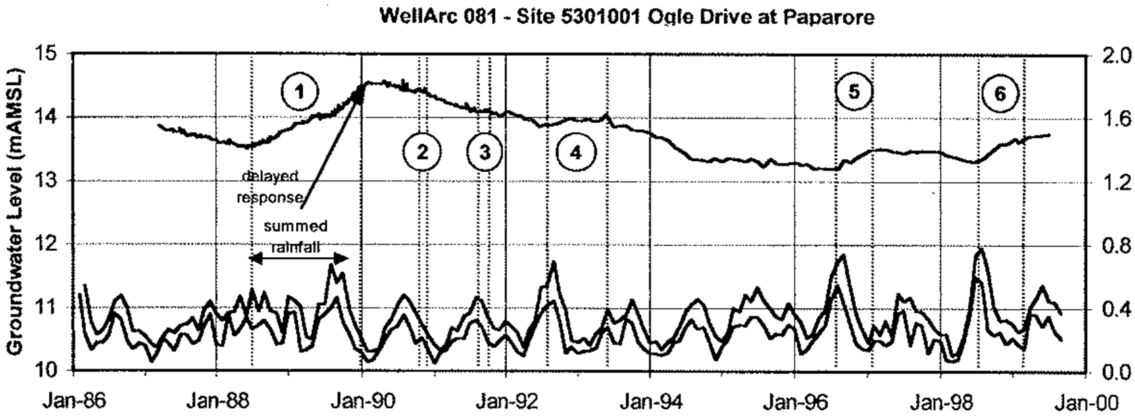
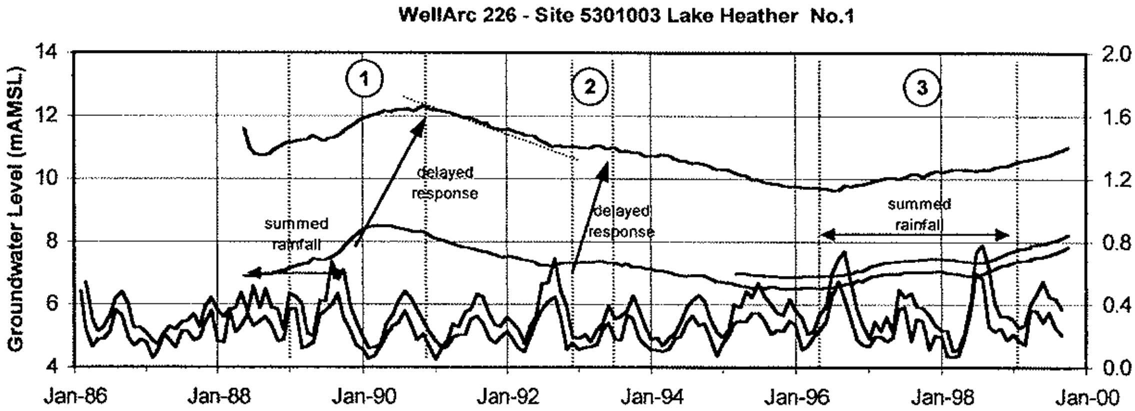




Note: The two and three month moving sums are calculated for the respective months preceeding a given date.

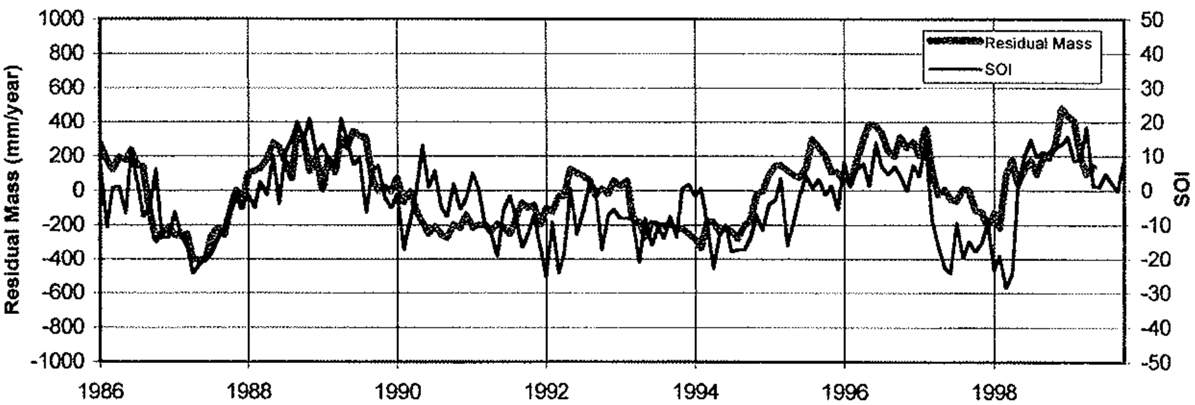


Figure B3

Appendix D – Soil Moisture Water Balance Model

The soil moisture water balance model (SMWBM) is employed as a preconditioner for assigning groundwater recharge to the MODFLOW model. The pre-conditioning of rainfall recharge through use of the soil moisture accounting model ensures that antecedent soil moisture conditions are considered in a realistic manner.

The model is a deterministic lumped parameter scheme, with algorithms adapted from those developed by Pitman (1976). The model utilises daily rainfall and mean monthly pan evaporation data to calculate soil moisture conditions and estimate percolation to the aquifer.

The model incorporates parameters that characterise the catchment in terms of interception storage, soil moisture storage capacity, soil moisture infiltration, percolation to groundwater, ands various other parameters. While no specific field measurements are available for characterisation of the aquifer material on the Aupouri Peninsula, some parameters have been obtained through reference to published research. Other parameters have been estimated on the basis of experienced judgement in the initial instance and ballpark estimates of wall balance components given in the NRC (1991) report. These were then refined in the process of calibrating overall catchment runoff/percolation against expected runoff (or lack thereof) and aquifer recharge.

