7. Agricultural Trial

7.1 Introduction

The original investigation plan for the agricultural trial involved application of a mixture of compost, urine and leachate to a pasture trial area and a crop trial area starting in Autumn 2008. However, the low usage of the toilets meant that there was insufficient material for a meaningful trial. Thus the plan was modified to make an application to growing pasture and crop in Spring 2008. By this time there was only a few kilograms of partly desiccated faecal matter and toilet paper and, in view of the absence of any evidence of composting having taken place, and the recognisable appearance of the material, it was decided to exclude solids from the application. The urine and leachate tanks were sampled for analysis, soil tests on the application site were organised and on 4 September 2008 a total of approximately 600 L of urine and leachate was removed from the toilets and applied at the test site. This section describes the implementation of and results from this agricultural trial.

7.2 Observations During Collection

The volumes in the urine tank and leachate tank were measured prior to arrival of the eductor truck. There was approximately 360 L in the urine tank and 375 L in the leachate tank. The eductor truck, operated by Sludgebusters of Maryborough, a septic tank and triple interceptor trap pump-out contractor, was washed out with water prior to collection. A 50 mm suction hose was used to remove the urine and leachate from the tank with approximately 320 L of urine and 265 L of leachate being removed to give a total of 585 L (all measurements accurate to plus or minus approximately 20 L).

The collection of urine and leachate was undertaken before school hours in case there was odour. In fact, a combination of the small volume removed and the fact that the eductor truck used a perfumed masking agent in the vacuum pump meant that no odour, other than a slight perfumed odour, was detected outside the toilet building. With the basement there was only minor odour when the tank hatches were removed, as there would have been little movement of air out of the tanks. If a full load was removed, the air within the tanker would have become more odorous and this may have overloaded the ability of the perfumed masking agent to mask the odour. However, the duration of pump-out, on this occasion, less than 5 minutes and even if tanks were full, probably less than 20 minutes, would limit the duration of odour.

The odour of the urine tank and leachate tank contents is described as sharp, unpleasant and of an amine/ammonia type. The smell is not like pure ammonia.

There was no spillage. The operator flushed the hose with around 2 L of tap water on completion. This would have diluted the 585 L collected, but this was not accounted for in any calculations.

7.3 Trial Plots and Nutrient Loading Rate

Discussion with the farmer and the local fertiliser supplier indicated that an appropriate application of urine and leachate would be at a rate equivalent to 50 kg of nitrogen per hectare both to the canola and the pasture to which trial application was to be made. 75 kg/ha of N had been applied to the canola crop on planting but there had been no recent fertiliser application to the pasture. The areas selected for application were within a 50 m by 50 m (0.25 ha) area previously marked out on pasture and a similar area previously marked out on a canola crop. Soil profiles and soil tests had been undertaken on these two areas in the preceding week, the results of which are discussed in Section 7.9. Using the measured concentrations of total nitrogen of 2.9 g/L in urine and 0.227 g/L in the leachate, it was estimated that the collected mixture of urine and leachate contained 988 g of total nitrogen. Since half of this was to be applied to a pasture plot and half to a canola plot, 494 g of total nitrogen was available to each plot. Note that because the analysis was for a slightly more dilute mixture from a week before, the actual mass may have been around 2.8% higher or around 508 g per plot. To achieve the required application of nitrogen of 50 kg/ha meant that plots needed to be 98.8 m^2 in area or 9.94 m by 9.94 m. Note that the actual total N application rate may have been up to 51.4 kg/ha on the plots to which urine and leachate was applied.

Three plots, each of 98.8 m^2, were laid out on the canola crop and three on the pasture crop, one to be treated with the urine/leachate mixture, one with chemical fertiliser and one with no treatment as a control.

The quantities of chemical fertiliser to apply were worked out to give the same nitrogen, phosphorus and (estimated) potassium loading rates as calculated for the urine/leachate plots.

Based on the analysis (actual may have been 2.8% higher), the loadings of phosphorus and potassium on the urine/leachate plots were calculated to be 4.85 kg/ha of P and an estimated 8.4 kg/ha of K. The potassium concentrations in the leachate and urine were not available at the time of application and the actual concentrations were substantially higher than estimated. Thus, the actual K application rate was 34.6 kg/ha, meaning that the urine plot received some four times the potassium application as the chemical plot.

Chemical fertiliser used comprised urea (46% nitrogen), 99% potassium chloride or muriate of potash (MOP) (approximately 52% K) and single superphosphate (8.8% P). These were provided by the local fertiliser supplier, who was engaged to undertake the soil testing. Appropriate masses of chemical were weighed out using a platform scale accurate to plus or minus 50 g. The quantities measured out for each chemical fertiliser plot were 1074 g of urea, 545 g of single superphosphate and 168 g of MOP (this was based on an incorrect 50% of K in the MOP). The accuracy of measurement was such that actual application rates on the chemical plots may have been around 5% higher or lower than intended (up to 7% higher or 3% lower for potassium).

7.4 Typical Fertiliser Application Rates

The local fertiliser supplier indicated that farmers in the Maryborough area might apply between zero and up to 50 kg of N/ha.yr. Farmers who crop continuously on most paddocks will apply nitrogen at the high end of this range. Farmers who rotate cropping with grazing of pasture may apply no nitrogen in most years and rely on the normal fixing of nitrogen achieved by pasture plants. It generally takes around four years of continuous cropping of a previous pasture paddock before soil nitrogen drops low enough to get an economic response from adding nitrogen. Low rainfall in the current period is reducing the crop yield and hence the nitrogen uptake. Further south towards Ballarat some farmers may apply as much as 60 kg N/ha.yr.

Nationally, data from FIFA (2007) indicates that the following total tonnages of N, P and K are applied to Australian soils per year:

N: 745 000 tonnes/yr

P: 382 000 tonnes/yr

K: 155 000 tonnes/yr

The ratio of N:P:K uses is therefore 100:51:21.

