Groundwater Recharge at the Kaharoa Rainfall Recharge Site - Rotorua

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Cover Photo: Mangorewa at Kaharoa – Monitoring Station

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I would like to thank Paul White from GNS Science for his support, Craig Putt, Matt Parker and Glen Ellery for the supply of data and site maintenance.

Executive summary

The Bay of Plenty Regional Council commissioned GNS Science to set up a site for the measurement of rainfall, rainfall percolation through the soil and collection of soil water samples. The water samples assessed nitrogen and phosphorus concentrations in the percolated rain water that recharges the groundwater system at Kaharoa. The aim of the Kaharoa monitoring site is to understand the volume and quality of rainfall recharge to the groundwater system under pastoral land use.

Rainfall recharge has been measured in two lysimeters, a ground level rain gauge and a standard rain gauge at the site since June 2005. Chemistry samples were gathered periodically between 4 December 2006 and 8 January 2008 but are no longer collected at the site although the site remains capable of capturing such data.

GNS Science reviewed both nutrient discharge and quantified rainfall recharge in the following two reports: GNS Science consultancy report 2008/320, December 2008 titled *"Nutrient discharge to groundwater at the Kaharoa rainfall recharge site*", Rotorua, and consultancy report 2007/220, titled "*Lake Rotorua groundwater and Lake Rotorua nutrients - phase 3 science program technical report".* These reports assessed and reported on data from between June 2005 and December 2008.

The Kaharoa monitoring site provides the Bay of Plenty Regional Council with a mechanism for quantifying and qualifying the rainfall recharge to the groundwater resource under certain conditions. In so doing providing information to guide the development of policy relating to groundwater recharge zones, and the sustainable use and allocation of groundwater resources, this may also include policy on land use and land management.

This report is a review of the rainfall recharge component from the Kaharoa site including data captured from December 2008 through to May 2010. This report reviews annual, seasonal and monthly rainfall, ground-level rainfall and rainfall recharge at Kaharoa.

Annual groundwater recharge for 2009 was in the region of 41% (712mm) of mean annual rainfall suggesting a 10% reduction when compared to mean annual recharge of 51% (970mm) for the entire data record. This reduction is consistent with a relatively dry 2009 and a comparative reduction in mean annual rainfall highlighting the effects of annual rainfall variation on groundwater recharge. Mean annual rainfall variation for the site is +/15% compared to +/-10% for recorded groundwater recharge. Seasonal trends have a far greater effect on recharge with up to 70% recharge recorded during winter months compared to 25% for the summer months.

Contents

Part 1: Introduction

Originally lysimeters were developed to measure the leaching of soils, but have also become a valuable tool for measuring rainfall recharge to groundwater systems. The monitoring and measurement techniques provide valuable data for assessing the impacts of land use on both the quantity and quality of rainfall percolation that recharges the groundwater resource.

1.1 Site description

The Kaharoa site is located on a mixed sheep, beef and deer farm overlooking Lake Rotorua (Figure 1). Stocking densities at the site are in the region of 12-13 stock units per hectare (White et al. 2008).

The Kaharoa site overlays the Mamaku Ignimbrite, and has been installed into New Zealand Soil Class described as “Orthic Pumice Soils” and more specifically the “Oropi” soil series name. This soil is characterised by low nutrient levels, strong leaching, coarse texture which is well drained. Pumice soils in the Bay of Plenty Region, are dominated by pumice or pumice sands typically with a low clay content (<10%). Summer drought is a dominate characteristic. The soils are derived from the Kaharoa and Taupo Tephra overlaying rhyolitic tephra (Rijkse and Guinto, 2010/11).

The Mamaku Ignimbrite which erupted from the Rotorua Caldera forms an extensive formation (145 km^3 in volume) in the Bay of Plenty Region. The formation ranges from densely welded to non-welded and stratographically overlays the Waimakariri ignimbrite. Both the Mamaku and Waimakariri ignimbrites are groundwater units. In the Rotorua lake catchment the Mamaku Ignimbrite expresses thickness of up to 1 km in the vicinity of the source, but logarithmically reduces with distance from the source (White et al. 2008).

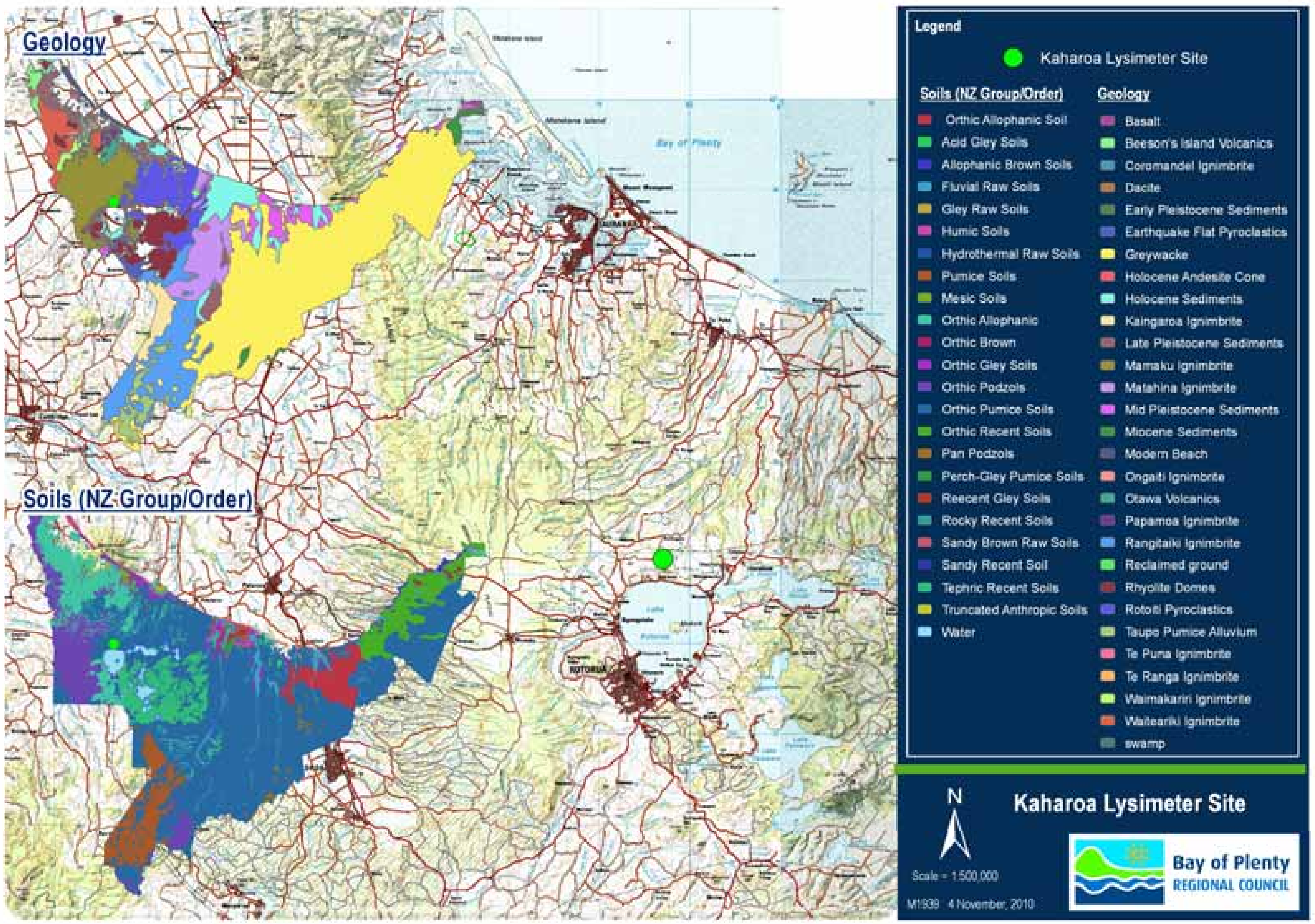

Figure 1 Site location, regional geology and New Zealand Soil Classification.

1.2 The purpose of lysimeter Installation

- To provide information on rainfall percolation below the root zone that is then available for groundwater recharge.

- To estimate water quality by measurement of nutrients leached through the soil profile.

Groundwater recharge is governed by the relationship between precipitation, infiltration and evapotranspiration. The amount of water entering the soil profile is determined by the infiltration capacity of a particular soil type. The infiltration capacity is dependent on antecedent soil moisture conditions, soil compaction, in wash of fine material into soil pore space, vegetative cover, temperature, and surface gradient (Bragg et al. 2001).

A lysimeter is designed to measure the exchange of soil water (retention) with groundwater (available for groundwater recharge) within the confines of an enclosed soil core or monolith. The general principle being, that if the exposed surface is typical of the general land use, the lysimeter can be used to infer water exchange or discharge to groundwater of that particular vegetation and soil type (Bragg et al. 2001). Discharge to groundwater, captured by a lysimeter is a measure of the balance between precipitation to the soil and evapotranspiration. In practice the relationship looks like:

$$\mathbf{P - E - D - \Delta W - \acute{\eta} = 0}$$

Where P = precipitation, E = evapotranspiration, D = ground and soil water discharge, ΔW = change in storage, ή = error. In principle the establishment of a water tight core that is separate from its surroundings breaks the natural continuum between the sample core and its surroundings. This introduces the potential for error (ή) as the accuracy of the lysimeter is dependent on its ability to represent natural soil moisture conditions (Bragg et al. 2001). Evapotranspiration can be estimated using the equation:

$$\mathbf{E = P - D}$$

The relationship discussed above is simplistic and does not take into account antecedent soil moisture conditions. The calculation for evapotranspiration (E) may contain a percentage of water, retained within the soil column and not lost to evapotranspiration. The soil column can act as a substantial water reservoir which in many cases stores more water then is available for plant use and lost to evapotranspiration (USDA, 2010). Direct measurement of recharge, with the use of lysimeters, accounts for soil characteristics e.g. permeability, which provides resistance and retention of groundwater flow/recharge, without the need for extensive analyses of these characteristics.

1.3 Lysimeter limitations

Lysimeters are designed to collect water passing through the root zone and into the groundwater body while at the same time representing the natural flux of water held within the soil. One of the primary limitations of lysimeter use is the separation of the soil core from the surrounding field conditions. This is necessary in order to accurately measure recharge for a known volume of soil however drainage can be affected due to alteration in the pressure potential of the soil column (Czigany et al. 2005). In principle a droplet of water will only be released from the soil column once the moisture holding ability of the soil or field capacity has been exceeded. Within the confines of a lysimeter the free draining lower boundary disrupts the hydraulic gradient and water will only flow once the entire profile is fully saturated. The result is that free draining lysimeters tend to record less groundwater recharge then would naturally occur (Czigany et al. 2005). This effect is greater in fine soils however Ingham et al. (2009) suggest that even in gravelly sand the groundwater recharge could be underestimated by as much as 15%.

The anoxic condition that exists as a consequence of the fully saturated condition has the potential to affect the suitability of lysimeters for measuring nutrient discharge. Pedological evidence suggests that permanent saturation can result in changing the redox condition which has the potential to increased denitrification, in so doing potentially underestimating actual nitrate quantities leached (Clothier et al. 2009).

Both of the limitations described above can be reduced with the use of a passive capillary wick.