The fundamental operation of the model is as follows:

- Daily rainfall is disaggregated into hourly intervals when a rainday occurs[1] 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 is assigned to a nominal soil moisture storage zone (ST). This zone is subject to evapotranspiration via root uptake (R) according to the mean monthly pan evaporation rate prorated on the current soil moisture status (i.e., soil evaporation (and transpiration) decrease as the soil dries out). The soil moisture zone also provides a source of water for deeper percolation (FT, POW) to the underlying aquifer. If rainfall is of sufficient intensity and duration to fill the soil moisture storage, then surface runoff also occurs.

- The amount of surface runoff is determined after accounting for interception and soil moisture storage. Runoff is controlled by three main factors comprising; the prevailing soil moisture deficit, the nominal soil moisture infiltration capacity (ZMIN & ZMAX), and the proportion of impervious portions of the catchment directly linked to drainage pathways (AI).

[1] For days where no rain occurred in the historical record, a one-day time step is implemented.

- Finally, the model produces daily summarises of the various components of the catchment water balance including surface runoff, percolation to groundwater (groundwater recharge) and total catchment discharge. The groundwater percolation component is employed as the preconditioned recharge in the MODFLOW model.

Model Parameters

Parameters used in the SMWBM of most significance comprise the following, and a summary of values used in each zone is given in Table D1:

ST: Maximum soil moisture capacity

The parameter ST is of major importance in that it is the most significant factor determining 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 by the catchment during wet periods, and during dry period results in more sustained baseflow contributions. Higher values of ST values are also subject to evaporation over a larger volume of soil.

The depth of the ST zone basically prescribes an active zone within which root uptake through plants can occur. The sand dunes are assigned a ST depth of 1000 mm, which relates to a field depth of 4 m assuming an effective porosity of 25%.

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 in all layers.

ZMIN & ZMAX: Minimum and maximum soil infiltration rate

ZMIN and ZMAX are nominal minimum and maximum infiltration rates in mm/hr. ZMIN ultimately determines the depth of rainfall required in any period to initiate surface runoff and thus has a strong influence on the amount of rainfall entering the soil profile.

ZMAX is the nominal maximum capacity of the soil to infiltrate rainfall and together with ZMIN, regulates the volume of water entering soil moisture storage and the resulting surface runoff.

FT: Percolation rate from soil moisture storage at full capacity

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

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 two 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) and is assigned zero for the Aupouri aquifer catchments.

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 curvilinear 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 exponentially according to the predefined function.

Table D1. Summary of major parameter settings for each zone.

Zone	Description	ST (mm)	FT (mm/day)	ZMN (mm/hr)	ZMX (mm/hr)	PI (mm)
1	Dune Zone	350	0.8	5	30	5
2	Forested Dune Zone	1000	1.0	5	30	2
3	Plains Zone	200	0.4	0	8	2

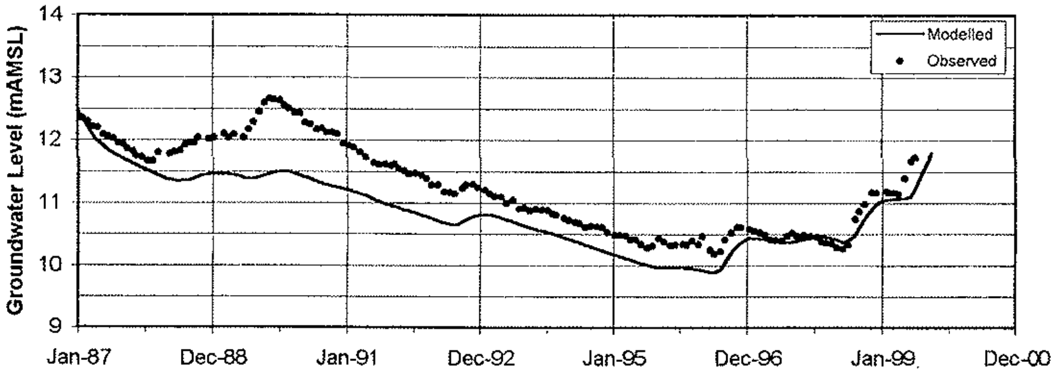
Table D2 summarises the characteristics and resulting water balances for each zone identified in the Aupouri aquifer region.

Table D2. Long-term average water balance summary for recharge zones.

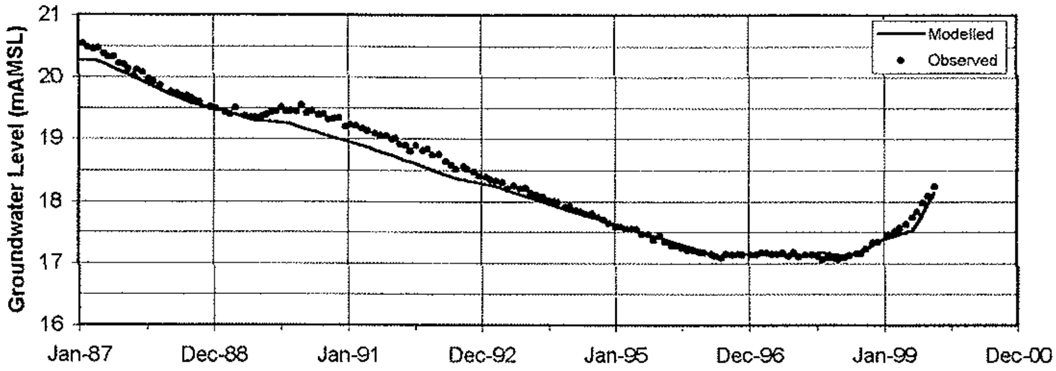
Zone	Description	Recharge	Evap.	Runoff	Characteristics
1	Dune Zone	18.1%	81.7%	0.2%	High infiltration capacity, medium soil moisture storage capacity, smaller active root zone, moderate evapotranspiration, low surface runoff.
2	Forested Dune Zone	10.4%	89.5%	0.1%	High infiltration capacity, high soil moisture storage capacity, large active root zone, high evapotranspiration, low surface runoff.
3	Plains Zone	12.0%	64.2%	23.8%	Reduced infiltration capacity, medium soil moisture storage capacity, smaller active root zone, lower evapotranspiration, greater surface runoff (interflow drainage).

