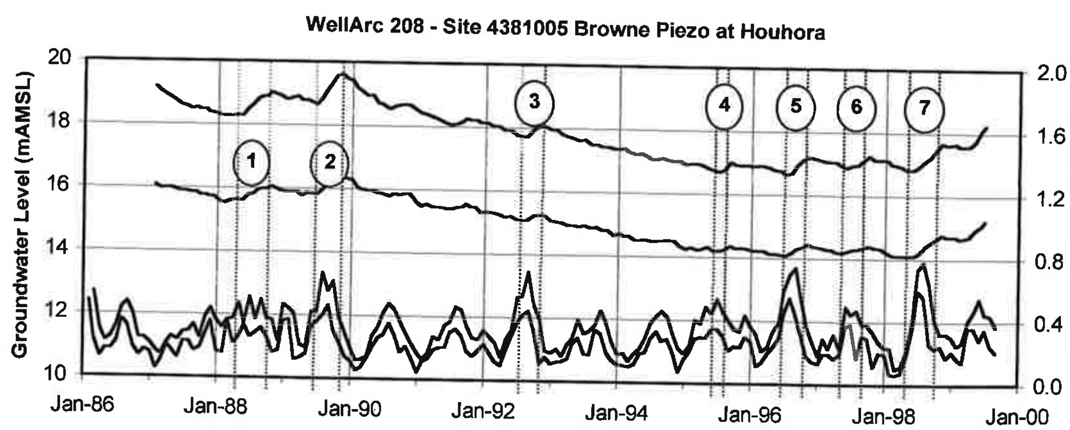
Groundwater level observations for Bore 207 (middle of forest) during 1990 to 1995 show a very consistent gradual depressurisation equating to an average of 1.12 mm/day. The climate during this period is dominated by a moderate El Niño phase of the SOI, indicating drier than normal conditions as shown on Figure 4b of the main report. This trend indicates that groundwater recharge is not significant enough to generate an increase in groundwater pressure, resulting in an acceleration of the afforestation-induced depressurisation. Conformation of this hypothesis is provided by comparing the drawdowns for a bore with similar lithological profile and piezometer completion but with differing surface vegetation types. Bore 081 (Ogle Drive), which is on the edge of the forest, had a drawdown of 0.76 m between 1990 and 1995, while Bore 207 had 2.29 m. This indicates approximately 300% greater depressurisation at Bore 207 as a result of the ET influence from the forest canopy.

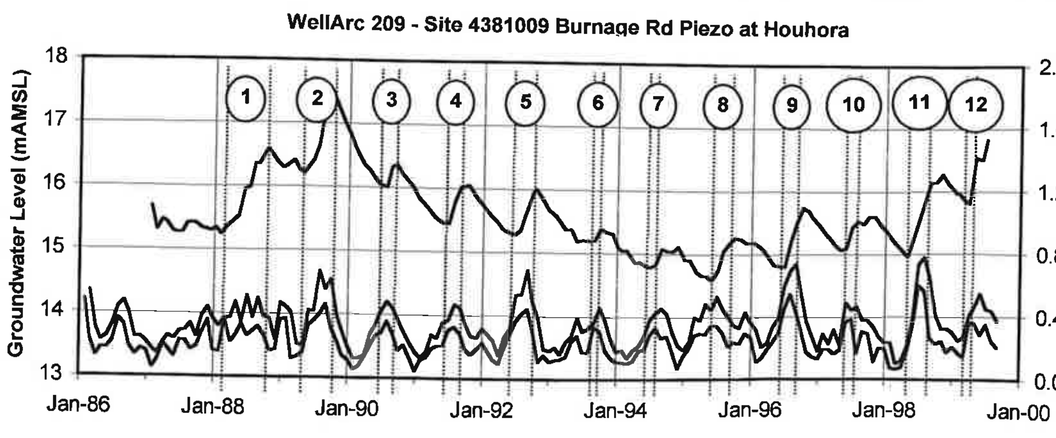
To understand the groundwater response to afforestation, the problem is simplified by considering an unconfined sand aquifer without tree cover that is subject to constant average rainfall conditions. The prevailing static groundwater table will reflect the given environmental variables. If the environmental variables are changed by the addition of trees, then the water table will naturally adjust to reflect these new conditions. In this case a groundwater depressurisation due to the increased interception and ET demand at the surface (i.e., reduction in the groundwater recharge rate) would occur. The full effects of afforestation will not occur instantaneously, taking some time for the groundwater table to re-equilibrate to the new imposed conditions (possibly years).