Part 2: Methods

2.1 Kaharoa lysimeter design

The Kaharoa lysimeter recording station has been installed adjacent to a long term BOPRC rainfall recording site (number 860205) operating since September 1985. The two 500 mm diameter by 700 mm deep lysimeters (site numbers 2597 and 2598) began operation on 31 October 2005 and included the installation of an additional ground level rain gauge (site number 2599). All sites record direct rainfall or rainfall percolation by means of a tipping bucket rainfall recorder. Rainfall and recharge real time data is available from the Bay of Plenty Regional Council's website http://www.envbop.govt.nz.

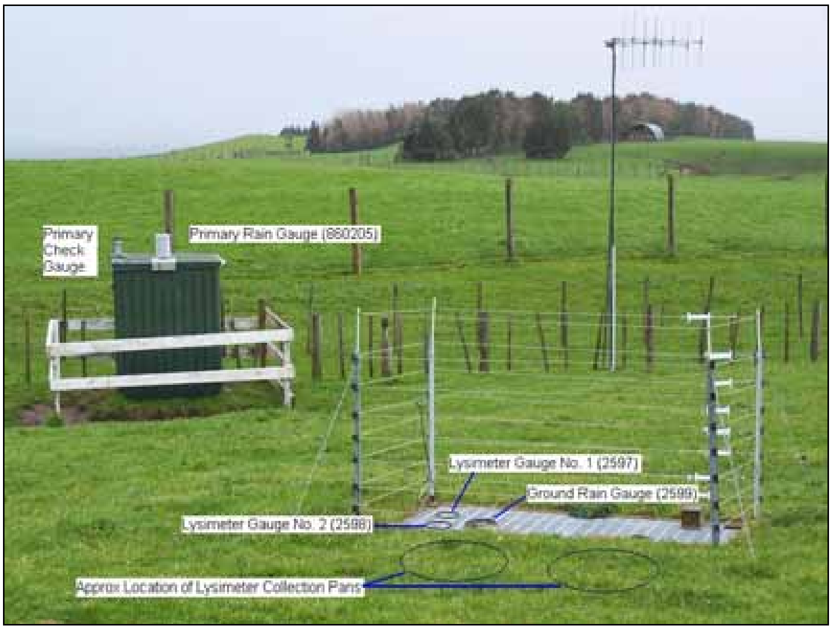

Figure 2 Kaharoa rainfall recharge site layout (White et al. 2007).

Figure 3 Kaharoa rainfall recharge site, instrument layout (White et al. 2007).

2.1.1 Data Review

The data captured from the Kaharoa Lysimeter has undergone quality checks undertaken by Bay of Plenty Regional Council's Environmental Data Services section. This follows a standard Quality Assessment (QA) process that is in alignment with New Zealand national standards. All data is reviewed by two staff members before being made available in Tideda (BOPRC data storage facility). Every two years all data is passed through an external audit process. Rain gauges are calibrated on 3 monthly bases, using a volumetric method. Gauges which vary by more than 3% from manufacturer specifications are replaced. (Glen Ellery and Matt Parker, pers. comm. October 2010). See appendix 1, 2 and 3 for a detailed list of calibration checks and repairs.

A further QA process has been undertaken in order to identify lysimeter specific error that may not have been picked up by the QA process. Lysimeter 2598 appear to continually under record (See section 3.1 of this report). An infiltration test, undertaken by Paul White from GNS Science confirmed this assumption. GNS Science (Stewart Cameron) removed lysimeter 2598 on the 13/03/2008, re-sealed the device and re-installed the lysimeter on the 18/03/2008. For the purposes of this analyses lysimeter 2598 has been reported on although it is recommended that its results are ignored until such time it is considered to be recording correctly. There should be sufficient data by the end of 2010 to assess the suitability of the repairs. See appendix 3 and 4 for a list of identified inconsistencies and repairs and maintenance.

The method used to assess lysimeter data is as follows:

1. Identify all rain days recorded by the ground rain gauge (2599) located at the site.
2. Extract all recharge tips from the lysimeter record that correspond with rainfall days.
3. Plot recharge versus rainfall on a monthly basis, for all rain days recorded and manually identify anomalies. Anomalies were then checked against the error log sheet detailed in appendix 5 and corrections made if necessary.

2.2 Rainfall Recharge to Groundwater

Rainfall measurement at the Kaharoa Lysimeter site is captured by a ground level rain gauge (site number 2599) and a conventional elevated rain gauge (Site #860205). Groundwater recharge is measure by two 500mm diameter x 700mm deep lysimeters (Site # 2597 and #2598) connected to tipping bucket recording gauges.

Recorded rainfall and groundwater recharge have been assessed from November 2005 to March 2010. The lysimeter sites have operated since June 2005. Data has been extracted with the use of Tideda software (NIWA 2008). This data has been further assessed as follows:

- Lysimeter 2598 repairs and performance.
- Monthly Rainfall Recharge (Entire data record October 2005 to May 2010).
- Seasonal Rainfall Recharge (01 December to 30 November for complete years).
- Annual Rainfall Recharge (01 December to 30 November for complete years).
- Briefly identify the relationship between rainfall and recharge.

Part 3: Results and Discussion

3.1 Lysimeter 2598 – repairs and maintenance

A review of annual accumulated and monthly rainfall and recharge was undertaken in order to assess repairs to lysimeter 2598. Figure 3 below of annual accumulated recharge and rainfall provides an illustration of the under recording trend exhibited in lysimeter 2598. It is apparent from the 2009 data series that lysimeter 2598 has been repaired as at August 2008. While 2598 still records less than 2597, the difference between the two lysimeters is comparable to the difference between the two rain gauges. White et al. (2007) identified the difference between a ground level rain gauge and a standard above ground rain gauge, as is the case at Kaharoa, is in the vicinity of 3%. Due to the large discrepancies identified in early 2010, it appears as if the drift between the two lysimeters has resurfaced and it is recommended that lysimeter 2598 is monitored and its results used with caution (Craig Putt, pers. comm.). For a full description of repairs and maintenance undertaken by GNS Science to lysimeter 2598 see appendix 4.

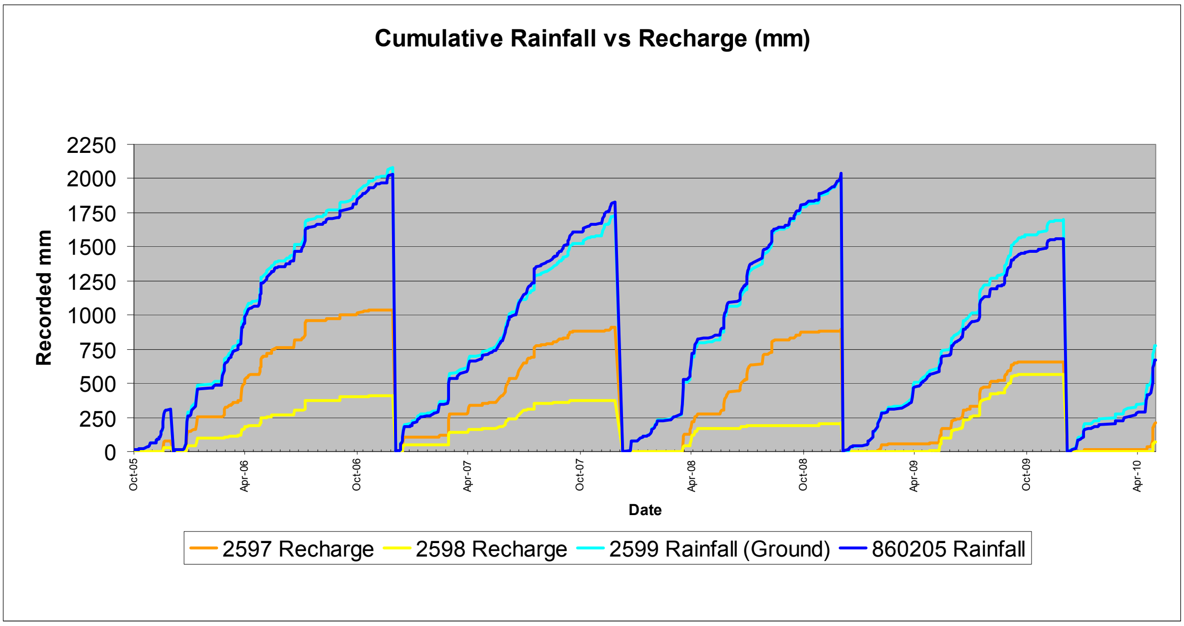

Figure 4 Annual accumulated rainfalls for the two lysimeter sites and rainfall recorders.

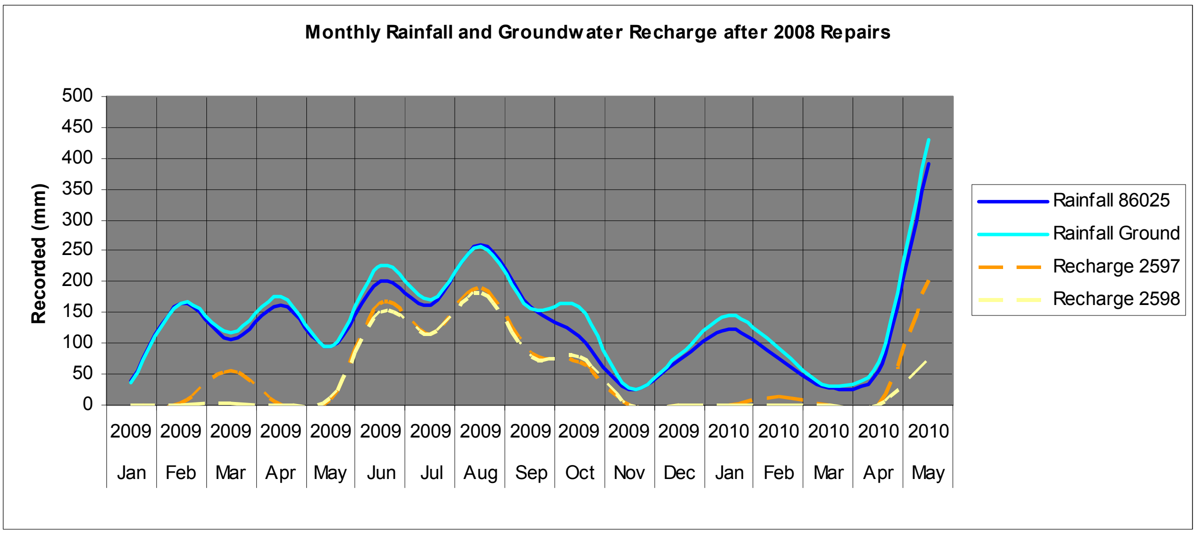

Figure 5 *2009 – 2010 monthly rainfall and recharge after repairs to lysimeter 2598.*

3.2 Monthly Rainfall Recharge to Groundwater

Table 1 *Kaharoa rainfall and groundwater recharge – monthly data summary. A "?" indicates periods of no record while a zero represents zero rainfall or recharge.*