ABS data (ABS 2008) indicates that the total area of land cropped or grazed in Australia in 2005 was 445 million hectares, which is 57.9% of the total area of Australia. Of this, 26.7 million hectares was cropping land. Since application of fertiliser to grazing land is limited, the approximate average application of N, P and K to Australian soils is of the order of:

27 kg N/ha.yr

14 kg P/ha.yr

5.6 kg K/ha.yr

If calculated on total land used for grazing and cropping the application rates drop to approximately:

1.7 kg N/ha.yr

0.86 kg P/ha.yr

0.35 kg K/ha.yr

7.5 Available Nutrients in Urine and Composted Faecal Matter

As a comparison to total N, P and K use in Australia, if all human excreta was recovered either as urine or compost from the current population of around 21 million people, the following masses of N, P and K would be available for use in Agriculture.

N tonne/yr: 77 000 in urine, 9 000 in compost, total 86 000 or 11.5% of current Australian use

P tonne/yr: 7 700 in urine, 3 800 in compost, total 11 500 or 3.0% of current Australian use

K tonne/yr: 11 500 in urine, 5 400 in compost, total 16 900 or 11% of current Australian use

Whilst it is clear from this comparison that human excreta could only replace a small part of current fertiliser used in Australia, it must be remembered that Australia's fertiliser use per-capita is high due to the large proportion of food production that is exported. For example, on average, around 65% of Australia's wheat crop is exported.

7.6 Application Methods

The urine/leachate mixture was discharged from the tanker into a 600 L plastic tank with closed top that the farmer had available. This was achieved by gravity although the tanker could blow out the contents if required. The tank on the tanker can also be tilted and this was done to fully drain the contents. Half the contents of the plastic tank (around 298 L) were pumped into a separate 440 L capacity tank on a utility and diluted with bore water. A fire pump was then used to spray this over the pasture plot, which had been measured and pegged. This method of application involved some spray drift and accuracy of distribution would not have been high. The additional water did allow about four minutes of pumping to achieve as even coverage as possible. It is estimated that N, P and K application rates over the plot could vary by between 25% and 150% of the target application rates.

Because of the risk of salt impact on the leaves, a further 440 L of bore water was then hosed over the plot to wash the diluted urine/leachate from the leaves. The total volume of liquid applied to the plots fertilised with urine/leachate mixture was thus 880 L equivalent to rainfall or irrigation of 8.9 mm.

The same application procedure was used for the urine/ leachate mixture applied to the canola.

During hosing of the urine/leachate mixture over the plots there was a moderate wind from the northeast. The principal investigator walked downwind of the spray and noted some odour characteristic of the urine and leachate and there was a visible mist that he walked through. The smell remained downwind of each plot for an hour or so after application. The farmer who undertook the hosing did not comment on particularly bad odour.

The preferable application method on bare soil, pasture or crop would be from a trickle bar on the back of the eductor tuck rather than a hose nozzle and this would probably generate less odour. Overall, the principal investigator considers that the odour was slight and was less than he had anticipated.

The chemicals to be applied to the chemical fertiliser plots were mixed together in a bucket and then broadcast by hand over each plot. This method did not provide a particularly even application and it is estimated that N, P and K application rates may have varied between 10% and 200% of target loadings over each plot. Chemical plots were hosed with 440 L of bore water after application to wash any dry chemical from the leaves, equivalent to rainfall/irrigation of around 4.4 mm.

Prior to application the soil was moist but after application there were puddles present for an hour or so.

The farmer considered that the additional water applied to the urine/leachate plots compared to the chemical and control plots would not have an impact on crop response since there was adequate soil moisture anyway, however this differing water application remains as a variable between the plots.

The photographs in Appendix K show the various plots. Plots were separated by around 9 to 11 m.

7.7 Crop Response

7.7.1 Initial Conditions

The photographs in Appendix K show the condition of the canola and pasture on the day of application. The pasture was dominated by barley grass with some sub-clover. There was a poorer grass cover over some of the urine plot than the chemical and control plots. Grass was between 2 and 120 cm high.

The principal investigator measured plant heights in the canola plots at five locations in each of the three plots (the plant closest to a point 1 m from the corners and at the centre). The specific plants measured were identified with plastic tape tied loosely around their bases.

The average of the five plant heights per plot measured on the day of application (4 September 2008) were:

550 mm on the urine plot (between 445 and 705 mm)

510 mm on the chemical plot (between 220 and 820 mm)

511 mm on the control plot (between 375 and 660 mm)

A further measurement of plant height was made on all plants over approximately 1 m^2 on the northeast corner of the urine plot. There were approximately 22 plants in this area varying from 230 to 700 mm in height. The average height was 442 mm.

The average height of all plants measured was 452 mm. The average height of all of the five plants measured on each plot and identified with plastic tape was 524 mm. This latter figure is considered to be most representative of the average height over all three plots. Statistical analysis using the Student T test indicated there was no significant difference between plant heights between the three trial plots at the 95% level of confidence.

7.7.2 Farmer's Observations

The farmer reported on 24 September 2008, 20 days after application, that the urine and chemical pasture plots became significantly greener within a few weeks of application compared to the control plot. Grazing of the pasture at a low stocking rate was continued throughout the trial. There were no observable detrimental effects noted on either the urine or chemical plots, both pasture and canola, post-application. There was no visible additional growth on the urine and chemical pasture plots but the author and farmer agreed that the urine canola plot showed some signs of plant height being greater than on either the chemical or control canola plots. The farmer stated that a visible difference such as this in the canola generally was only observed where crop yield was around 20% increased.

7.7.3 Rainfall Record

Table 9 shows the rainfall recorded in Carisbrook (which is south west of the property) and Baringhup (to the north east of the property) over the period July to mid-November 2008. It can be seen that rainfall was reasonable before the trial started on 4 September but September was dry and October was very dry. This low spring rainfall resulted in early cutting of the canola on 6 November 2008, compared with normal cutting in December.

The additional 8.9 mm of water applied to the urine plots and 4.4 mm applied to the chemical plots on 4 September may have made some difference to crop response, but it was applied at a time when earlier rain had left the soil moist. The opinion of the farmer was that the water added to the Urine and Chemical Plots would not have made a significant difference to their responses compared to the Control Plots.