In reality, rainfall is variable thus lower than average rainfall will accelerate the depressurisation, as is shown during 1990 to 1995, while higher than average rainfall may temporarily stabilise or reverse the depressurisation.

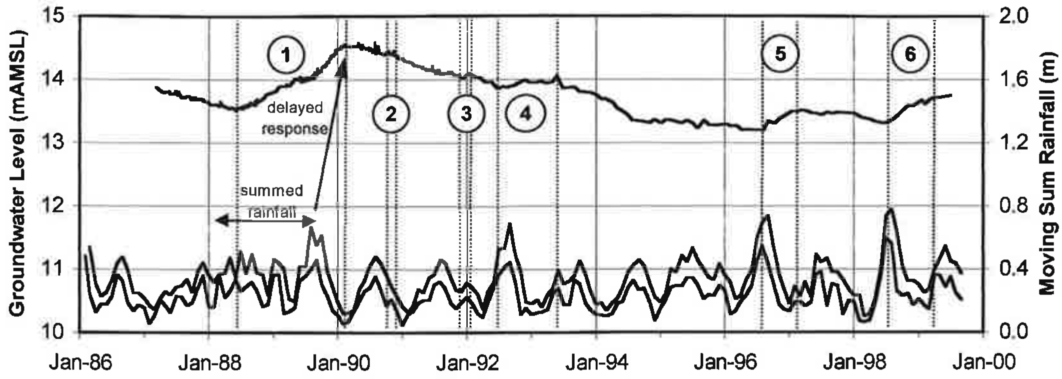

WellArc 206 - Site 4380003 Hukatere Piezo at Houhora
Groundwater Level (mAMSL)
Moving Sum Rainfall (m)
1
2
3
4


WellArc 207 - Site 4381007 Forest Piezo at Houhora
Groundwater Level (mAMSL)
Moving Sum Rainfall (m)
insignificant or no recharge
1
2

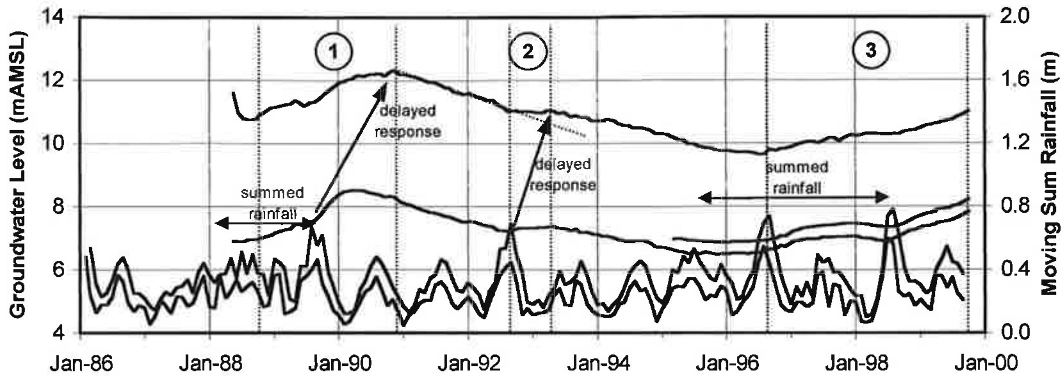

WellArc 208 - Site 4381005 Browne Piezo at Houhora
Groundwater Level (mAMSL)
Moving Sum Rainfall (m)
1
2
3
4
5
6
7


WellArc 209 - Site 4381009 Burnage Rd Piezo at Houhora
Groundwater Level (mAMSL)
Moving Sum Rainfall (m)
1
2
3
4
5
6
7
8
9
10
11
12