Notes:
Values indicate the long-term average as a percentage of rainfall from the 1874 to 1999 record.
Evap. refers to total evaporation losses including interception, evaporation and transpiration.

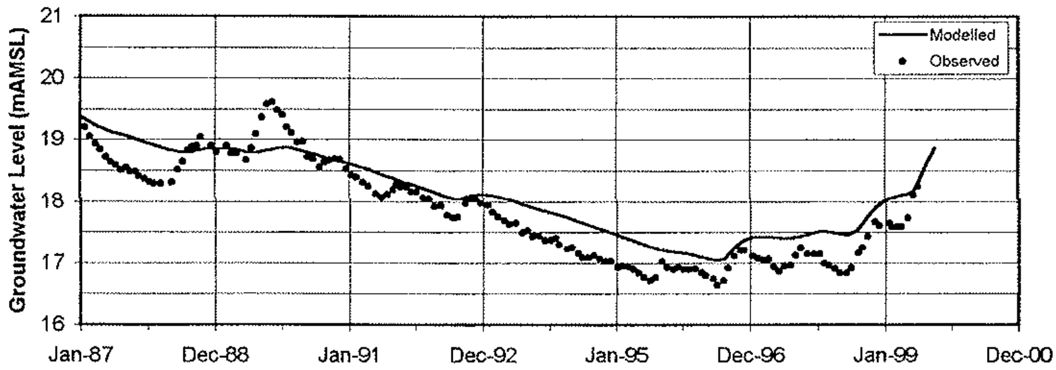
WellArc 206 - Site 4380003 Hukatere Piezo at Houhora



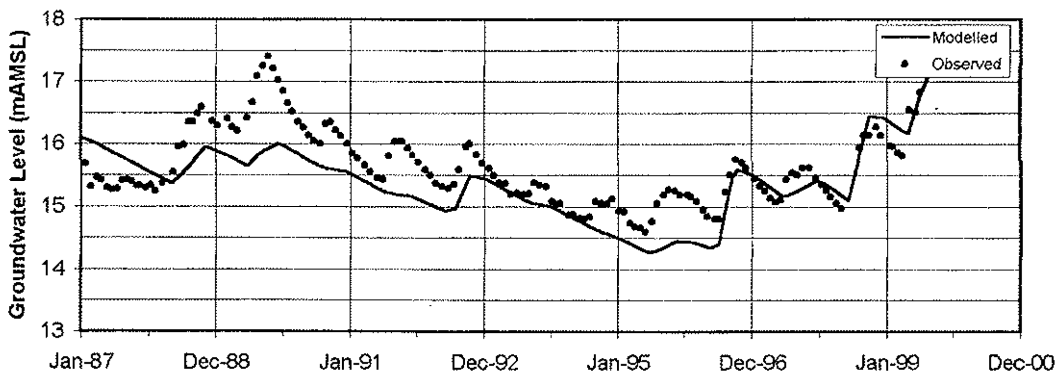
WellArc 207 - Site 4381007 Forest Piezo at Houhora

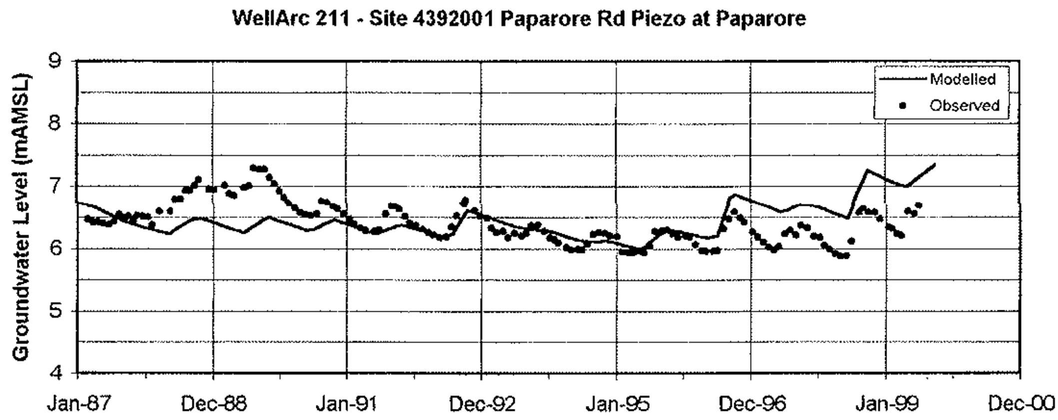


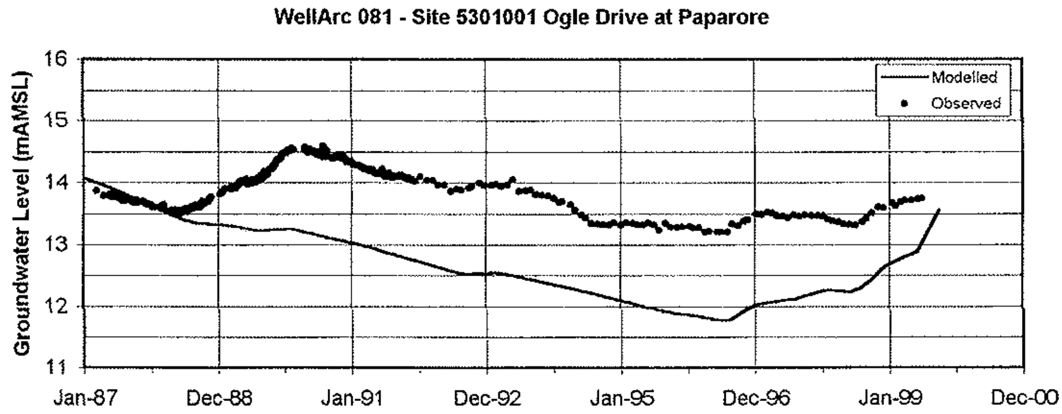
WellArc 208 - Site 4381005 Browne Piezo at Houhora