Table 9 Rainfall Records During Agricultural Trial

	Total Rainfall	
Date	**Carisbrook**	**Baringhup**
1-Jul-08 to 31-Jul-08	63.4	59.6
2-Aug-08 to 31-Aug-08	32	45.8
1-Sep-08 to 30-Sep-08	24.4	12.4
1-Oct-08 to 31-Oct-08	9.4	8.2
1-Nov-08 to 12-Nov-08	25.6	24.9
Agricultural trial total 4-Sep-08 to 6-Nov-08	29.6	17.1

7.7.4 Measured Canola Response

Measurements were taken on the canola plots on the morning of 6 November 2008, 9 weeks after application of the urine and chemical. The canola was cut and windrowed on the afternoon of the same day, as the lack of rain meant that no further seed development was expected.

The measurements undertaken were:

- Counts of seeds per pod and pods per stem on five plants in each plot
- Measurement of the heights of the five marked plants in each plot
- An attempt to estimate the average height of plants in each plot from photographs
- Cutting of at least two rows per plot at approximately 50 to 100 mm above the soil and immediate weighing of the cut plants.

Table 10 summarises the measurements and details are included in Appendix J. Photographs of the canola plots on 6 November are included in Appendix K.

Table 10 Measured Canola Response

Measurement	Unit	Urine Plot	Chemical Plot	Control Plot	Comments
Average plant height of 5 plants at start of trial	mm	560	512	511	The difference between the means for the Urine and Chemical Plots was not significant at the 95% level of confidence.
Total water applied at start of trial	mm	8.9	4.4	0	The farmer considered at both the start and end of the trial that the difference in applied water would not have made any significant difference. The soil on all plots was damp before application.
Estimated rainfall during trial	mm	25	25	25	
Average plant height of 5 plants at cutting	mm	1120	1094	1112	The difference in means between the Urine and the Chemical and the Urine and Control Plots was not statistically significant at the 95% level of confidence.
Estimated typical plant height from photographs	mm	1190	1180	1160	This is not a reliable method of comparing plant heights but tends to support the farmers impression that plants on the Urine Plot were possibly higher, at least higher than on the control plot.
Plant mass estimated	kg/ha	22934	18472	15463	The accuracy of these estimates is probably not better than ±15 to 20% so the differences cannot be regarded as significant.
Mean no of seeds per pod	number	17	13	15	The difference between the mean for the Urine Plot and the means for the other two plots was statistically significant at the 95% level of confidence. The difference between the means for the chemical and control plots was not significant.
Mean number of pods per middle plant stem	number	40	45	45	The difference between the means for the Urine and Chemical plots was not statistically significant at the 95% level.
Mean number of seeds per stem	number	687	609	676	Implies some lower yield on chemical plot but urine and control plots having a similar yield.

Photographs in Appendix K show the condition of the three plots on completion of the trial, as well as the equipment used to measure and cut the crop.

Initial inspection of the results in Appendix J suggests that plant height, the number of seeds per pod and the plant mass was higher on the Urine Plot than on the other two plots. Where there were sufficient data for evaluating statistical significance between calculated means, the Student T test was applied and this showed that the only mean plant height and seeds/pod showed any significant differences between plots and that these data indicated higher values for the Urine Plot than for the Control Plot and possibly the Chemical Plot. The estimated plant mass was not a very accurate measurement because it is common for the mechanical seeder to leave gaps in some rows and only two rows were cut and used in the averages for each plot.

The initial plant height appeared to be higher on the Urine Plot (that is before the application of urine) but the difference was not statistically significant from the Chemical or Control Plots. Nevertheless, the fact that final plant height on the Urine Plot appeared to be greater may in part be due to a higher average starting height.

The greater addition of water to the Urine Plot is also a potential reason for higher plant height and seed count on the Urine Plot.

The lower number of seeds per pod on the Chemical Plot may have indicated some inhibition by over-application of fertiliser. The local fertiliser supplier advised that this response has been noted this year and is attributed to the lack of rain and the potential for applied chemical to inhibit plant growth if water is limited. ‘Watering in’ of the fertiliser in this case may have overcome or partly overcome any such effect and it is relevant that such an effect was not noted on the Urine Plot.

The advice from the farmer and from the local fertiliser supplier is that the count of seeds per pod is the best overall indicator of canola response to growth conditions. On this basis perhaps the Urine Plot showed an improved response.

The only conclusion that can be reliably drawn from the measurements is that the canola plants on the Urine Plot were not detrimentally impacted by application of the urine/leachate mixture and may have shown some improved yield of seeds when compared with for the Chemical and Control Plots.

7.7.5 Measured Pasture Response

Because the pasture was totally dry for the last few weeks of the trial there was limited potential for any differences in the plots to be measured. The dried pasture was only around 75 to 150 mm high at the conclusion of the trial and there was no discernable difference in height between plots. The photographs in Appendix K illustrate this.

A domestic lawn mower with catcher was used to cut two diagonal strips per plot and the mass of dry pasture collected was measured on platform scales. This required two cuts and weighings on all plots and because varying amounts of cut pasture was left on the ground, the method is not considered accurate. Results are included in Appendix J and indicate around 2.3 tonne of cut pasture (at an unmeasured field moisture content) per hectare on both the Chemical and Urine Plots, compared to 2.2 tonne per hectare on the Control Plot. This possibly higher yield is consistent with the visual observations by the farmer in the first few weeks after application, but again, this may have been a response to the added water.

The conclusion is similar to that for the canola plots: that application of the urine/leachate mixture did not have any detrimental effect and may have had a slightly beneficial effect similar to that from the chemical application.

7.8 Financial Value of Urine and Compost

Table 11 shows how the costs per kilogram of nitrogen, phosphorus and potassium as components of fertiliser have varied, from October 2007 to May 2009 (based on advice from Dellavedova Fertilisers in Maryborough).

Based on these costs for N, P and K as fertiliser and the measured amounts of each nutrient in the urine and compost samples collected from the installation, it is possible to estimate an approximate value of the urine and compost for use as a fertiliser.

As the composition analyses (see Table 3 and Table 4) suggest, the compost (which contains a greater amount of key nutrients (N, P and K) per kilogram) would have a much higher value per tonne as a fertiliser than the urine sample because of the large mass of liquid in the latter. The calculations are based on the average concentrations of N, P and K in the three samples and moisture content of 28%. If moisture content were greater, the value per tonne of wet material would of course reduce.