Mean Monthly Data Summary - Kaharoa Rainfall and Groundwater Recharge Site (mm)														
	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rain Gauge 860205	2005	42	63	159	29	342	160	195	177	140	319	53	249	1926
	2006	261	196	183	340	244	112	115	192	45	133	110	70	1998
	2007	203	55	269	93	73	169	300	212	114	127	59	153	1824
	2008	76	89	79	471	115	253	296	255	168	150	83	142	2173
	2009	38	166	106	161	95	202	161	261	158	112	24	72	1554
	2010	123	75	28	56	391	?	?	?	?	?	?	?	673
	Mean	124	107	137	192	210	179	213	219	125	168	66	137	1895
	STDDev	91	59	85	176	136	52	82	37	49	85	32	73	229
Rain Gauge 2599	2005	?	?	?	?	?	?	?	?	?	11	53	237	301
	2006	288	198	192	338	253	110	119	202	44	128	104	70	2043
	2007	219	54	286	89	66	169	201	189	100	115	54	145	1685
	2008	76	92	70	437	114	252	235	152	180	148	85	150	1989
	2009	37	166	118	175	94	227	169	256	157	158	27	80	1663
	2010	146	93	30	69	429	?	?	?	?	?	?	?	766
	Mean	153	121	139	222	191	190	181	200	120	137	68	111	1845
	STDDev	102	59	102	160	151	63	49	43	61	19	34	42	199
Lysimeter 2597	2005	?	?	?	?	?	?	?	?	?	0	0	82	82
	2006	151	114	68	211	170	68	63	146	12	43	22	2	1070
	2007	122	0	175	26	59	107	209	175	49	65	0	31	1018
	2008	0	0	0	221	60	158	202	184	106	63	5	18	1018
	2009	0	3	56	0	9	164	115	191	83	71	0	0	694
	2010	0	14	0	0	200	?	?	?	?	?	?	?	214
	Mean	55	26	60	92	100	124	147	174	62	48	6	27	950
	STDDev	75	49	72	114	81	46	70	20	41	29	10	33	173
Lysimeter 2598	2005	?	?	?	?	?	?	?	?	?	0	0	31	31
	2006	42	54	12	75	64	18	37	71	2	28	3	2	408
	2007	50	0	96	7	16	48	90	67	1	15	0	5	396
	2008	0	0	3	115	59	0	20	16	0	0	22	10	247
	2009	0	0	4	0	11	150	115	181	79	78	0	0	618
	2010	0	0	0	0	72	?	?	?	?	?	?	?	73
	Mean	19	11	23	39	45	54	65	84	21	30	6	4	417
	STDDev	25.3	24.2	41.1	52.7	28.8	66.7	44.1	69.7	39.1	32.4	9.8	12.6	153

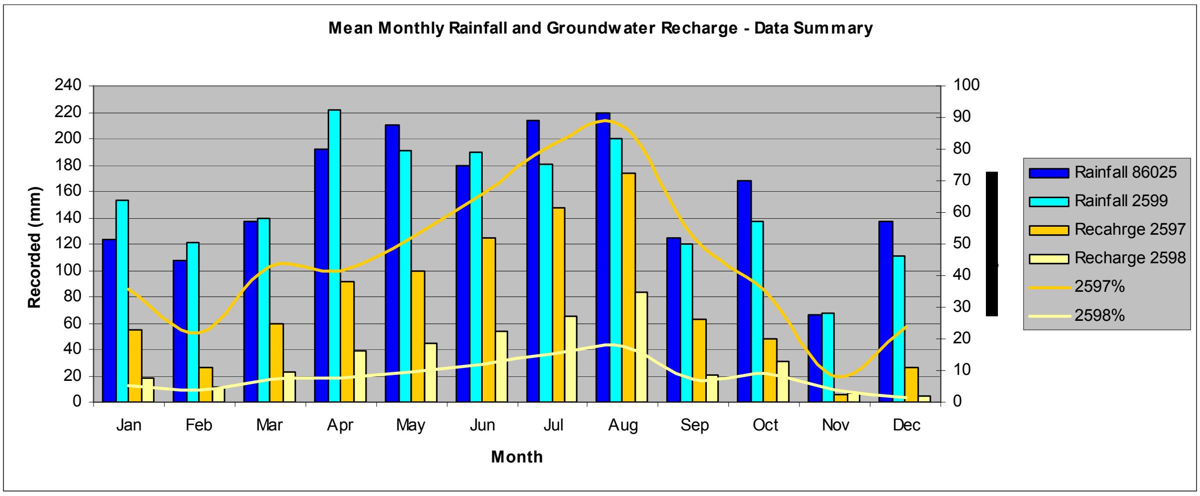

Figure 6   *Mean monthly rainfall, groundwater recharge and percentage groundwater recharge of rainfall.*

Monthly rainfall recharge results, for both lysimeters, exhibit distinct seasonality. A review of the results for lysimeter 2597 suggests that hotter summer months show greater losses and considerably reduced recharge, most probably due to increased evapotranspiration and drying of the soil column e.g. February mean monthly ground rainfall (site 2599) of approximately 121 mm resulted in a mean monthly recharge of 26 mm or recharge of about 22% of mean monthly rainfall. Figure 6 above indicates that for individual dry summers zero recharge can occur e.g. February 2007. It is important to note that the standard deviation of monthly recharge for some summer months e.g. February is almost double (+-200%) the mean recharge, suggesting considerable variation between years. Furthermore it is apparent that the occurrence of high intensity rainfall events during summer appears to drive this variability e.g. a single rainfall event spanning three days with a total rainfall of 144 mm contributed to 84% of recharge during that February 2006. Rainfall events of up to 60 mm/day for the same site in January 2008 did not record any recharge.

A review of winter months for lysimeter 2597 e.g. August 2008 paints a rather different picture. Mean monthly ground rainfall (site 2599) of 219 mm shows recharge of 174 mm or 87% of rainfall. The standard deviation of recharge for the same month and lysimeter was 20 mm (+-10%) of the mean. This appears to be typical for the majority of the winter months and is consistent with reduced evapotranspiration and soil saturation approximating field capacity.

Field capacity at Lake Ōkaro in the Rotorua area has been measured at approximately 51% (by volume), for the top 10 cm (Danny Guinto – Bay of Plenty Regional Council Soil Scientist, pers. comm.). Mean soil moisture percent for the Ōkaro site is at or about 50% for the winter months, suggesting that any rainfall, not lost in the form of run-off, should discharge to ground resulting in an increasingly direct relationship between rainfall and run-off. Transposing these results to the Kaharoa site appears to confirm this assumption. As soil moisture levels approximate field capacity almost all rainfall discharges to ground. Mean monthly figures for winter e.g. August suggest that antecedent soil conditions play a major role in rainfall recharge to groundwater at the Kaharoa site.

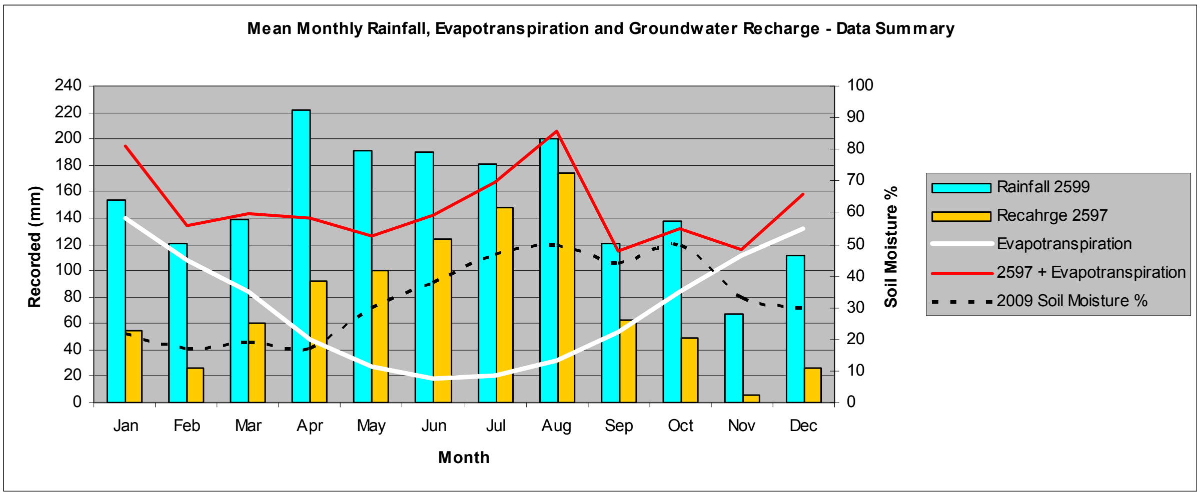

Figure 7 *Mean monthly rainfall and groundwater recharge for Kaharoa compared to evapotranspiration for Taupo from Fleming (1996) and mean soil moisture percentage for 2009 from the Bay of Plenty Regional Council's soil moisture probe at Lake Okaro. Measured field capacity at the Ōkaro site is in the region of 51%.*

A comparison with evapotranspiration data from Fleming, (1996) suggests that reduced recharge during summer is predominantly due to evapotranspirative losses. It is difficult to draw such a conclusion particularly considering the variability of summer recharge values. It would appear that the closer the soil is to saturation/field capacity the better this relationship. A detailed analysis of soil moisture content is beyond the scope of this review but would provide considerable insight into site specific conditions at the Kaharoa lysimeter site.

3.3 Seasonal/quarterly rainfall recharge to groundwater

For the purposes of this report seasons are as follows:

- Summer – December, January, February
- Autumn – March, April, May
- Winter – June, July, August
- Spring – September, October, November

Table 2 Seasonal rainfall, rainfall recharge and rainfall recharge as a percentage of rainfall.

		Rainfall		Recharge		Recharge % Rainfall	
Season	**Season**	**860205**	**Ground**	**2597**	**2598**	**2597**	**2598**
Dec-Feb	Summer 06	706	723	346	127	49%	18%
Apr-May	Autumn 06	767	783	449	152	59%	19%
June-Aug	Winter 06	419	431	277	126	66%	29%
Sept-Nov	Spring 06	288	276	77	32	27%	12%
Dec-Feb	Summer 07	328	343	124	52	38%	15%
Apr-May	Autumn 07	435	441	260	119	60%	27%
June-Aug	Winter 07	681	559	490	205	72%	37%
Sept-Nov	Spring 07	300	269	114	16	38%	6%
Dec-Feb	Summer 08	318	313	31	5	10%	2%
Apr-May	Autumn 08	665	621	281	177	42%	29%
June-Aug	Winter 08	804	639	545	37	68%	6%
Sept-Nov	Spring 08	401	413	174	23	43%	6%
Dec-Feb	Summer 09	346	353	21	10	6%	3%
Apr-09	Autumn 09	362	387	65	15	18%	4%
Jul-09	Winter 09	624	652	470	445	75%	68%
Oct-09	Spring 09	294	342	154	158	53%	46%
Jan-10	Summer 10	270	319	14	1	5%	0%
Apr-10	Autumn 10	475	528	200	73	42%	14%

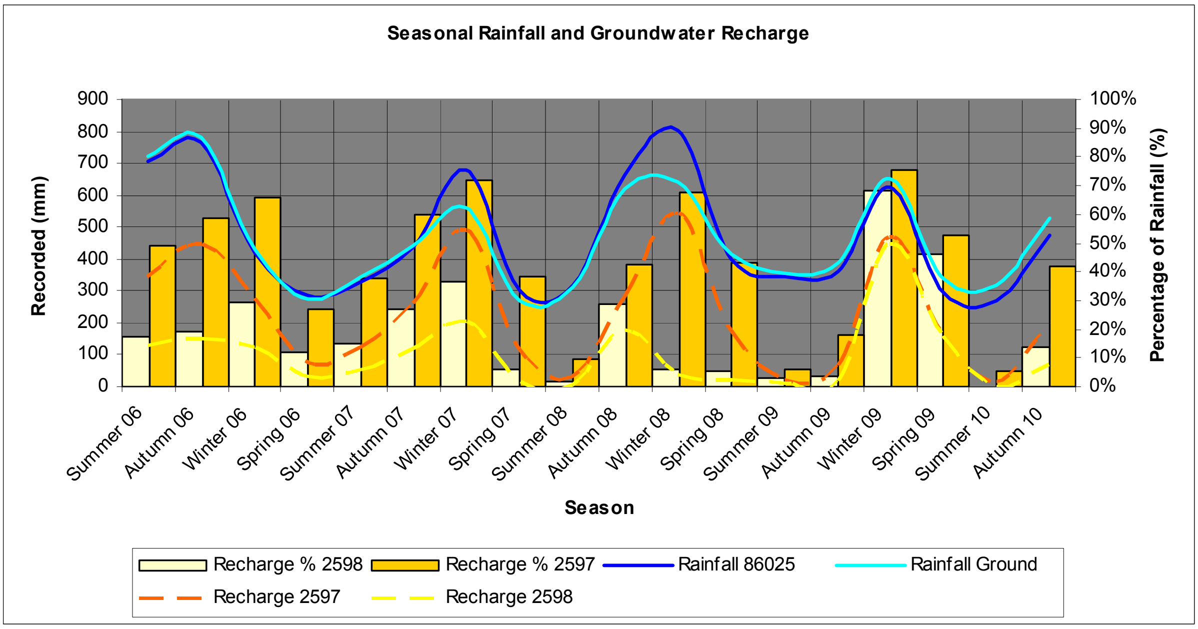

Figure 8 Seasonal rainfall recharge and rainfall recharge as a percentage of rainfall.