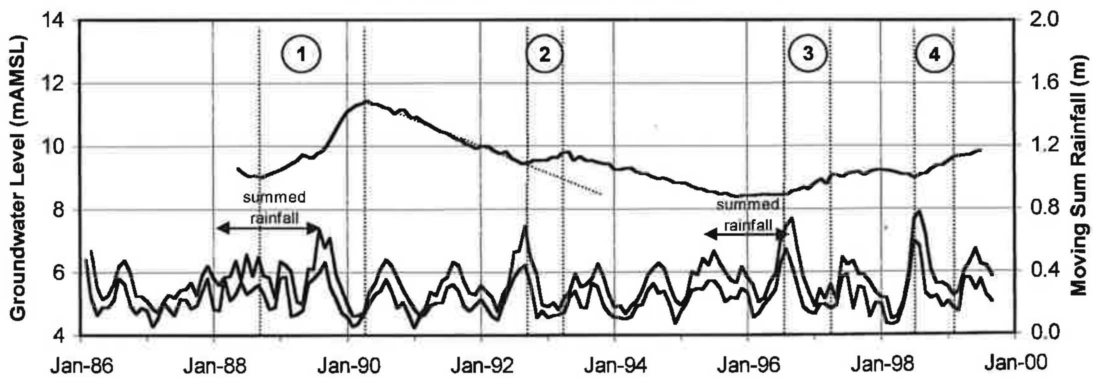
WellArc 081 - Site 5301001 Ogle Drive at Paparore



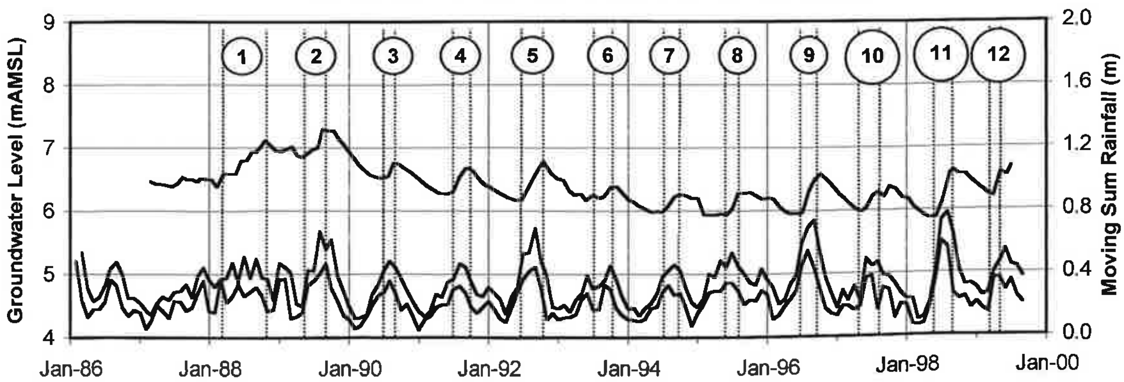
WellArc 226 - Site 5301003 Lake Heather No.1



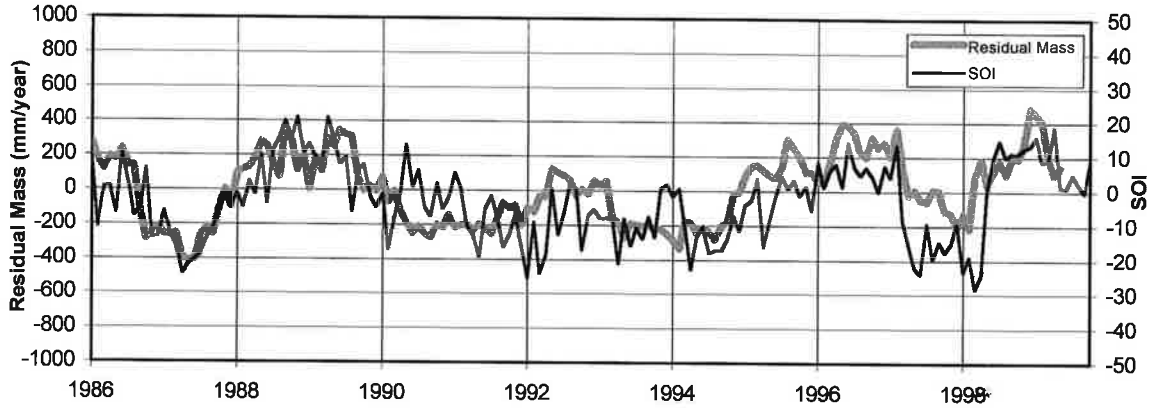
WellArc 227 - Site 5301005 Lake Heather No.2



WellArc 211 - Site 4392001 Paparore Rd Piezo at Paparore



Note: The two and three month moving sums are calculated for the respective months preceeding a given date.



Residual Mass (mm/year)
SOI
Residual Mass
SOI
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
50
40
30
20
10
0
-10
-20
-30
-40
-50
1986
1988
1990
1992
1994
1996
1998