The value of N, P and K as fertiliser has varied significantly over the period from October 2007 to May 2009, as shown in the table. The values peaked around December 2008, with costs for nitrogen, phosphorus and potassium at approximately 2.25, 6.75 and 3 AUD per kilogram of each element respectively. Using these peak values for the costs of these key components, the respective values of the urine and compost are estimated to be around 20 AUD/kL and 160 AUD/tonne for the same period.

Using current (May 2009) costs of N, P and K per kilogram, the estimated values for urine and compost are around 13 AUD/kL and 110 AUD/tonne respectively.

By contrast, the price of conventional chemical fertilisers at the peak prices in December 2008 were around: 1 035 AUD/tonne for urea containing 45% N, 590 AUD/tonne for single superphosphate containing 8.8% P and 1 500 AUD/tonne for potassium chloride (muriate of potash) containing 50% K.

Compared to these percentages of nutrients in chemical fertilisers, urine is a very dilute source (weight percentages of around 0.45%, 0.03% and 0.23% of N, P and K respectively) and compost is also contains fairly low percentages by weight (1.8%, 1.2% and 1.4% of N, P and K respectively).

If it is assumed that the price of compost and urine at the source is zero then a farmer should be willing to pay a transport and application cost up to the equivalent of what is paid for conventional fertilisers.

If the farmer wishes to apply 100 kg N/ha then he will need to apply 5.6 tonnes of compost per ha or 21.4 tonne of urine per ha. The value of the N, P and K in compost at May 2009 prices is around 110 AUD/tonne and the value of these nutrients in urine is around 13 AUD/tonne. Thus the farmer could pay up to 110 AUD/tonne for cartage and application of compost and up to 13 AUD/tonne for cartage and application of urine. However, if the farmer applies 5.6 tonne/ha of compost, he will be applying 67 kg/ha of P and 78 kg/ha of K. If he applies 21.4 tonne/ha of urine he will be applying 7.4 kg/ha of P and 50 kg/ha of K. Thus, particularly for the compost, P and K would be over-applied so the farmer may either cut the nitrogen application from compost or make it up with urea to achieve a more appropriate balance. Similarly for urine, the farmer may cut the N application from urine so that potassium is not over applied and may also apply urea and superphosphate. Thus, he may not be willing to pay transport costs of 110 and 13 AUD/tonne. At peak fertilizer prices in December 2008 the value of fertilizer in these applications would have been 160 and 20 AUD/tonne in fertiliser and urine respectively although, likewise, the farmer may not be willing to pay this in transport and application cost.

The compost would be a more economic proposition to transport but in terms of available nutrients from total excreta, most will be in the urine. However, it could well be that fertiliser costs increase further with the introduction of a price on carbon dioxide emissions to the atmosphere and on a large scale residue collection and use scheme, cartage costs for short distances to farms could well come down to the range 5 to 10 AUD/tonne. Furthermore, there is a growing awareness that available phosphate deposits are being depleted and supply of cheap phosphorus fertilisers may have peaked.

Table 11 Approximate Financial Value of Nutrients in Urine and Compost

	Fertiliser Costs				Urine				Compost at 28% moisture			
	Units	Nitrogen	Phosphorus	Potassium	Units	Nitrogen	Phosphorus	Potassium	Units	Nitrogen	Phosphorus	Potassium
Amount	-	-	-	-	mg/L	4 613	342	2 303	kg/tonne wet basis	18.2	12.0	13.9
Current value (May 2009)	$AUD /kg	1.5	4.5	2.00	$AUD/kL	6.9	1.5	4.6	$AUD/ tonne	27	54	28
Peak value (December 2008)	$AUD /kg	2.25	6.75	3.00	$AUD/kL	10	2.30	6.9	$AUD/ tonne	41	81	42
Value as at October 2007	$AUD /kg	1.1	2.5	1.00	$AUD/kL	5.1	0.86	2.3	$AUD/ tonne	20	30	14
Total current value May 2009 (N, P, K)					**$AUD/kL**		**13**		**$AUD/tonne wet basis**		**110**	
Total peak value December 2008 (N, P, K)					**$AUD/kL**		**20**		**$AUD/tonne wet basis**		**160**	
Total value October 2007 (N, P, K)					**$AUD/kL**		**8.2**		**$AUD/tonne wet basis**		**64**	

7.9 Soil Testing

7.9.1 Method

The local Maryborough fertiliser supplier, Dellavedova Fertiliser Services Pty Ltd, was engaged to undertake the soil testing on the trial areas prior to the trial in early September 2008 and at the conclusion of the trial in early December. Three surface soil samples (0 to 100 mm) were taken from each of the 50 m by 50 m areas identified on the pasture and canola crop. Each sample was a composite of 20 sub samples. Post-trial samples also included samples taken at a depth of 100 to 600 mm. Soil bores were carried out to classify the surface soils. The soil is volcanic, red brown in colour with high clay content.

7.9.2 Results

The results of soil tests are presented in Table 12.

From the results presented in Table 12, it appears that nutrients in the plots used for the trial were probably at an adequate level to grow pasture and canola crops before application. Pre-trial levels of phosphorus (Colwell) ranged from 31-51 mg/kg (less than 30 mg/kg is sub-optimal). Pre-trial levels of available potassium ranged from 320-470 mg/kg (50-400 mg/kg is typical). Total nitrogen levels across the plots for both the canola and pasture were not measured.

Analysis of the results indicates that there was an increase in nitrate nitrogen for both the canola and pasture plots from before to after application (and after harvesting of the canola) both for plots using the urine/leachate mixture and also the chemical fertiliser. The increase in post-trial nitrate nitrogen level for the canola plot fertilised with the urine/leachate mixture was significantly greater than the canola plot to which a chemical fertiliser was applied. Conversely, post-trial nitrate nitrogen levels for the chemically fertilised pasture plot had increased by a greater amount when compared with the pasture plot fertilised by the urine/leachate mix. It is possible that faecal matter from grazing stock on the pasture plot or dried vegetation falling from the canola plants could have contributed organic matter to the soil, and may have had an effect on the nitrate nitrogen levels as measured for the canola and pasture plots, potentially accounting for some of the differences described above. This may also provide an explanation for the increase in nitrate nitrogen recorded for the canola and pasture control plots. Long-term monitoring would be required for any further significant conclusions. Elevated nitrate nitrogen levels were recorded in the shallow (0-100 mm) samples only – of the samples at depth (100-600 mm), a maximum of 1.7 mg/kg of nitrate nitrogen was recorded.