Table 3 Rainfall recharge, annual versus seasonal recharge (Dec 2006-May 2010).

Mean Annual versus Mean Seasonal Recharge (% or mm)							
Season	**Months**	**Lysimeter 2597 (%)**	**Lysimeter 2598 (%)**	**Lysimeter 2597 (mm)**	**Lysimeter 2598 (mm)**	**Rainfall 2599 (mm)**	**Rainfall 860205 (mm)**
Spring	Sept, Oct, Nov	41	18	130	57	325	321
Summer	Dec, Jan, Feb	27	9	107	39	410	394
Autumn	Mar, April, May	46	19	251	107	552	541
Winter	June, July, Aug	71	36	446	203	570	632
Mean Annual	Dec to Jan	51	23	970	425	1886	1935

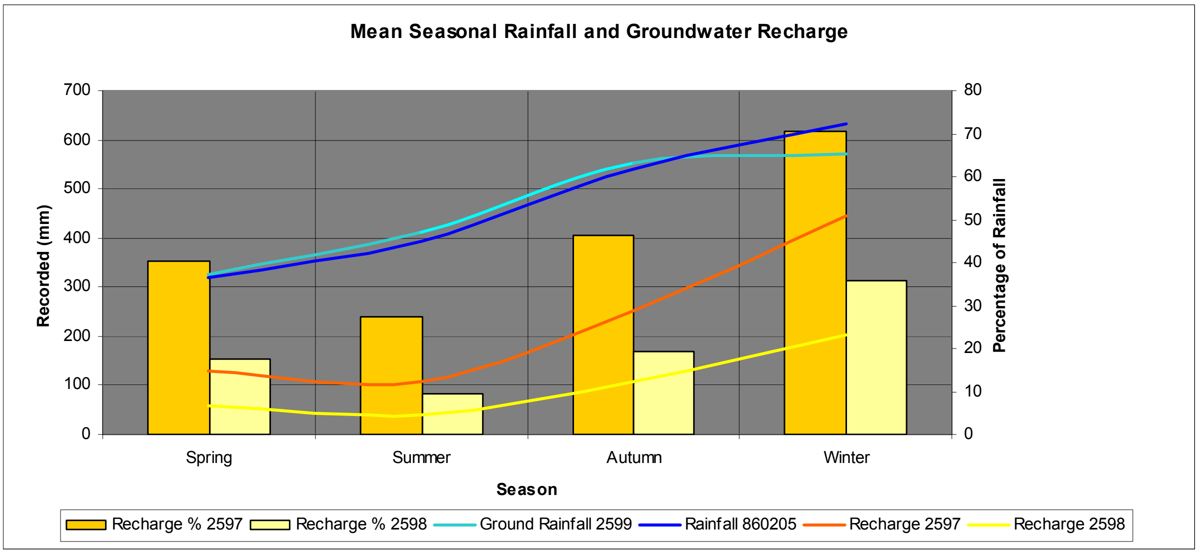

Figure 9 Mean seasonal rainfall recharge (Dec 2006-May 2010).

An assessment of seasonal rainfall recharge confirms what has already been discussed in a review of monthly discharge i.e. a distinct seasonal trend with regards to rainfall recharge. For lysimeter 2597, mean summer (December-February) and winter recharge are 27% and 71% respectively of mean rainfall. Spring and autumn rainfall recharge figures are quite comparable and in the region of 41% to 46% respectively.

3.4 Annual

For the purposes of this report an "annual" period is from 1 December to 30 November. This is consistent with the analyses of seasonal trends.

Table 4 Annual rainfall recharge in millimetres (mm) and as a percentage of mean annual rainfall.

Mean Annual Rainfall and Rainfall Recharge 2006 to 2009 (% or mm)						
Year	**Lysimeter 2597 (%)**	**Lysimeter 2598 (%)**	**Lysimeter 2597**	**Lysimeter 2598**	**Rainfall 2599**	**Rainfall 860205**
2006	52	20	1150	437	2213	2180
2007	61	24	989	392	1612	1744
2008	52	12	1031	242	1986	2188
2009	41	36	712	628	1734	1626
Mean Annual	51	23	970	425	1886	1935
Std Dev	8	10	185	159	268	292

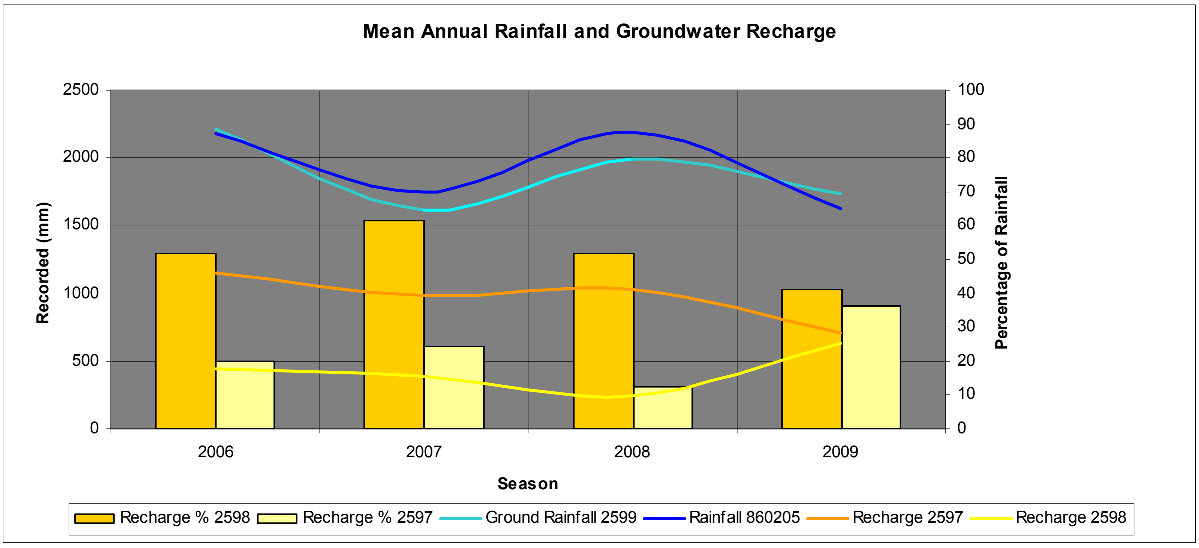

Figure 10 Mean annual rainfall recharge for 2006-2009.

Mean annual rainfall recharge is approximately 51% of mean annual rainfall, for the period 1 January 2006 to the 30 December 2009. Previous reports have estimated recharge at the Kaharoa site and in the Rotorua region as follows:

- 49% of rainfall and 37% of rainfall for the periods August 2005 to July 2006 and 24 January 2007 to 8 January 2008 respectively using data from the Kaharoa lysimeter site (White et al. 2007 and Cameron et al. 2008).

- 52% of rainfall, using water balance techniques (Dell. P. M. 1982a and 1982b).

The data presented here indicates quite a substantial reduction in recharge for the 2009 period, suggesting significant reduction in recharge during dry years e.g. 41% compared to a mean annual recharge of 51%. This is in-consistent with 2007 data which shows less rainfall then 2009 but higher recharge (61% of rainfall). Reasons for such a disparity are unclear. What is clear from a review of annual data is the apparent reduction in variation, when compared to monthly data. Mean annual rainfall and recharge figures illustrate a standard deviation of 14% and 19% of mean annual ground rainfall site 2599 and lysimeter 2597 respectively. As would be expected, reporting on an annual basis moderates the results.

3.5 Relationship between rainfall and recharge

The relationship between rainfall and recharge has been assessed using regression analyses for monthly rainfall totals and based on rainfall intensity for the entire data record. These analyses only involved comparison of lysimeter 2597 and ground rainfall site 2599.

3.5.1 Monthly rainfall and monthly recharge

Lysimeter 2597, illustrates a reasonable relationship $R^2 = 0.671$. A value of 1 would suggest a direct relationship between rainfall and recharge with recharge increasing as rainfall increases (Hayslett, 1981). A correlation of 0 suggests that this relationship is significant. There are several ground – atmospheric, groundwater – surface and vadose zone interactions that influence the relationship between rainfall and recharge (see section 1.3 of this report) but an analysis of these is beyond the scope of this review.