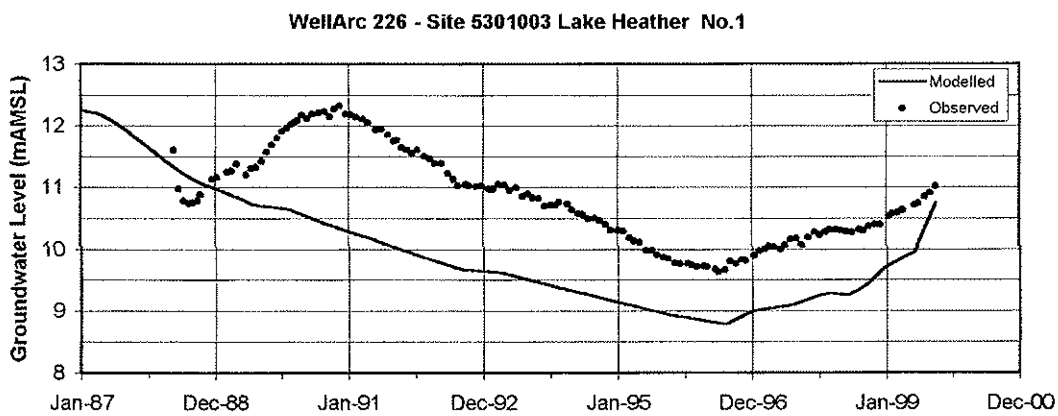


WellArc 209 - Site 4381009 Burnage Rd Piezo at Houhora

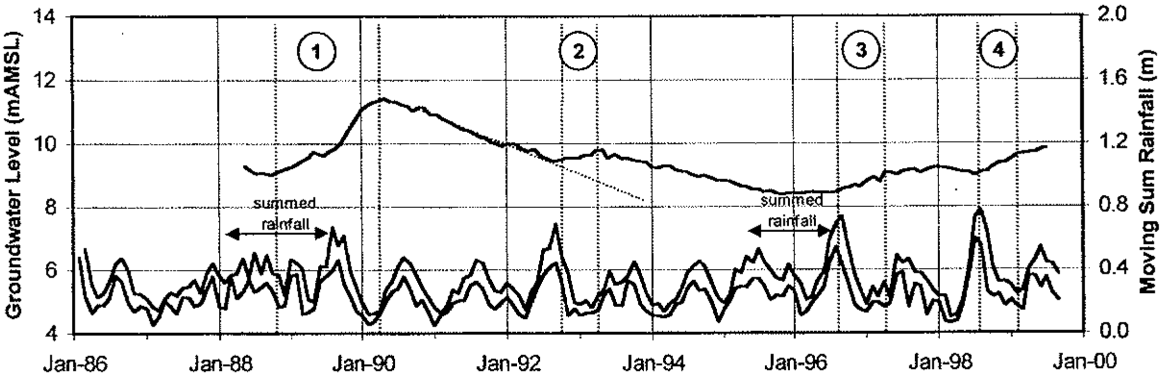



WellArc 211 - Site 4392001 Paparore Rd Piezo at Paparore
Groundwater Level (mAMSL)
9
8
7
6
5
4
Jan-87
Dec-88
Jan-91
Dec-92
Jan-95
Dec-96
Jan-99
Dec-00
Modelled
Observed

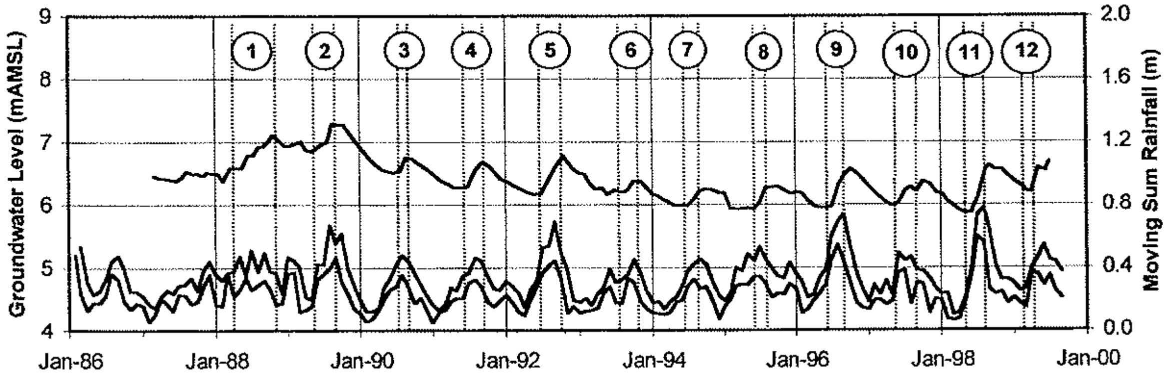

WellArc 081 - Site 5301001 Ogle Drive at Paparore
Groundwater Level (mAMSL)
16
15
14
13
12
11
Jan-87
Dec-88
Jan-91
Dec-92
Jan-95
Dec-96
Jan-99
Dec-00
Modelled
Observed


WellArc 226 - Site 5301003 Lake Heather No.1
Groundwater Level (mAMSL)
13
12
11
10
9
8
Jan-87
Dec-88
Jan-91
Dec-92
Jan-95
Dec-96
Jan-99
Dec-00
Modelled
Observed

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.