Measurements for phosphorus (Colwell) indicate that this had decreased at the completion of the trial for both the urine/leachate mixture and chemical pasture and canola plots. Levels for the pasture plots fertilised with urine/leachate mixture and chemical fertiliser had decreased to below 30 mg/kg. The decrease in phosphorus (Colwell) was larger for the plots fertilised with the urine/leachate mix. It is possible that this may indicate that the urine/leachate mix has an effect on the availability of phosphorus in the soil, and hence could affect plant growth. It is not known why phosphorus (Colwell) levels also decreased in both the pasture and canola control plots.

Similarly, post-trial measurements indicated that available potassium levels had decreased for canola and pasture plots fertilised with the urine/leachate mix. Whilst these post-trial levels remain well within the typical range, long-term monitoring would be recommended over repeated application to determine if decreases are important, as reduction of levels to below 50 mg/kg is likely to affect plant growth. Available potassium increased for the canola and pasture plots to which chemical fertiliser was applied. It is not known why available potassium levels decreased in both the pasture and canola control plots.

Where measured, the amount of metals in the soils both pre- and post-trial does not appear to be high enough to have a negative effect on plant growth. However, it is suggested that the increase in aluminium levels (measured only for the canola plots) in both the chemical and urine plots would need to be measured over repeated applications of the fertilisers to monitor any residual increases.

The levels of chloride, sodium and electrical conductivity for both the urine and chemical pasture and canola plots had increased when compared with those measured before the start of the trial. The increase in chloride was significantly higher in the urine/leachate mixture plots than for the chemically fertilised plots (particularly for the canola crop) and was also higher for sodium.

Whilst the above analysis may give some indications of the effect of urine/leachate mixture and chemical fertilisers on the canola and pasture plots, it is acknowledged that a longer trial with monitoring over the whole trial period would be required to measure any residual effects and for any further significant conclusions.

Table 12 Results of Pre-trial and Post-trial Soil Testing

Soil Conditions	Unit	CANOLA PLOTS								PASTURE PLOTS							
		Chemical		Urine			Control			Chemical		Urine			Control		
Sample Plot		Pre-trial	Post-trial	Pre-trial	Post-trial		Pre-trial	Post-trial		Pre-trial	Post-trial	Pre-trial	Post-trial		Pre-trial	Post-trial	
Sample Depth	cm	0-10	0-10	0-10	0-10	10-60	0-10	0-10	10-60	0-10	0-10	0-10	0-10	10-60	0-10	0-10	10-60
pH (1:5 Water)		5.70	5.50	5.70	5.10	-	5.70	5.70	-	6.30	6.60	6.30	6.50	-	6.70	6.60	-
pH (1:5 CaCl2)		4.60	4.50	4.70	4.50	-	4.60	4.60	-	5.40	5.90	5.40	5.50	-	5.90	5.80	-
Aluminium Saturation	%	1.7	3.7	1.4	4.1	-	2.9	2.8	-	1.1	-	1.1	-	-	-	-	-
Organic Carbon (OC)	%	2.10	1.70	2.20	1.80	-	1.90	1.50	-	1.80	1.80	2.20	1.70	-	2.10	2.20	-
Nitrate Nitrogen (NO3)	mg/kg	8.6	13.0	19.0	67.0	1.0	7.1	9.3	1.0	3.8	33.0	11.0	21.0	1.0	13.0	24.0	1.7
Ammonium Nitrogen (KCl)	mg/kg	3.3	-	2.7	-	0.6	2.8	-	1.2	4.2	-	9.8	-	0.9	28.0	-	1.3
Total Nitrogen	%	-	0.16		0.15	0.05	-	0.1	0.05	-	0.18	-	0.04	0.22	-	0.22	0.06
Phosphorus (Olsen)	mg/kg	11	13	17	17	-	10	9	-	10	12	11	9	-	14	16	-
Phosphorus (Colwell)	mg/kg	36	34	51	47	-	34	24	-	32	29	31	23	-	40	39	-
Phosphorus Buffer Index (PBI-Col)		81	81	87	91	-	80	89	-	62	75	67	75	-	75	71	-
Total Phosphorus	%	-	0.04		0.04	0.02	-	0.04	0.02	-	0.04	-	0.02	0.05	-	0.05	0.02
Available Potassium	mg/kg	350	380	390	370	-	340	310	-	320	610	370	350	-	470	460	-
Sulfate Sulfur (KCl40)	mg/kg	7.3	7.7	11.0	13.0	6.2	7.8	4.7	9.3	6.1	6.0	4.7	4.7	25.0	8.3	5.4	98.0
Zinc (DTPA)	mg/kg	0.30	-	0.49	-	-	0.37	-	-	2.50	-	2.20	-	-	1.60	-	-
Copper (DTPA)	mg/kg	0.96	-	0.92	-	-	0.87	-	-	0.96	-	0.96	-	-	1.10	-	-
Iron (DTPA)	mg/kg	160.0	-	160.0	-	-	100.0	-	-	77.0	-	84.0	-	-	61.0	-	-
Manganese (DTPA)	mg/kg	36.00	-	36.00	-	-	36.00	-	-	24.00	-	28.00	-	-	25.00	-	-
Boron (Hot CaCl2)	mg/kg	1.50	-	1.80	-	-	1.60	-	-	1.90	-	1.80	-	-	2.40	-	-
Chloride	mg/kg	38.0	41.0	100.0	190.0	220.0	53.0	48.0	15.0	42.0	58.0	39.0	66.0	240.0	68.0	70.0	580.0
Electrical Conductivity	dS/m	0.08	0.09	0.15	0.28	-	0.08	0.09	-	0.10	0.17	0.11	0.13	-	0.15	0.15	-
Electrical Conductivity (Saturated Extract)	dS/m	0.60	0.80	1.10	2.50	-	0.60	0.80	-	0.70	0.00	0.80	1.00	-	1.10	1.10	-
Cation Exchange Capacity	meq/100g	7.72	7.11	7.59	7.84	-	7.20	7.78	-	9.20	15.00	9.39	10.70	-	12.70	14.90	-
Aluminium (KCl)	mg/kg	12.00	23.00	10.00	29.00	-	19.00	20.00	-	9.00	-	9.00	-	-		-	-
Aluminium (KCl)	meq/100g	0.13	0.26	0.11	0.32	-	0.21	0.22	-	0.10	-	0.10	-	-		-	-
Calcium (Amm-acet.)	meq/100g	4.30	3.30	3.40	3.40	-	3.20	3.50	-	4.30	7.50	4.40	4.80	-	6.00	7.00	-
Calcium (Amm-acet.)	%	56.00	46.00	45.00	43.00	-	44.00	45.00	-	47.00	50.00	47.00	45.00	-	47.00	47.00	-
Magnesium (Amm-acet.)	meq/100g	2.00	2.20	2.30	2.30	-	2.40	2.70	-	3.50	5.30	3.50	4.30	-	4.90	6.10	-
Magnesium (Amm-acet.)	%	26.00	31.00	30.00	29.00	-	33.00	35.00	-	38.00	35.00	37.00	40.00	-	39.00	41.00	-
Sodium (Amm-acet.)	meq/100g	0.39	0.39	0.78	0.87	-	0.52	0.57	-	0.48	0.65	0.43	0.74	-	0.57	0.61	-
Sodium (Amm-acet.)	%	-	-	-	-	-	-	-	-	-	4.30	-	6.90	-	-	4.10	-
Sodium % of Cations (ESP)	%	5.1	5.5	10.0	11.0	-	7.2	7.3	-	5.2	-	4.6	-	-	4.50	-	-
Potassium (Amm-acet.)	meq/100g	0.90	0.96	1.00	0.95	-	0.87	0.79	-	0.82	1.60	0.96	0.89	-	1.20	1.20	-
Potassium (Amm-acet.)	%	12.00	14.00	13.00	12.00	-	12.00	10.00	-	8.90	11.00	10.00	8.30	-	9.40	8.10	-
Calcium/Magnesium Ratio		2.2	1.5	1.5	1.5	-	1.3	1.3	-	1.2	1.4	1.3	1.1	-	1.2	1.1	-
Potassium to Magnesium Ratio		0.5	0.4	0.4	0.4	-	0.4	0.3	-	0.2	0.3	0.3	0.2	-	0.2	0.2	-
Soil Texture		Clay	Clay Loam	Clay	Clay Loam	-	Clay	Clay Loam	-	Clay	Clay	Clay	Clay Loam	-	Clay	Clay Loam	-
Soil Colour		Brown	Brown	Brown	Brown	-	Brown	Brown	-	Brown	Brown	Brown	Brown	-	Brown	Brown	-
Disp. Index, Loveday/Pyle		4		5	-	-	10	-	-	5	-	5	-	-	7	-	-