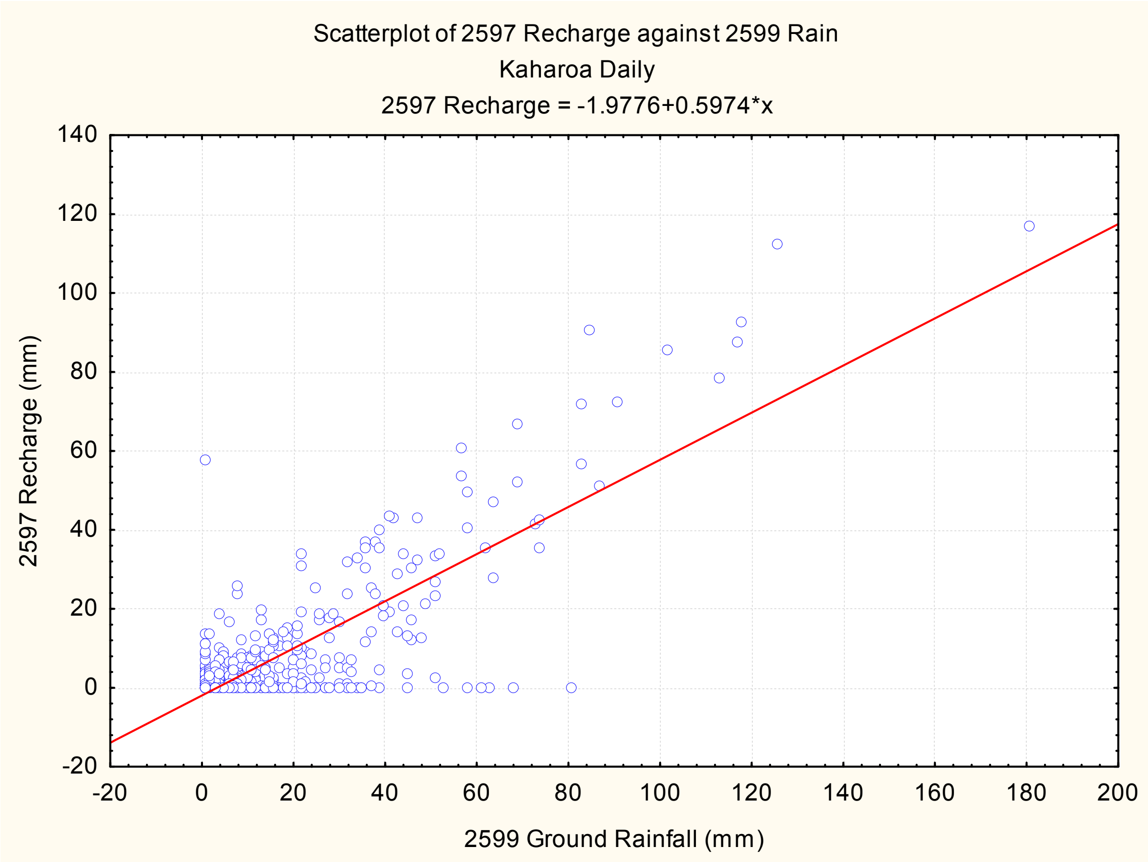

Figure 11 Relationship between ground rainfall and lysimeter 2597. Regression Summary for Dependent Variable: 2597 Recharge (Kaharoa Daily) R= .81938174 R²= .67138644 Adjusted R²= .67090460 F(1,682)=1393.4 p<0.0000 Std. Error of estimate: 7.9702 (Statistical 9.0). Zero data values have not been removed as these are considered significant to the relationship between rainfall and recharge. The inclusion of zero recharge data may result in under prediction at the upper extent of the distribution.

It is apparent from Figure 11 that zero recharge measurements for relatively large events slightly reduce the fit for events at the upper extreme of the record.

3.5.2 Rainfall intensity and its relationship with recharge

A brief overview of rainfall events resulting in recharge was undertaken in order to better understand the characteristics of the rainfall – recharge relationship at Kaharoa. Monthly rainfall recharge indicated that rainfall intensity may affect recharge. The rainfall recorded for the Kaharoa site for Lysimeter 2597 and the ground rainfall recorder 2599, has been grouped into the following daily (24 hour) intensities:

- ≤5 mm
- >5 but ≤10 mm
- >10 but ≤20 mm
- >20 mm

Table 5 Total rainfall recorded for the entire Kaharoa rainfall record relative to specific daily rainfall intensity events i.e. recharge relative to daily rainfall events of ≤5 mm, >5 mm but ≤10 mm, >10 mm but ≤20 mm and >20 mm, for the entire data record 31 October 2005 to 29 May 2010.

Parameter	Rainfall Event (mm/day)									Total Recharge	Total Rain
	Zero Rain	<5mm		5-10mm		10-20mm		>20mm			
	Recharge	Recharge	Rainfall	Recharge	Rainfall	Recharge	Rainfall	Recharge	Rainfall		
Recorded (mm)	297	407	731	257	907	348	1455	2786	5530	4095	8623
No Days	177	117	338	62	119	49	102	98	125	326	684
% of Total Record	7	10	8	6	11	9	17	68	64	100	100

Rainfall recharge relationships are complex. Aside from the obvious influence of soil hydrodynamics and evapotranspiration, the relationship between a rainfall event and a recharge event is not direct. Table 6 below illustrates a number of records showing the effect of a lag in time between rainfall recharge.

Table 6 Delayed recharge relative to event recharge.

Date	Recharge (mm)	Rainfall (mm)	Preceding event rainfall (mm)
13/06/2006	23.6	8	30
01/07/2007	25.68	8	64
26/04/2006	18.24	4	106
28/06/2006	13.52	1	75

It appears that this time lag is responsible for an increase in recharge events corresponding with rainfall of less than 5 mm, possibly due to high intensity rainfall events spanning more that 24 hours, resulting in some residual rainfall before or after an event finishes. For the entire record, 252 days illustrate recharge greater than rainfall, mostly due to the recharge event being preceded by a substantial rainfall event. Rainfall events of zero and ≤5 mm account for an additional 297mm and 125 mm of recharge respectively, which is potentially part of a larger event. What is apparent from the data is that over 68% of recharge is received from high intensity rainfall in excess of 20 mm/day. Such rainfall events accounts for 64% of rainfall at Kaharoa.

Table 7 Peak rainfall relative to peak recharge, illustrating delayed recharge, at an hourly interval.

Date	Recharge Peak	Rainfall Peak	Lag (minutes)
10/02/2006	11.2 mm at 9.00 pm	12 mm at 8.00 pm	1 hour
6/08/2006	7.6 mm at 8.00 pm	10 mm at 7.00 pm	1 hour
14/01/2007	6.56 mm at 7.00 pm	12 mm at 5.00 am	2 hours
13/03/2007	1 mm at 5.00 am	8 mm at 1.00 am	4 hours
15/04/2008	19.2 mm at 6.00 pm	38 mm at 5.00 pm	1 hour
29/30/12/2008	1.44 mm at 1.00 am	8 mm at 4.00 pm	9 hours
01/02/2010	4 mm at 4.00 pm	11 mm at 1.00 am	15 hours

Peak rainfall to peak recharge event is variable. White et al. (2007), identifies a time lag of approximately 1.5 hours to 8 hours from peak rainfall event to peak recharge. It is apparent that the time lag between rainfall and recharge is not consistent between all rainfall and recharge events. An event analysis of rainfall event relative to recharge events would provide greater insight into the rainfall recharge relationship then the figures provided here based on a rainfall event of 24 hours. A more detailed analysis of the rainfall event relative to recharge is beyond the scope of this report.

3.6 Lysimeters as a tool for water allocation

The proposed Ministry for The Environment (MfE), National Environmental Standard (NES) (MFE website, 2010) for groundwater recommends allocation limits for mean annual recharge of 15% for coastal aquifers and 35% for all other aquifers. The data presented in this report suggests that mean annual recharge at Kaharoa is 51% of annual rainfall or 970 mm/year at that site. The proposed NES suggested by MFE equates to 340 mm/year per square meter of land area, for aquifers represented by the Kaharoa recharge site. Such a localized figure, as an estimate of catchment scale recharge, is to be used with caution and is only recommended where surface catchments exhibit uniform soil, vegetative and rainfall intensity characteristics. Such a technique may be appropriate at a regional scale in conjunction with a comprehensive lysimeter network however the margins for error may be large.

Safe yield in an aquifer is the rate at which groundwater can be withdrawn without causing long term decline in the water table i.e. the average replenishment rate in the aquifer (Bouwer. 1978). Safe aquifer yield should also include the effects on stream depletion and aquifer contamination such as saltwater intrusion (Freeze and Cherry. 1979). Using lysimeters in conjunction with other techniques, such as rainfall-run-off models, may serve to confirm recharge estimates made with the use of lysimeters and substantiate or refute their application on a catchment scale. The concept of safe or sustainable yield is one which is to be used with caution and a conservative approach is recommended (Stranger.1994).

A recent report prepared for Environment Canterbury (Clothier et al. 2009) suggests that groundwater recharge may be greater for those land use practices under irrigated agriculture. Irrigated recharge was found to be somewhat higher than that for dry land pasture. This is due to a number of factors including; rainfall falling onto already moist soils instead of a dry soil profile requiring saturation before discharge would occur. On average Clothier et al. (2009) established that between 29% and 86% of applied irrigation drained through the lysimeters and ended up as recharge. This increased recharge could have a twofold impact, one being an increase in recharge in areas under irrigation and the second being the identification of inefficient irrigation systems and the potential for cost and water saving through increased efficiency.

Part 4: Summary and conclusion

Measurement of infiltration and field capacity, and its relationship with soil moisture, would improve an understanding of water balance characteristics at the Kaharoa site. Such information could facilitate a modelled approach to groundwater recharge with the use of known variables e.g. rainfall, evapotranspiration, field capacity, soil moisture and soil infiltration. A representative network of lysimeters would be essential for the calibration of such a model.

An alternative technique is that of rainfall run-off modelling, which provide a more accurate representation of whole of catchment characteristics. Rainfall-runoff techniques will require the establishment of a diverse and representative stream gauging network, without which the margin for error can be large (Wilson, 1991).

Annual groundwater recharge figures at the Kaharoa site for 2009 illustrate a reduction (41% of rainfall) in groundwater recharge when compared to previous years and previous academic work. This is below a mean annual figure of 51% for the entire record but consistent with a relatively dry year and almost zero summer groundwater recharge. Rainfall recharge relationships are complex. Mean monthly summer rainfall suggests a high degree of uncertainty with regards to predicting recharge, as was illustrated by highly variable mean monthly recharge estimates particularly for the summer months. The *"recharge = rainfall – evapotranspiration"* relationship, as was expected, does not completely account for rainfall not discharging to groundwater. This is most likely due to the variability of rainfall characteristics e.g. intensity/run-off characteristics and antecedent soil moisture characteristics which highlight the benefits of direct measurement of recharge using lysimeters over a modelled or other approach.

Part 5: Recommendations

The following recommendations are made to improve our understanding of rainfall recharge in the Bay of Plenty;

- Installation of a soil moisture probe at the Kaharoa lysimeter site and analyses of soil moisture characteristics at the site (field capacity, infiltration rates etc). Although not necessary to quantify the amount of recharge at the site, it would be a requirement should the results from the site need to be extrapolated to other sites based on soil properties alone.

- Regional analyses of soil characteristics is undertaken in order to identify and map rainfall-runoff/recharge characteristics and identify gauged catchments that may be representative of ungauged catchments.

- A review of and the application of rainfall run-off techniques may be more appropriate for quantifying recharge across the Bay of Plenty. Considering the number of gauging sites operated by Bay of Plenty Regional Council such a technique would possibly provide a better estimation of rainfall-run-off and recharge relevant to general catchment characteristics, rather then a snapshot relating to an individual site.

- The installation of lysimeters under irrigated agriculture to investigate potential recharge from irrigation. Currently the Kaharoa site is representative of sheep and beef farming. A second site at Pongakawa, has been installed in 2010 under dairy land use however neither of these sites are representative of recharge under irrigated agriculture e.g. frost protection of kiwifruit. Research suggests that such land use could contribute to groundwater recharge particularly in highly porous soils.

- Continued review of lysimeter 2598 to ensure it is operating correctly.

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Appendices

Appendix 1 – Maintenance and Calibration 10 November 2008

Lysimeter 2 | 10 November 2008 | Paul White (GNS) Craig Putt (BOPRC)

About 16:00 hours (NZDT)

Checks:

1) Checked alcathene pipe to lysimeter 2 tipping bucket

   - water in pipe
   - fed to tipping bucket - about 3 tips heard

2) Removed tunnel to tipping bucket – no cracks around top or joins.

3) Inspected alcathene pipe to lysimeter – no cracks.

4) No kinks in pipe.

5) Checked tipping bucket funnel – ok, no leaks.

6) Lysimeter base inspection tube – no water lying in white PVC tube – no water around fittings.

7) Checked alcathene tube for internal blockages – none.

8) Reassemble funnel and alcathene pipe.