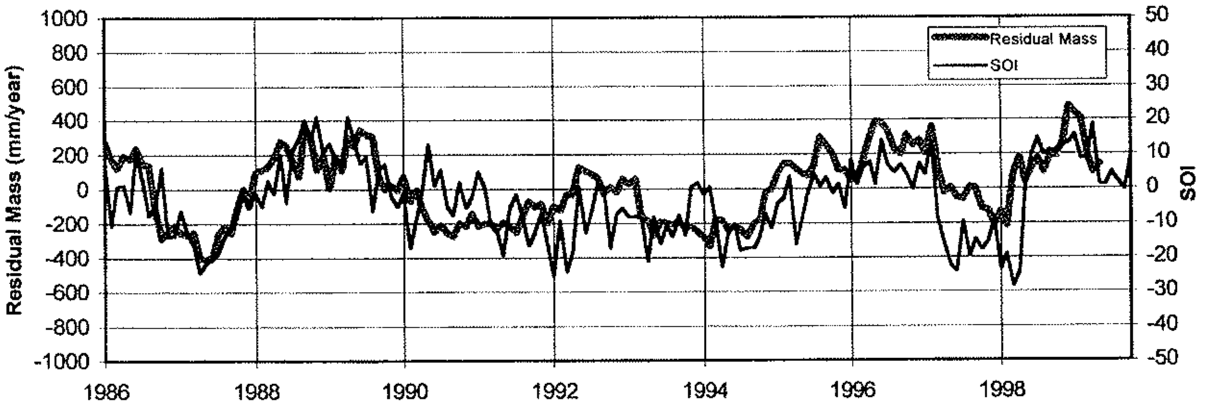
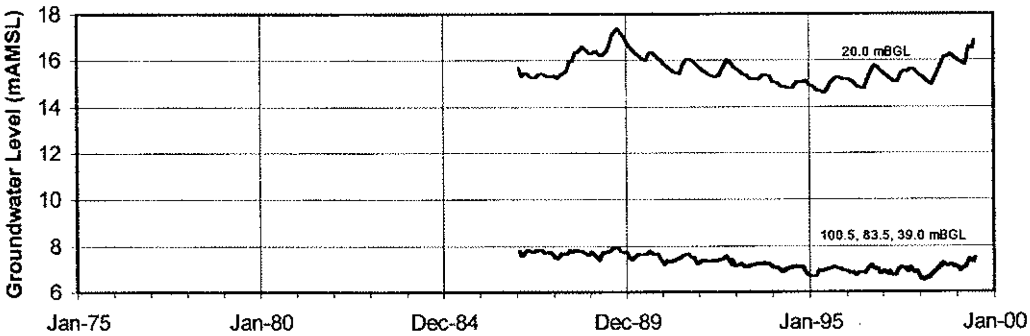
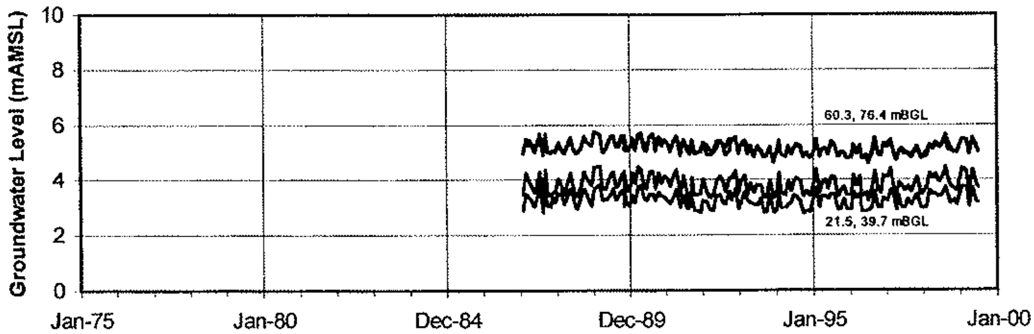


Figure B4

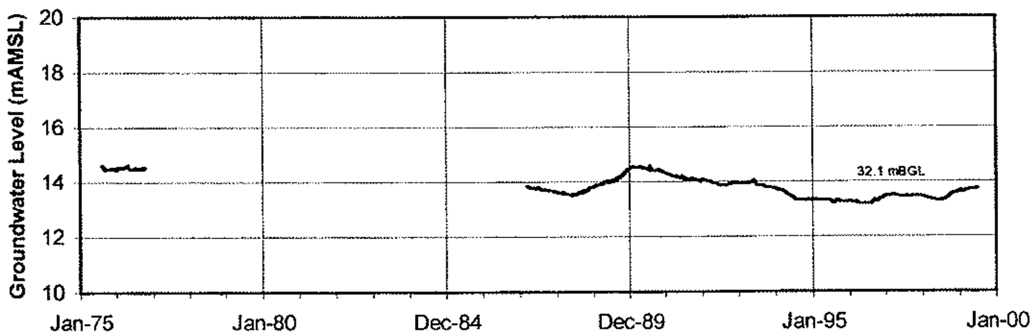
WellArc 209 - Site 4381009 Burnage Rd Piezo at Houhora