7.9.3 Comparison of Changes in Soil to Additions from Urine/Leachate

Table 13 sets out calculated addition of individual components of the applied urine and leachate assuming 100% accumulates in the top 100 mm of soil and there is no uptake by plants. It has been assumed that soil density is 1 800 kg/m^3 on a dry basis.

Table 13 Calculated Additions to Soil from the Application of Urine and Leachate

Consituent		**Weighted Average Urine Analysis**	**kg/ha.yr**	**Calculated addition to top 100 mm of soil (mg/kg dry soil) at 50 kg N/ha.yr**
Sodium	mg/L	2 845	31	17
Potassium	mg/L	2 430	26	15
Chloride	mg/L	5 102	55	31
Total Dissolved Solids (105°C)	mg/L	23 457	253	141
Total Nitrogen N	mg/L	4 613	50	28
Nitrate plus nitrite N	mg/L	2 216	24	13
Total Phosporus as P	mg/L	342	3.7	2.1

Comparison of the added amounts to measured changes in the top 100 mm of soil indicates the following. For nitrate nitrogen, measured increases were 48 and 10 mg/kg on the canola and pasture plots respectively compared to a calculated addition of 13 mg/kg. This places some doubt on the high measured increase on the canola plot. Of course nitrate is not conservative in the soil so it would be expected that the increase should be below the added amount unless there is significant activity of nitrogen fixing organisms in the soil. For sodium, which should be conservative (although there will be leaching of some sodium to deeper soils and groundwater), the measured increases were 0.09 and 0.31 meq/100 g. These changes are equivalent to 21 and 71 mg/kg respectively. Thus the sodium increase on the canola plot was of the order expected whereas the measurement on the pasture plot indicated an increase over 3 times the added sodium. For potassium, there were measured decreases in both available potassium (20 mg/kg) rather than increases and in ammonium acetate–soluble potassium (0.05 and 0.07 meq/100 g), which were equivalent to 20 and 27 mg/kg. This suggests that there was uptake and leaching of potassium from the top 100 mm of soil considerably in excess of the amount applied. Since the actual potassium loading was high compared to typical additions of fertiliser, this suggests that there is probably considerable migration of potassium into deeper profiles and possibly into groundwater. There was little change to a few mg/kg decrease in the various phosphorus forms and this is consistent with the minor addition of 2 mg/kg combined with plant uptake.

The distribution of the urine/leachate mixture over the plots was probably not entirely even and it is quite probable that this, coupled with the soil sampling procedure could either lead to under or over-estimates of the changes in soil composition. Nevertheless, for sodium, the agreement on the canola plot between added sodium and measured sodium increase was good suggesting that it is probably that most sodium is exchanged in the top 100 mm of soil and held there. The general similarity between measured increases and decreases with the magnitude of additions provides (that is no addition was so different from the measured change that it cast real doubt on the soil testing) some support for the reliability of the soil testing.

7.10 Impact of Urine Application on Soil

Table 4 sets out an averaged, best estimate of the composition of urine. This estimate has been used in Table 14 to calculate the possible accumulation of metals in the top 100 mm of soil after 100 years of application of urine at two different annual nitrogen loading rates. In addition, the table compares the annual salt application rates at three nitrogen application rates to the application rates of sodium, chloride and total dissolved solids that would result at three typical irrigation rates using an irrigation water of 500 mg/L TDS.