9) Pressure test on funnel and alcathene pipe, tipped water into alcathene pipe at funnel end

   - no leaks in pipe or fittings at lysimeter
   - put 3 L into alcathene pipe
   - emptied alcathene pipe – 500 ml came out immediately
   - waited 15 minutes and no more water came out

10) Calibrate lysimeter 2 tipping bucket
   - 16:45 (NZDT) calibrate lysimeter 2 tipping bucket – start
   - reassemble yellow funnel on lysimeter 2 tipping bucket

11) Infiltration test
   - infiltrate 8 L through funnel in middle of lysimeter 2, buried about 2.5 mm
   - start infiltration test 17:00 hours with funnel, hose, head system (jury rigged)

   No leakage across the soil observed
   - at 17:00(NZDT) started infiltration
   - at 17:30 (NZDT) 2 L passed total
   - at 18:04 (NZDT) 4 L passed total
   - at 18:41 (NZDT) 6 L passed total
   - at 19:45 (NZDT) 8 L passed total
   - finish test
   - replaced grill and electric fence

Appendix 2 – Maintenance and Calibration 13 November 2008

13 November 2008 Kaharoa Lysimeter 2 Infiltration Test
- Paul White and Geoffrey Undereiner, GNS Science

Start time	10.00 am	NZDT	valve on
2 L injection	10.21 am	NZDT	
4 L injection	10.43 am	NZDT	
6 L injection	11.04 am	NZDT	
8 L injection	11.28 am	NZDT	
10 L injection	11.41 am	NZDT	valve off

i.e. 10 L injection in 101 minutes

No water seepage through grass outside the boundaries of the lysimeter observed during the time of the test.

Appendix 3 – Repairs and Maintenance Lysimeters

@@ 2597-2599 20051027 131500
Initial comment for the soil infiltration monitoring sensors situated at the rainfall monitoring site Mangorewa at Kaharoa Link (Site No. 860205). Until 2008, this site also provided a microlink for Environment BOP's VHF radio network. Site numbers for the soil infiltration project are:

2597 - Lysimeter No. 1
2598 - Lysimeter No. 2
2599 - Ground Level Rain Gauge.

The site is situated at map reference U15: 971 493 and an altitude of 420 m (+/- 15 m).

The local recording authority is Environment B O P. Data is collected by Environment BOP and analysed by Geological & Nuclear Sciences (GNS, contact Paul White) on behalf of Environment BOP.

Additional Information-

The recording instruments are OTA tipping bucket raingauges with a resolution of 500 micrometers. They are connected to an iQuest DS-4483 datalogger, having a time resolution of 15 minutes.

The lysimeter gauges are mounted on steel rails in a fenced pit (~2 metres below ground level). Rainfall infiltrating through the soil column is collected by two seperate pans, which are buried adjacent to the south wall of the pit. Each pan is connected by alcathene pipe to one of the OTA tipping bucket gauges. Each of these two gauges acts as a check on the other. The top of the orifice on the ground level gauge is set at ground level. It is surrounded by a steel grid and an electric fence, to prevent stock and/or people falling in to the pit.

The site is located on the property of Pukeha Farms, 414 Te Waerenga Rd (contact Steve Hewson, Farm Manager), in the Upper Kaituna catchment.

All correspondence to:

The Manager
Environmental Data Services
Bay of Plenty Regional Council
P.O.Box 364
Whakatane

DUE TO ONGOING ISSUES WITH OPERATION OF LYSIMETER GAUGES, A TRANSCRIPT OF CHECK SHEET COMMENTS SINCE 20071102 104000, HAVE BEEN INCLUDED IN THIS FILE IN ORDER TO ISOLATE FAULTS AND SHARE INFORMATION WITH GEOLOGICAL & NUCLEAR SCIENCES (GNS - Contact: Paul White).

@@ 2597-2599 20051027 131500
Soil infiltration gauges installed and operational.

@@ 2599 20051027 131500
Data from Kaharoa roof-mounted rain gauge (860205) used to fill gap in ground-level rain gauge (2599) data from 20070528 170000 to 20070727 090000. Incorrect multiplier applied to data during routine software upgrade of datalogger.

@@ 2597-2599 20071102 104000
R. Reeves (GNS): "Cleared out Ground rain gauges at lysimeter site due to blockage in line. Offsite at 1020hrs NZST."

@@ 2597-2599 20071127 094500
K. Knowles (EBOP) Check Sheet: "Checked calibration on all gauges. Infiltration #2 gauge failed (under-reading by 10 percent). Delete all tips between 0945-1115hrs."

Roof check gauge: 54.0 mm (tote = 260.0 mm - cause of discrepency unknown)
Ground check gauge: 54.0 mm (tote = 249.5 mm - cause of discrepency unknown)

@@ 2598 20080313 120000
S. Cameron (GNS) Check Sheet: "Disconnected and removed faulty lysimeter #2."

@@ 2598 20080318 150000
S. Cameron (GNS) Check Sheet: "Re-installed 'fixed' lysimeter #2."

@@ 2597-2599 20080526 153000
M. Parker (EBOP) Check Sheet: "Checked calibration on all gauges. Replaced roof rain gauge (failed calibration) and ground gauge (trap door was accidentally dropped on gauge)." EBOP gauge temporarily installed as Ground R/G on same day, while repairs were carried out. Delete all tips between 1545-1800hrs."
Roof check gauge: 6.0 mm (tote = 981.5 mm - CG blocked)
Ground check gauge: 930.0 mm (tote = 930.0 mm)

@@ 2597 20080527 094500
M. Parker (EBOP) Check Sheet: "Delete all tips between 0945-1130hrs."

@@ 2597-2599 20080619 091500
M. Parker (EBOP) Check Sheet: "Check gauge was blocked with thistles. No mains power; site running off batteries. Delete all tips between 0930-1300hrs."
Roof check gauge: 69.5 mm (tote = 1078.0 mm - CG blocked)
Ground check gauge: not recorded (tote = 1010.0 mm)

@@ 2597-2599 20080702 114500
Suspect missing record from 20080702 114500 to 20080717 004500. Cause unknown. During this time, the primary (roof-mounted) rain gauge at this site collected 60.5mm of rain.

@@ 2597-2599 20080729 143000
C. Putt (EBOP) Check Sheet: "Reset mains power circuit breaker and replaced batteries."
Roof check gauge: 85.0 mm (tote = 369.5 mm - CG blocked)
Ground check gauge: 353.0 mm (tote = 306.5 mm)

@@ 2597-2599 20080811 203000
Suspect missing record from 20080811 203000 to 20080823 200000. Cause unknown. During this time, the primary (roof-mounted) rain gauge at this site collected 115.0 mm of rain.

@@ 2597-2599 20080821 123000
M. Parker (EBOP) Check Sheet: Checked calibration on all gauges. Lysimeter #1 gauge failed (under-reading by 6 percent) - replacement gauges pending. Delete all tips between 1315-1430hrs."
Roof check gauge: 216.0 mm (tote = 641.0 mm - CG blocked?)
Ground check gauge: 282.0 mm (tote = 457.0 mm - CG blocked?)

@@ 2599 20080822 133000
C. Putt & M. Parker (EBOP) Check Sheet: "Re-installed original (repaired) GNS Ground-level rain gauge and removed temporary EBOP gauge. Delete all tips between 1345-1630hrs."

@@ 2597-2599 20080904 094500
C. Putt & M. Parker (EBOP) Check Sheet: "Checked mains power working 12V power supply operation - OK."
Roof check gauge: - mm (tote = 122.0 mm)
Ground check gauge: - mm (tote = 137.5 mm)

@@ 2597-2599 20081105 120000
C. Putt (EBOP) Check Sheet: "Tested Ground R/G and both Lysimeter gauges by putting water through top of gauges and tracing them through to telemetry

system. All test tips recorded accurately. Delete all tips between 1200-1230hrs. Downloaded all data from logger (back to late August 2008)."
Roof check gauge: 459.0 mm (tote = 433.0 mm)
Ground check gauge: 454.0 mm (tote = 455.5 mm)

@@ 2598 20081110 144500
C. Putt (EBOP) & P. White (GNS) Check Sheet: "Calibrated Infiltration #2 gauge 1545-1600hrs (passed). P. White ran infiltration test (10L volume) from 1600hrs." On 20081114, P. White advises "the lysimeter recovered approx 6.9 L (438 tips) of the 10L infiltration. So I think there is evidence for removal and resealing of the lysimeter." Calibration data left in data set - affects period 20081110 151500 to 20081111 230000.
Roof check gauge: 7.5 mm (tote = 7.5 mm)
Ground check gauge: 6.5 mm (tote = 6.5 mm)

@@ 2598 20081113 090000
P. White & G. Undereiner carry out second infiltration test on lysimeter #2 from 20081113 090000 to 104100 (NZST). P. White notes that "No water seepage through grass outside the boundaries of the lysimeter observed during the time of the test." However, there still appears to be a leakage issue. Calibration data left in data set - affects period 20081113 94500 to 20081115 103000.

@@ 2597-2599 20081217 154500
Environment BOP switched from 15 minute data logging resolution, to one minute event-based rainfall logging.

@@ 2597-2599 20090313 101500
M. Parker (EBOP) Check Sheet: "Checked calibration on all gauges (4) on-site. Both lysimeter gauges failed - replacement gauges pending. Delete all tips between 20090313 1015-1130hrs."
Lysimeter #1 gauge under-reading by 7 percent.
Lysimeter #2 gauge under-reading by 5 percent.
Roof check gauge: 332.0 mm (tote = 474.5 mm) - 42.9% difference - CG blocked
Ground check gauge: 515.5 mm (tote = 496.0 mm) - 3.8% difference

@@ 2597 20090327 140000
M. Parker (EBOP) Check Sheet: "Replaced lysimeter #1 gauge. Delete 3 test tips at 1407hrs (NZST)."

@@ 2597-2598 20090416 140000
C. Putt & M. Parker (EBOP) Check Sheet: "Cleaned Lysimeter #1 and #2 gauges and re-checked calibration. Both lysimeter gauges failed twice and were replaced with TB3 type gauges to simplify future gauge replacement while allowing for water sample collection from bottom of rain gauge drains."
Roof check gauge: 40.0 mm (tote = 47.0 mm) - 17.5% difference
Ground check gauge: 42.5 mm (tote = 42.5 mm) - 0.0% difference

@@ 2597-2598 20090416 161500
Gap from 20090416 161500 to 20090522 120000 of 35.82 days. Funnels between soil infiltration collecting pans and rain gauges were accidentally left disconnected from intensity gauges, from 20090416 (1600) to 20090522 (1315).

@@ 2597-2598 20090522 131500
M. Parker (EBOP) Check Sheet: "Checked calibration on all gauges (4) on-site. Lysimeter #1 gauges failed and replaced. Delete all tips between 20090522 1330-1615hrs."
Roof check gauge: 181.0 mm (tote = 224.0 mm) - 19.1% difference
Ground check gauge: 253.0 mm (tote = 237.5 mm) - 6.5% difference

@@ 2597-2598 20090821 121500
M. Parker (EBOP) Check Sheet: "Checked calibration on all gauges (4) on-site. Ground R/G and Lysimeter #2 gauge failed. Ground R/G replaced. Suspect reed switch on Roof R/G is faulty - gauge calibrates correctly, but rain tote for this period is suspect. Wired both reed switches together to resolve problem. Delete all tips between 20090821 1230-1530hrs."
Roof check gauge: 455.0 mm (tote = 573.5 mm) - 20.6% difference

Ground check gauge: 671.0 mm (tote = 629.0 mm) - 6.3% difference

@@ 2597-2598 20090921 114500
M. Parker (EBOP) Check Sheet: "Replaced faulty Lysimeter #2 gauge. Delete all tips between 20090921 1200-1245hrs."
Roof check gauge: 71.0 mm (tote = 102.5 mm) - 30.7% difference
Ground check gauge: 38.0 mm (tote = 76.5 mm) - 50.3% difference
Suspect fault with roof check gauge - M. Parker replaced tubing 20090930.