WellArc 210 - Site 4381001 Waterfront Piezo at Houhora



WellArc 081 - Site 5301001 Ogle Drive at Paparore



WellArc 211 - Site 4392001 Paparore Rd Piezo at Paparore

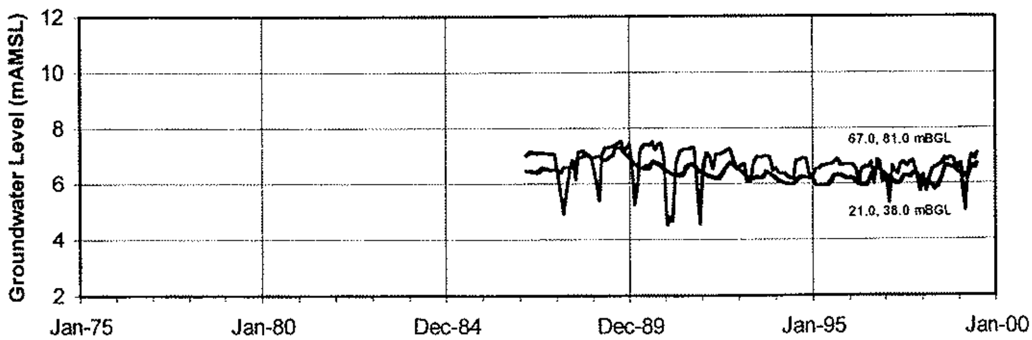
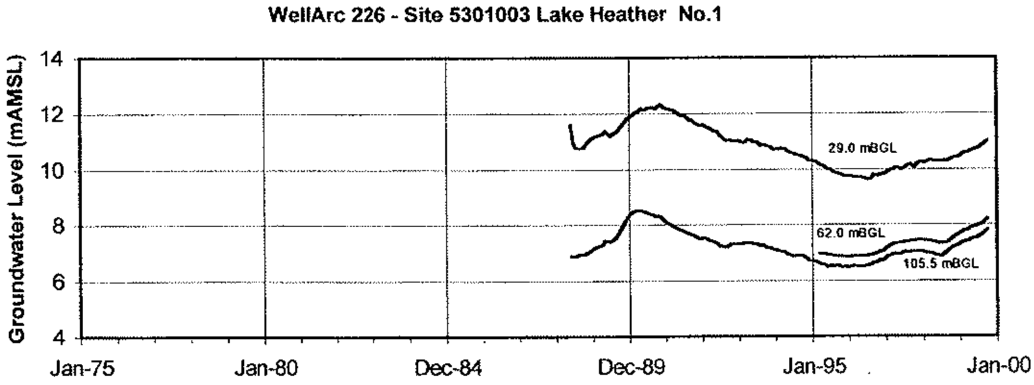
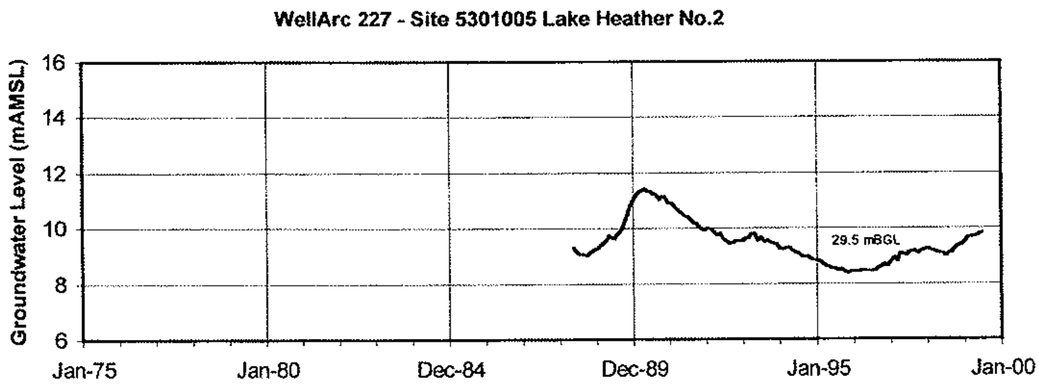
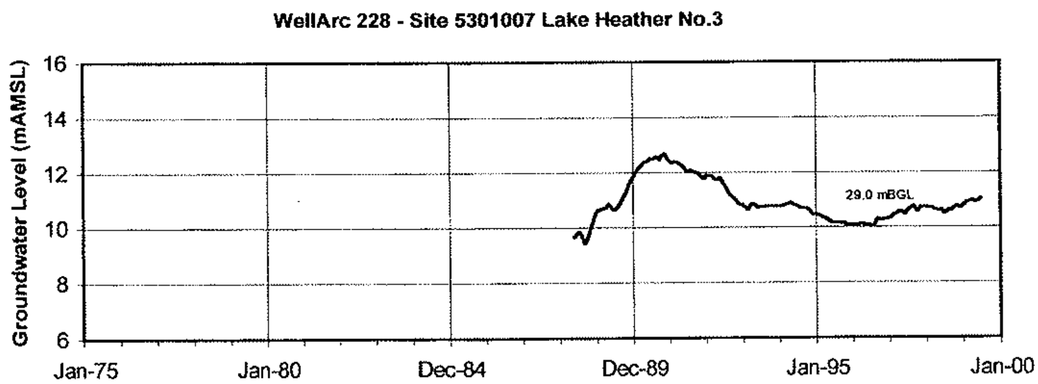


Figure C2


WellArc 226 - Site 5301003 Lake Heather No.1
Groundwater Level (mAMSL)
29.0 mBGL
62.0 mBGL
105.5 mBGL
Jan-75
Jan-80
Dec-84
Dec-89
Jan-95
Jan-00


WellArc 227 - Site 5301005 Lake Heather No.2
Groundwater Level (mAMSL)
29.5 mBGL
Jan-75
Jan-80
Dec-84
Dec-89
Jan-95
Jan-00


WellArc 228 - Site 5301007 Lake Heather No.3
Groundwater Level (mAMSL)
29.0 mBGL
Jan-75
Jan-80
Dec-84
Dec-89
Jan-95
Jan-00

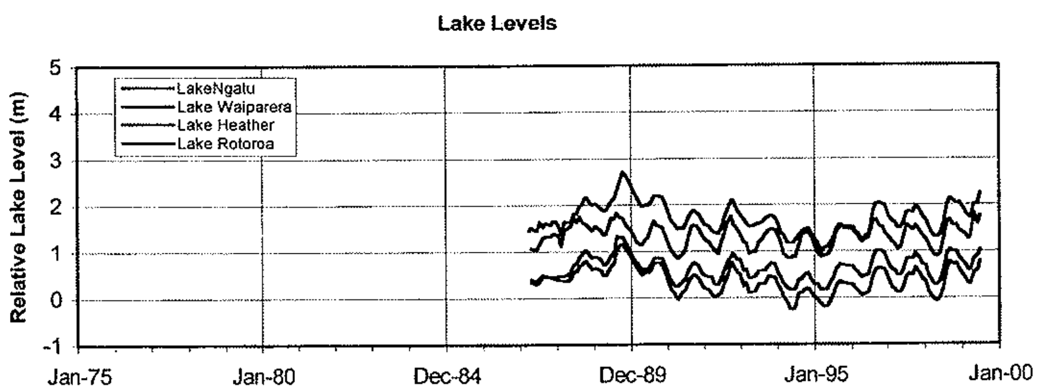

Lake Levels
Relative Lake Level (m)
LakeNgatu
Lake Waiparera
Lake Heather
Lake Rotoroa
Jan-75
Jan-80
Dec-84
Dec-89
Jan-95
Jan-00

Figure C3

Appendix C – Monitoring Bore Hydrographs

Hydrographs for NRC monitoring bores are shown in Figures C1 to C3. A summary of the hydrographic response for each bore and the implications from these is provided below.