It can be seen from comparison of the two yellow-shaded columns in the bottom part of the table showing metal concentrations that the concentrations of metals in the urine (the left hand column) are far lower than the C1 Biosolids guidelines for biosolids that can be applied to soil where use is unrestricted. In addition, the calculated accumulations of metals at an application rate of urine equivalent to even 500 kg N/ha.yr (in the second brown-shaded column) after 100 years of this application, are much lower (by around two orders of magnitude) than the National Environment Protection (Assessment of Contaminated Sites) Measure 1999 Health Investigation A guidelines for unrestricted use of residential land and the Interim Urban Ecological Protection Levels (presented in the two right hand brown-shaded columns). It is apparent that there is unlikely to be any impact of metals present in urine on soil. It can therefore be concluded that sampling of urine for metals on an ongoing basis in any agricultural use scheme is unnecessary. This is a very useful conclusion.

In relation to salt application, the comparison of the loads applied from urine in the three left hand pink-shaded columns with the loadings that would result from application of irrigation water at low to typical rates, shows that unless the equivalent nitrogen application rate is several hundred kg N/ha.yr, the loads of sodium, chloride and TDS applied would be lower than applied in a low TDS irrigation water at a low irrigation application rate of 3 ML/ha.yr. Since irrigation rates are usually higher than this it suggests that at likely loadings of urine for dry land crops, the applied salts are probably unlikely to have a significant impact on the soil provided there is adequate rainfall to prevent build-up. If urine is used in more intensive agriculture at high nitrogen application rates the applied salt loadings will in fact be similar to those from irrigation water and on this basis there may be some impact from the combined urine/irrigation water salt loads. However, many irrigation waters have much higher salt contents. Of course, these observations do not take into account the very high SAR of urine which is discussed in Section 5.3.

Table 14 Estimate of Effects on Soil on Long-Term Urine Application

Analyte	Units	Weighted Average Urine Analysis mg/L	Application Rate and Loadings from Urine			Salt Loadings for Typical Irrigation Practice			
			kL or kg/ha.yr	kL or kg/ha.yr	kL or kg/ha.yr	Assumed Irrigation Water Composition mg/L	Irrigation Application Rate ML/ha.yr (or mm/yr)		
Urine Application Rate	**kL/ha.yr**		10.8	43	108		3	5	8
Specific Gravity		1.017					**Salt Loading on Soil kg/ha.yr**		
Sodium	mg/L	2 845	30.8	123	308	100	300	500	800
Potassium	mg/L	2 430	**26.3**	**105**	**263**	50	150	250	400
Chloride	mg/L	5 102	55.3	221	553	210	630	1050	1680
Total Dissolved Solids (105oC)	mg/L	23 457	254	1017	2 543	1 000	3 000	5 000	8 000
Total Nitrogen N	mg/L	4 613	**50**	**200**	**500**				
Total Phosporus as P	mg/L	342	**3.71**	**15**	**37.1**				

Metal accumulation in soil (mg/kg dry soil) assuming 100 years of application, accumulation in the top 100 mm and a soil dry density of 1.8 kg/m3 for 50 kg N/ha.yr

		Weighted Average Urine Analysis mg/L	kg/ha.yr	Metal accum. in soil (mg/kg dry soil) at 50 kg N/ha.yr	kg/ha.yr	Metal accum. in soil (mg/kg dry soil) at 500 kg N/ha.yr	Biosolids Guidelines Grade C1 (Unrestricted Use) mg/kg dry soilids	NEPM 1999 A sensitive use mg/kg in soil	NEPM 1999 E Interim Urban mg/kg in soil
Total Arsenic	mg/L	0.013	0.00014	0.0078	0.00141	0.078	20	100	20
Total Boron	mg/L	0.92	0.0100	0.55	0.100	5.5			
Total Cadmium	mg/L	0.0003	0.0000033	0.00018	0.000033	0.00181	1	20	3
Total Cobalt	mg/L	0.009	0.00010	0.0054	0.00098	0.054		100	
Total Chromium	mg/L	0.011	0.00012	0.0066	0.00119	0.0662	400 Cr III	100 Cr VI	1 Cr VI
Total Copper	mg/L	0.571	0.0062	0.34	0.062	3.4	100(150)	1 000	100
Total Iron	mg/L	6.9	0.075	4.2	0.75	42			
Total Manganese	mg/L	0.14	0.0015	0.084	0.0152	0.84		1 500	500
Total Molybdenum	mg/L	0.035	0.00038	0.021	0.0038	0.211			
Mercury by cold vapour	mg/L	0.0001	0.0000011	0.000060	0.0000108	0.00060	1	15	1
Total Nickel	mg/L	0.023	0.00025	0.014	0.0025	0.139	60	600	60
Total Lead	mg/L	0.023	0.00025	0.014	0.0025	0.139	300	300	600
Total Selenium	mg/L	0.014	0.00015	0.0084	0.00152	0.084	3		
Total Tin	mg/L	0.004	0.000043	0.0024	0.00043	0.0241			
Total Zinc	mg/L	0.36	0.0039	0.22	0.039	2.17	200(300)	7 000	200

Value in brackets for Cu and Zn is for composted biosolids

7.11 Experiment to Determine the Rate of Die-off of Bacteria in Urine and Leachate

7.11.1 Objective and Background

Höglund (2001) conducted a study into the persistence of pathogens in source-separated human urine, and an assessment of the risks. The major findings from the study were summarised in a report by GHD (2003) and included:

» Pathogens excreted in urine present a minor risk in relation to the reuse of human urine;

» Any faecal cross-contamination that may occur is regarded as a possible health risk;

  - The degree of faecal contamination may be related to the number and type of users, and to the type of toilet used;

» Bacteria generally died off more quickly in undiluted urine than in diluted urine, at both 4°C and 20°C;

  - A fivefold increase in survival time was noted for *E.coli* in 1:9 diluted urine compared to undiluted urine;
  - Lower storage temperatures corresponded to longer survival times; and
  - pH was approximately the same in all dilutions, however most bacteria had better survival at pH 6 than at pH 8.9.