@@ 2597-2598 20091120 081500
M. Parker (EBOP) Check Sheet: Checked Calibration on all gauges (4) on-site. All gauges passed calibration. Delete all tips between 081500 and 110000
Roof check gauge = 132 mm (tote = 171 mm) - 22.8% difference
Ground check gauge = 182 mm (tote = 171.5 mm) - 6.1% difference

@@ 2597-2598 20100317 100000
M. Parker (EBOP) Check Sheet: Checked calibration on all gauges (4) on-site. All gauges passed calibration. Delete all tips between 101500 and 115000
Roof check gauge = 276 mm (tote = 307.5 mm) - 10% difference
Ground check gauge = 326 mm (tote = 323 mm) - 0.9% difference

@@ 2597-2598 20100531 143000
M. Parker (EBOP) Check Sheet: Checked calibration on all (4) gauges on-site. All gauges passed calibration. Delete all tips between 143000 and 160000. Gap in infilration 2 data from 20100531 143000 to 20100621 163000 (21.08 days). Funnel between soil infiltration gauge 2 collecting pan and rain gauge became detached from intensity gauge sometime after this inspection, re-attached on 20100621 163000
Roof check gauge = 447 mm (tote = 495 mm) - 9.6% difference
Ground check gauge = 500 mm (tote = 474 mm) - 5.48% difference

@@ 2597-2598 20100908 124500
M. Parker (EBOP) Check Sheet: Checked calibration on all gauges (4) on-site. Infiltration 1 failed calibration within 1ml of the acceptable range, left on-site. Delete all tips between 130000 and 145000
Roof check gauge = 630 mm (tote = 836 mm) - 24.6% difference
Ground check gauge = 870 mm (tote = 833.5 mm) - 4.4% difference

Appendix 4 – GNS Report – Test and Maintenance of lysimeter at the Bay of Plenty Regional Council Kaharoa rainfall recharge site

Letter Report No: 2008/135LR
Project No: 520W2115

7 July 2008

Environment Bay of Plenty
PO Box 364
WHAKATANE 3158

Attention: Dougall Gordon

Dear Dougall

Re: Test and reinstallation of a lysimeter at the Environment Bay of Plenty Kaharoa rainfall recharge site

EXECUTIVE SUMMARY

Two lysimeters were installed in June 2005 to measure groundwater recharge at the Environment Bay of Plenty Kaharoa rainfall site as part of the Lake Rotorua groundwater study. Field studies showed that one of these lysimeters (number 2598) was leaking.

A laboratory test of lysimeter 2598 confirmed that it was leaking around the join between the base plate and the lysimeter wall. The join was probably not properly sealed since installation of lysimeter 2598. This join was replaced and a test showed no leaks were occurring. Lysimeter 2598 was then reinstalled at Kaharoa.

Recommendations for future lysimeter installation include:

- the join between the base plate and the lysimeter wall should be tested, and defects in the join remedied, prior to lysimeter installation;
- artificially high soil moisture at the commencement of monitoring, due to the test of the join between base plate and lysimeter wall, is considered during interpretation of monitoring results; and
- a two ton excavator should be used to lift lysimeters and enclosed soil columns as this excavator has the capacity to ensure that lifting is done safely.

1.0 INTRODUCTION

Groundwater recharge from rainfall has been measured at Kaharoa, north of Rotorua, since June 2005 (White et al. 2007) in lysimeters 2597 and 2598 (Figure 1 and Figure 2). Lysimeter 2598 has recorded significantly less rainfall recharge than lysimeter 2597. For example lysimeter 2598 recorded about one third of the rainfall recharge recorded by lysimeter 2597 in the period August 2005 to July 2006 (Table 1).

Table 1 Kaharoa rainfall recharge site – data summary (White et al. 2007).

Kaharoa rainfall recharge site					
Year	**Month**	**Rainfall recharge lysimeter 2597 (mm)**	**Rainfall recharge lysimeter 2598 (mm)**	**Ground-level rainfall site 2599 (mm)**	**Primary rain gauge rainfall site 860205 (mm)**
2005	August	123	6	182	177
2005	September	4	20	131	140
2005	October	203	64	338	318
2005	November	0	0	53	49
2005	December	34	31	237	239
2006	January	151	42	288	261
2006	February	114	54	198	196
2006	March	68	12	192	183
2006	April	211	75	338	340
2006	May	168	64	253	243
2006	June	68	18	110	112
2006	July	63	37	119	115
sum August 2005 – July 2006		1207	423	2439	2372

Given the large discrepancy between rainfall recharge measured in the two lysimeters, White et al. (2007) recommended that:

- a constant volume test should be made on lysimeter 2598 with enough water to saturate the soil column. Depending on the inspection, the following corrective actions could be taken including:
  - reseal the base of the lysimeter;
  - replace, or reseal, the drain line.
- a constant volume test could be completed, following corrective actions, to ensure correct functioning of lysimeter.

This report describes the field testing of lysimeters 2597 and 2598. After field testing, lysimeter 2598 was removed and tested in the laboratory and leaks were identified. A laboratory test was completed after lysimeter 2598 was resealed and lysimeter 2598 was reinstalled at the Kaharoa site.

3.0 FIELD INFILTRATION TEST OF LYSIMETERS 2597 AND 2598

The infiltration test was undertaken on 10 August 2007 by Stewart Cameron. This date was selected as no rainfall had occurred at the site over the previous four days and the weather forecast predicted no rain for the next three days. 10 L of deionised (DI) water was discharged on top of lysimeter 2597 and lysimeter 2598 over a 1.5 hour period. The infiltration rate is approximately the maximum natural rainfall infiltration rate that had been measured at the site since December 2006. The neck of a small funnel was inserted to approximately 5 cm depth at the centre of each lysimeter. The DI water was then tipped into the funnels and allowed to partially drain before refilling. No surface flow around the outside of the necks of the funnels was observed suggesting most, if not all, of the 10L volume drained into the lysimeters. The lysimeters were then covered by a tarpaulin so that infiltration of rainfall would not occur should non-forecasted rainfall occur during the period of monitoring.

The tipping bucket gauges began receiving infiltration test water approximately 1 hour after the start of the test. The volume of water that flowed into the collection containers was measured daily by Martin Hawke. The volumes of water measured in each lysimeter are summarised in Table 2.

Table 2 Summary of field infiltration test undertaken on 10 August 2007. Measurements in mL.

Lysimeter	11/8/07	12/8/07	13/8/07	Totals
2597	6950	360	160	7470
2598	3100	20	10	3130

Approximately 7470 mL of water collected in the container from lysimeter 2597, while only 3130 mL of water was collected in the container from lysimeter 2598. These results indicate that lysimeter 2598 was leaking. The leak was most likely to be from the join between the base plate and cylinder wall of the lysimeter. During installation of the lysimeters in March 2005 the join was "sealed" with a silicone-based compound. The integrity of the seal was not tested prior to installation. Therefore, it was decided that lysimeter 2598 should be removed and tested during summer 2007/2008.

4.0 REMOVAL OF LYSIMETER 2598

Lysimeter 2598 was removed on 12 March 2008 by GNS Science personnel (Stewart Cameron, Stephanie Cave and Geoffrey Undereiner). The site was excavated and the lysimeter removed by a 1.5 ton excavator (Figure 3). Future excavation of a similar size lysimeter should be undertaken with a 2 ton excavator as the 1.5 tonne excavator was at the limit of its lifting capacity.

The lysimeter was taken to GNS Science Wairakei Research Centre for testing. The grass sod that was removed from the lysimeter site was also taken to Wairakei so it could be watered during the period of lysimeter tests.

5.0 LABORATORY INFILTRATION TEST OF LYSIMETER 2598

Ten litres of tap water was input into the lysimeter through five tubes that were inserted approximately 3 cm into the soil column (Figure 4) on 13 March 2008. The results of the infiltration test are summarised in Table 3.

Table 3 Summary of laboratory infiltration test of lysimeter 2598 undertaken on 13 March 2008

Time since start (min)	Cumulative total water into lysimeter (L)	Cumulative total water out from lysimeter drain (L)	Leak observed
65	2.0		
73	3.1		
78	4.0		
80		Flow starts	
85			Leak 1
92	6.0	1.0	
95			Leak 2
97			Leak 3
102		1.8	
107	8.0		
110		2.0	Leaks stop flowing
111		Valve closed	Leaks start flowing
112			Leaks 4 and 5
122	10.0		Significant flow from all leaks

Water began to flow from the lysimeter drain line after 80 minutes. For approximately 30 minutes after the water started flowing only very small seepage leaks were observed around the join between the base plate and the lysimeter wall (Figure 5). The rate of seepage through leaks between the base plate and lysimeter wall was insufficient to account for the assumed leakage measured during the field infiltration test in August 2007. After 111 minutes from the start of the test the drainage line from the lysimeter was closed to raise the water level in the lysimeter. This caused significant increase in leakage from the join between the base plate and the lysimeter wall. The rate of leakage was easily enough to account for the discrepancy measured in the field infiltration test. An attempt was made to stop the leakage by tightening the four vertical rods that hold the base plate in place (Figure 5). This was ineffective. At this time the testing was abandoned and the lysimeter was allowed to drain overnight.

6.0 REPAIR AND LABORATORY TESTING OF LYSIMETER 2598

The next day all of the silicone sealant was removed from the join by cutting knife, wire brush, and a wire brush mounted on an angle grinder. The steel around the join was regalvanised after the leakage had completely ceased and water evaporated. Galvanised paint was allowed 24 hours to dry as specified in the manufacturer's instruction. On 15 March 2008 the joint was sealed with marine grade silicone sealant. The silicone sealant was given 48 hrs to cure as specified in the manufacturer's instructions.

Another laboratory infiltration test was performed on the lysimeter on 17 March 2008 to check the integrity of the new seal. The results of the test are summarised in Table 4. No leaks were observed during this test even after the outlet line was closed and water level in the lysimeter allowed to increase.

Table 4 Summary of laboratory infiltration test of lysimeter 2598 undertaken on 17 March 2008

Time since start (min)	Cumulative total water in (L)	Cumulative total water out (L)	Leak observed
8	2.0		
16	4.0		
20		Flow starts	
26	6.0		
37	8.0		
40		2.0	
48	10.0		
60		4.5	
130		5.5	
137		Valve closed	
180			

Lysimeter 2598 was reinstalled at the Kaharoa site on 18 March 2008 by GNS Staff (Stewart Cameron, Stephanie Cave and Erika Kovacova) (Figure 6). The reinstallation was undertaken with assistance from a 1.5 ton excavator. A layer of stiff cardboard was placed around the base plate-wall join to protect the sealant. The plumbing from the lysimeter to the tipping bucket rain gauge was reconnected and the grass sod relayed (Figure 7).

7.0 RECOMMENDATIONS

The join between the base plate and the lysimeter wall should be tested prior to lysimeter installation and a test like that outlined in Section 5 is recommended. This test will add approximately 48 hours to lysimeter installation time. Equipment to test the join will be required for field operations.