Hukatere to Houhora Transect Bores

Bores 206 and 48 – Hukatere Piezos and Bore at Houhora

The response of these two bores is identical for the piezo at 20 mBGL. Groundwater pressures decrease with depth, although piezos show similar response at all depths. This indicates that the area is a groundwater recharge area. The difference in groundwater pressure between the top two piezos and the bottom two indicates that the sediments are more homogenous at great depths. The electrical resistivity trace from the borelog is oscillatory but overall shows a trend of decreasing resistively with depth. This indicates compaction of sediments with depth and the greater presence of lower permeability materials such as bands of silty fine sand, silt and clay.

The hydrographic responsiveness compared to bore 207 (middle of forest) indicates the influence of greater more frequent recharge.

Bore 207 – Forest Piezo at Hukatere

Groundwater pressures reduce with depth indicating a downward pressure gradient (i.e., recharge area). The two deeper piezos at 82.1 and 67.5 mBGL show equivalent groundwater pressures indicating homogenous aquifer conditions at these depths.

The electrical resistivity test indicates a general increase in resistivity with depth, and a marked increase at approximately 52 mBGL, which occurs just after a clayey zone. This indicates that the sands become cleaner with depth and thus vertical anisotropy is anticipated to be significant in only the upper parts of the aquifer.

The hydrographic response is very mitigated at all depths in comparison to the other bores, indicating the effects of afforestation (i.e., reduced recharge). Comparison of the upper and lower piezo hydrographs indicates that the upper aquifer is depressurising slightly faster than the lower.

Bore 208 - Browne Piezo at Houhora

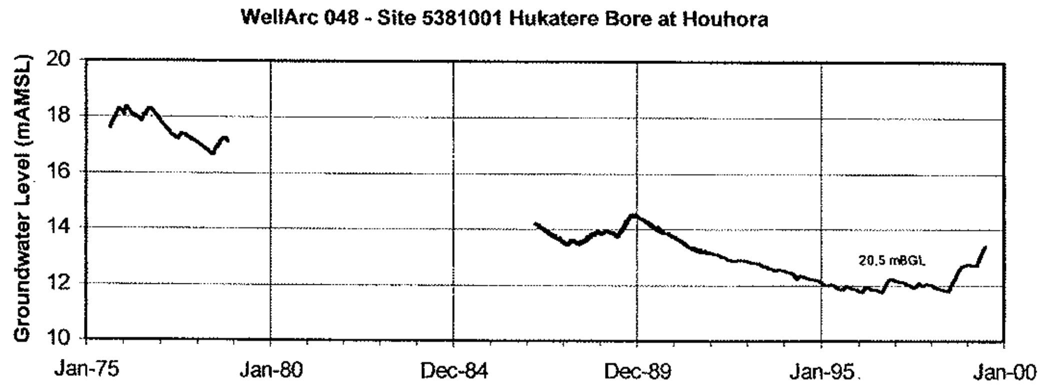
Groundwater pressures decrease with depth in each piezo. There is no distinct confining layer indicated in the borelogs, therefore it is assumed that inherent in the aquifer is some degree of vertical anisotropy (i.e., horizontal permeability is greater than vertical). This is typical in fluvial and aeolian sediments where horizontal or sub-horizontal bedding features are common.

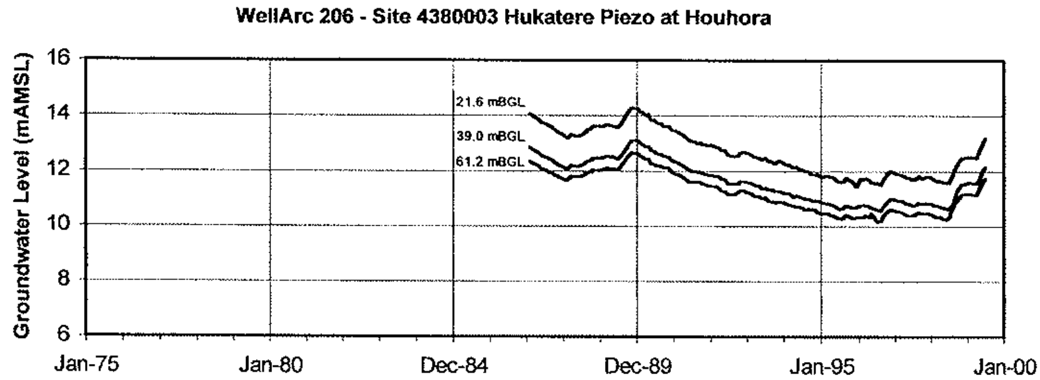
to some extent, but the depth to groundwater and low permeability layers would attenuate this.

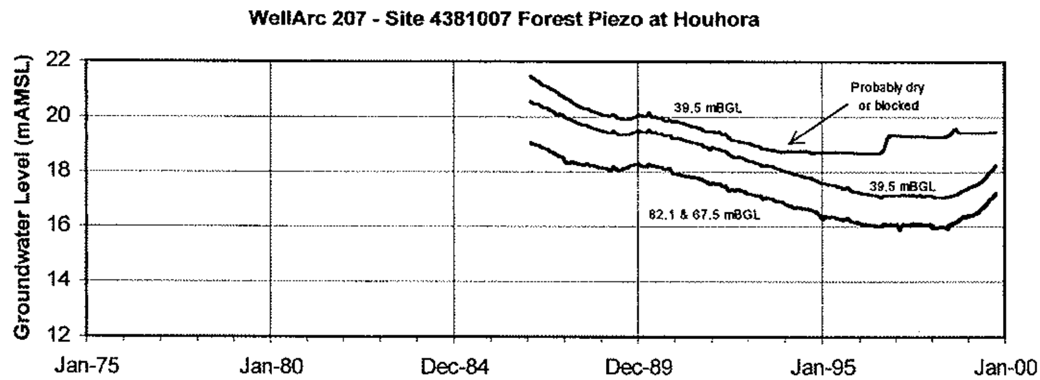
Bores 226, 227, 228 – Lake Heather Piezos

Hydrographs shows a very attenuated response, probably due to the peat layer approximately 7 m thick from 12-19 mBGL. Fine sands prevail throughout the deeper aquifer. Aquifer pressures decrease downwards indicating recharge is occurring.

Lake Heather may also act as a slow release leaky reservoir. The lake is perched above the underlying sands probably by a basal confining layer of fine silts, clay and iron pans. The lake system may be likened to a dish that leaks slowly through its base and during extreme wet periods the dish may overflow it rim. Lake water would then percolate downward through the higher permeability materials surrounding the lake.


WellArc 048 - Site 5381001 Hukatere Bore at Houhora
Groundwater Level (mAMSL)
20.5 mBGL
Jan-75
Jan-80
Dec-84
Dec-89
Jan-95
Jan-00


WellArc 206 - Site 4380003 Hukatere Piezo at Houhora
Groundwater Level (mAMSL)
21.6 mBGL
39.0 mBGL
61.2 mBGL
Jan-75
Jan-80
Dec-84
Dec-89
Jan-95
Jan-00


WellArc 207 - Site 4381007 Forest Piezo at Houhora
Groundwater Level (mAMSL)
Probably dry or blocked
39.5 mBGL
39.5 mBGL
82.1 & 67.5 mBGL
Jan-75
Jan-80
Dec-84
Dec-89
Jan-95
Jan-00

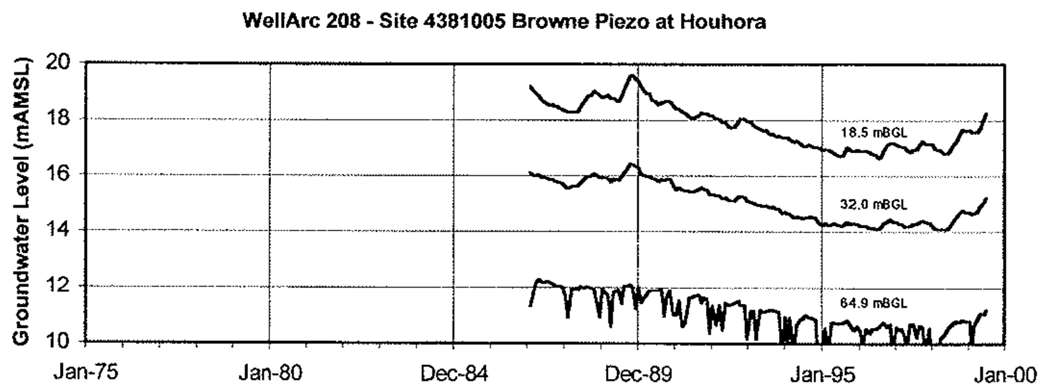

WellArc 208 - Site 4381005 Browne Piezo at Houhora
Groundwater Level (mAMSL)
18.5 mBGL
32.0 mBGL
64.9 mBGL
Jan-75
Jan-80
Dec-84
Dec-89
Jan-95
Jan-00

Figure C1

The site displays less oscillatory response to rainfall than bore 209 indicating its close proximity to the forest and possibly that the permeability and storage characteristics of the aquifer materials are slightly higher.

Bore 209 – Burnage Rd Piezo at Houhora

The piezo at 20 mBGL shows significantly higher pressures than the deeper piezos. All the piezos deeper than 20 mBGL show equivalent pressures indicating homogenous aquifer conditions. The borelog indicates a unit of lower permeability silty fine sand with occasional silty clays and peat from approximately 20-30 mBGL. This may impart some degree of semi-confinement on the lower part of the aquifer.

The bore shows some degree of impact from pumping in the deeper piezos as indicated by the mitigated recoveries in comparison to the upper piezo.

Bore 210 Waterfront Piezo at Houhora

Deep piezos at 60 and 70 mBGL have equivalent pressures, which are approximately 2 m greater than the shallower piezos. The piezo at 39.7 mBGL has an average pressure of about 0.5 to 1 m greater that the shallow piezo at 21.5 mBGL. This indicates groundwater discharge to the coast (i.e., upward leakage). Tidal effect is shown in piezos at all depths.

Borelog indicates lower permeability fine to very fine silty sand layer with a peat base from 40 to 50 mBGL. This layer probably acts as a semi-confining bed or imparts a degree of vertical anisotropy, although the lateral extent is not known.

Paparore-Sweetwater Bores

Bore 211 – Paparore Rd Piezo at Paparore

Deep piezos at 67 and 81 mBGL show identical hydrographic responses, as do the two shallow piezos at 21 and 38 mBGL. This indicates two distinct aquifer systems. Deep bores show rapid pumping induced depressurisation (up to 5m head losses) and rapid recovery at the end of the summer growing season.

The bore log indicates a 10 m thick low permeability silty clay layer from 40 to 50 mBGL. This may semi-confine the lower aquifer from the shallow.

Bore 81 – Ogle Drive Bore at Paparore

The hydrograph shows a very attenuated response to rainfall, similar to that of the Lake Heather bores. The borelog indicates the occurrence of low permeability iron pans and clay layers; similar to that of the Lake Heather bores. The absolute variation in groundwater oscillation over the monitoring period is small in comparison to other bores (except Lake Heather which is similar). This indicates that the lakes in the area may be acting as slow release surface reservoirs and maintaining a low but reasonable constant rate of groundwater recharge. The rate would be head driven by lake levels

Appendix E – Transient Calibration Bore Hydrographs