The test of the join between the base plate and the lysimeter wall may impact on rainfall recharge measurements soon after installation. This is because the test necessarily involves saturating the soil column in the lysimeter. Therefore the lysimeter will commence monitoring with an artificially high soil moisture level. For example a lysimeter installation in summer, with a test of the join between the base plate and the lysimeter wall, would probably result in soil saturation that is higher than normal in the lysimeter soil column.

The lysimeter will take longer to 'settle' to measurement of natural groundwater recharge after the test of the join between the base plate and the lysimeter. It is recommended that assessment of groundwater recharge immediately after installation, and after a test of the join between the base plate and the lysimeter, considers the artificially high soil moisture levels at the start of monitoring. Rainfall recharge measurements in the month after installation could be assessed in relation to the full period of record. For example rainfall recharge recorded in the month, or so, after installation may be larger than average for the period, and time of year. This may indicate that water from the test of the join between the base plate and the lysimeter is impacting on the monitoring results.

The soil at Kaharoa drains relatively quickly (Table 4). Therefore the lysimeter will probably reach natural moisture, and produce natural rainfall recharge, beyond a week after installation.

It is also recommended that a two ton excavator is used to lift lysimeters and enclosed soil column as this excavator has the capacity to ensure that lifting is done safely.

8.0 REFERENCE

White, P.A, Zemansky, G., Hong, T., Kilgour, G., Wall, M., 2007. Lake Rotorua groundwater and Lake Rotorua nutrients – phase 3 science programme technical report. *GNS Client report 2007/220 to Environment Bay of Plenty. 402p.*

Yours sincerely

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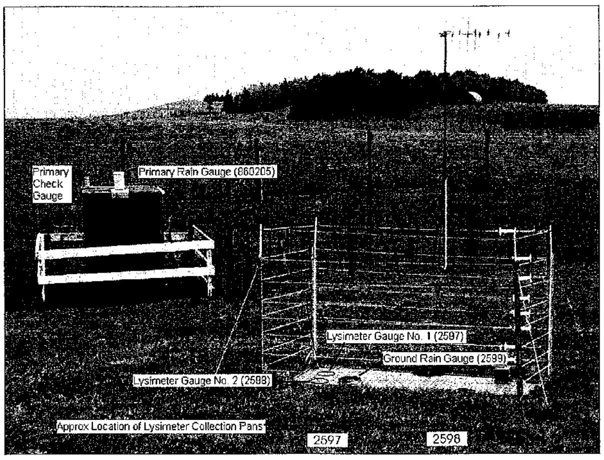

Figure 1 Kaharoa rainfall recharge site (White et al. 2007).

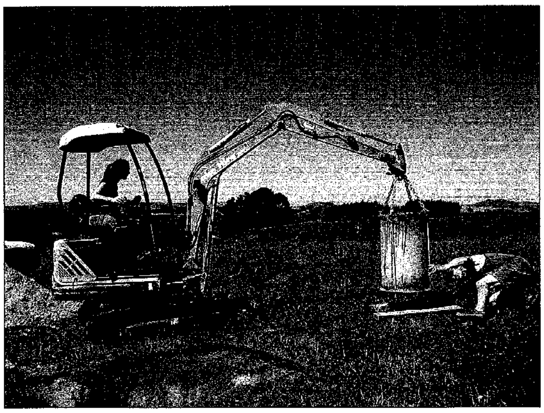

Figure 3 Removal of lysimeter 2598 in March 2008.

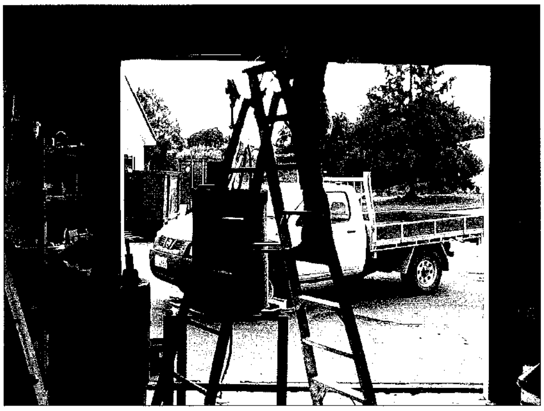

Figure 4 Laboratory testing of lysimeter 2598 for leaks.

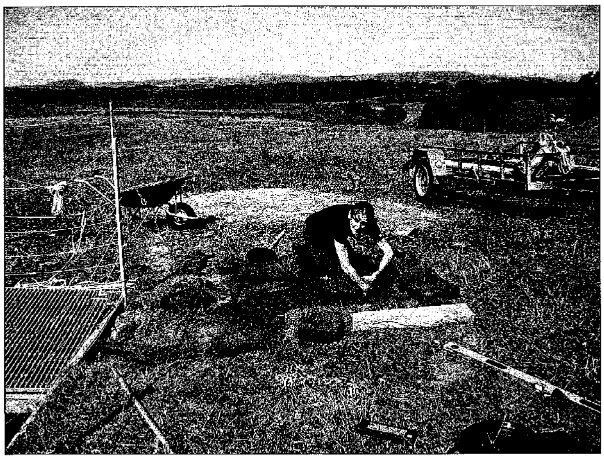

Figure 7 Laying grass sod after reinstallation of lysimeter 2598.

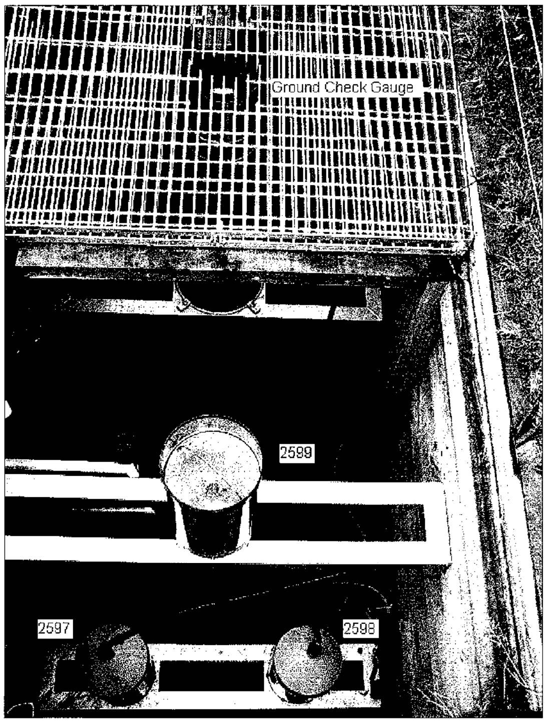

Figure 2 Kaharoa rainfall recharge site – instruments (White et al. 2007).

Figure 5 Water leakage around the join of base plate and lysimeter wall. Note vertical rod holding base plate in place.

Figure 6 Photograph of reinstallation of lysimeter 2598 showing protective cardboard 'skirt' around the base plate-wall join.

Appendix 5 – Anomalies associated with Lysimeter and Rainfall Data

Date	Recharge		Rainfall		Anomalies identified for Lysimeter 2597 and 2598	
	2597	2598	2599	860205	Problem	Answer
09-12-05	0	0	12	0	Zero 860205 Rain	CGP did an inspection on this day which hasn't been recorded in the comments. The calibration tips for RG 2599 were not removed from the data set. Calibration tips have now been removed – see attached .mtd file
29-07-07	38.08	24.72	70	1	Zero 860205 Rain	No explanation
30-07-07	23.76	10	25	0	Zero 860205 Rain	No explanation
31-07-07	3.92	0	5	0	Zero 860205 Rain	No explanation
04-09-07	0	0	6	0	Zero 860205 Rain	No explanation
04-07-08	2.4	0	5	0	Zero 860205 Rain	No explanation
05-07-08	5.6	0	10	0	Zero 860205 Rain	No explanation
06-07-08	1.52	0	1	0	Zero 860205 Rain	No explanation
10-07-08	0	0	3	0	Zero 860205 Rain	No explanation
11-07-08	2.56	0	11	0	Zero 860205 Rain	No explanation
12-07-08	11.84	0	16	0	Zero 860205 Rain	No explanation
11/08/2008 to 23 /08/2008					Ground Rain Appears Faulty No Data Capture for a substantial event	No explanation
02/07/2008 to 12/07/2008					860205 recorded no data but this was a reasonable event	No explanation
24-12-07					2597 = 0 until the 14-04-2008. No rainfall recharge recorded?	No comments or check sheets to explain the absence of recharge over this period. Craig P processed this batch of data so will check if he knows anything more about it, he is away until 18/10. Infiltration gauge 2 was disconnected and removed for repair on 13/3/08 and reinstalled on 18/3/08.
06-03-09	33.84	0	48	55	0mm in 2598?	Unexplained…leaking? CGP processed this batch so will check with him
01-02-10	13.2	0.24	42	53	Lysimeter 2 appears to be leaking again	Yes there is no other explanation for the lack of inf 2 recharge on this day other than a leaking issue. This seems to be more of an issue during drier periods, perhaps when the soil is already saturated the recharge water has nowhere else to go and so the leak is less apparent.

Appendix 5 – Monthly Rainfall and Rainfall Recharge

Monthly Rainfall and Recharge December 2005 to May 2010					
		Rainfall Gauge		Recharge Gauge	
Month	**Year**	**2599**	**860205**	**2597**	**2598**
Dec	2005	237	249	82	31
Jan	2006	288	261	150.56	42
Feb	2006	198	196	113.68	54.24
Mar	2006	192	183	67.52	12.48
Apr	2006	338	340	211.28	75.36
May	2006	253	244	170.4	64.24
Jun	2006	110	112	67.92	17.6
Jul	2006	119	115	63.44	37.12
Aug	2006	202	192	145.76	71.04
Sep	2006	44	45	11.52	1.76
Oct	2006	128	133	43.12	27.52
Nov	2006	104	110	22.4	3.12
Dec	2006	70	70	2.16	1.52
Jan	2007	219	203	122	50.16
Feb	2007	54	55	0	0.08
Mar	2007	286	269	175.04	96.16
Apr	2007	89	93	26.48	6.64
May	2007	66	73	58.64	16.48
Jun	2007	169	169	106.96	47.76
Jul	2007	201	300	208.56	89.68
Aug	2007	189	212	174.64	67.28
Sep	2007	100	114	48.88	1.12
Oct	2007	115	127	65.44	15.36
Nov	2007	54	59	0	0
Dec	2007	145	153	30.96	4.88
Jan	2008	76	76	0	0.24
Feb	2008	92	89	0	0.08
Mar	2008	70	79	0	3.28
Apr	2008	437	471	220.88	114.64
May	2008	114	115	60.4	59.44
Jun	2008	252	253	158.48	0.48
Jul	2008	235	296	202.32	20.4
Aug	2008	152	255	184	15.68
Sep	2008	180	168	106	0.24
Oct	2008	148	150	62.64	0.16
Nov	2008	85	83	5.44	22.48
Dec	2008	150	142	18	9.52
Feb	2009	166	166	3.28	0
Mar	2009	118	106	56.16	3.92
Apr	2009	175	161	0	0
May	2009	94	95	9.12	10.88
Jun	2009	227	202	164.24	149.52
Jul	2009	169	161	115.04	114.64
Aug	2009	256	261	191.2	181.28
Sep	2009	157	158	83.36	79.28
Oct	2009	158	112	71.12	78.48
Nov	2009	27	24	0	0
Dec	2009	80	72	0	0.24
Jan	2010	146	123	0	0.32
Feb	2010	93	75	14.16	0.32
Mar	2010	30	28	0	0
Apr	2010	69	56	0	0.08
May	2010	429	391	199.92	72.48