An experiment was set up in an attempt to determine the rate of die-off of bacteria in both urine and leachate during storage, without any addition of new material. The purpose was to try and demonstrate that storage was an effective means of reducing the numbers of viable bacteria of different types, including indicator bacteria for faecal contamination. Various laboratories and university staff were consulted about the feasibility of identifying actual pathogens and also bacteria phages but the advice was that this would be a major exercise beyond the time and financial budget for this project. The advice of several researchers was to monitor normal indicator bacteria first and only move to pathogens or bacteria phages once behaviour of indicator bacteria was understood. A further problem identified was the potential difficulty of using standard bacteriological testing methods for water on urine and leachate, because their high concentrations of salts.

7.11.2 Method

On 6 November 2008 samples of urine and leachate were taken from the storage tank and placed in several 1.25 L empty PET mineral water bottles. One bottle of urine and one bottle of leachate were delivered to the laboratory for analysis the following day and the other bottles, three of each, were placed in unused bins in Composter F2 for storage at approximately 20 degrees Celsius for several months. The bacteriological results were very low so the three remaining bottles of each sample were remixed on 8 December 2008 and around 10 g of faecal matter from one of the compost bins was added to each bucket to act as a seed. After mixing, the contents were placed back into separate bottles and one of each was sent to the laboratory for analysis. Two bottles of each sample were placed back in unused bins in Composter F2.

The second and third bottles of urine and leachate were removed from the Composter and sent for analysis on 10 February and 31 March 2009. Thus storage time overall was 3.8 months from the spiking with faecal matter or 4.8 months from the original sampling.

Initial laboratory testing for *E. coli* was by the presumptive membrane method, which gave very low values, so the laboratory undertook subsequent testing by the MPN multiple dilution method. In addition, total coliforms and faecal coliforms were included in some later testing.

7.11.3 Results

Table 15 sets out the results of this testing and includes some earlier results for the urine and leachate used in the agricultural trial (sample date of 27/8/08). Temperature of the air leaving the composter and temperature of compost in a separate bin was recorded over the period. From these records (see Section 5.4, Figure 10) it can reasonably be concluded that the temperature of air surrounding the bottles would not have varied outside the range 15 to 35 degrees Celsius and average air temperature was probably of the order of 22 degrees Celsius.

Included are analyses of nitrogen, which were undertaken to monitor any changes in ammonia.

Table 15 Results of Bacteriological Testing

Date	Urine											Leachate										
	pH	TVAC org/mL	Total Coliforms MPN org/100 mL	Faecal Coliforms MPN org/100 mL	E. coli MPN org/100 mL	Presumptive E. coli org/100 mL	Faecal Streptococci org/100 mL	TKN mg/L	Ammonia N mg/L	Org N mg/L	Oxidised N mg/L	pH	TVAC org/mL	Total Coliforms MPN org/100 mL	Faecal Coliforms MPN org/100 mL	E. coli MPN org/100 mL	Presumptive E. coli org/100 mL	Faecal Streptococci org/100 mL	TKN mg/L	Ammonia N mg/L	Org N mg/L	Oxidised N mg/L
27/08/2008	7.8	570000				<10	120000	1700	230	1500	1200	6.5	100000				130	30	150	120	31	93
6/11/2008	7.7	5000				<10	<10	2300	1800	530	2000	4.5	1800				<10	<10	110	76	30	110
8/12/2008		130000		<2	<2		310						13000		23	23		20				
10/02/2009		9700		230	230		2						9600		130	130		<1				
31/03/2009		73000	<20	<20	<20		20	2700	2300	410			50000	<20	<20	<20		20	520	470	50	

7.11.4 Discussion of Results

The results were disappointing, in that numbers of indicator bacteria after seeding with faecal matter on 6/11/08 were still low and subsequent results were variable, suggesting that the test methods were not particularly precise or reliable for these samples. An attempt was made to plot the logs of the results for *E. coli* and Faecal *Streptococci* to get some measure of die-off rate but, as expected from the table, this yielded no useful conclusion because of the variation both up and down. If the greatest decrease in *E. coli* were taken (e.g. from 230 down to 10 in urine), it would suggest a die-off rate of 1 log to the base 10 in about 1½ months. If this is in any way representative of actual die-off rate of *E. coli* in urine and if the typical first order die-off model is used, then high levels of *E. coli* would be expected to be reduced within a few months of storage of the urine (e.g. 10^8 down to 100 orgs/100 mL in 6 months).

It would appear that the addition of faecal matter as seed increased TKN by around 400 mg/L in both leachate and urine, which is reasonably consistent with the mass of fairly dry faecal matter used as seed. The fact that the faecal matter was not fresh and was fairly dry may be part of the reason for low *E. coli* counts after seeding.

Note that the pH of urine was relatively low (7.7) compared to higher values reported in the literature. This may be the result of storage, as the average age of the urine used in the test was around 2 months. The sample taken on 27/8/08 would have had an average age closer to 9 months and in fact had a slightly higher pH.

Looking at individual indicators in urine and leachate suggests that Total Viable Aerobic Count (at 37^{o}C) is consistently higher in urine than leachate, despite the more limited opportunity for faecal matter to access the urine stream. Similarly, the urine samples show consistently higher Faecal *Streptococci* counts on the earlier samples (particularly on the August 2008 sample, which gave a very high 120 000 orgs/100 mL), although counts were low in both urine and leachate after storage once there were no new additions of urine or leachate.

The highest *E. coli* counts by either test method were 130 org/100 mL in leachate and 230 org/100 mL in urine. The lower value in leachate is not consistent with the passage of leachate through faecal matter and this does cast some doubt on the reliability of the tests. For example, *E. coli* concentrations in raw sewage are typically in the 10^6 to 10^9 range. The low leachate counts could also be related to the low usage of the toilets and hence the limited amount of fresh faecal matter present.

The final concentrations suggest that *E. coli* and Faecal *Streptococci* do not survive for more than a few months in either urine or leachate held at around 20 degrees Celsius. During the discussions relating to approval of the agricultural trial with the EPA and Council, the EPA indicated it would have no objections provided the urine and leachate met the requirements of the Biosolids Land Application Guidelines (EPA, 2004). The parameter for *E. coli* in these guidelines in that not more than 10% of samples contain *E. coli* at more than 100 orgs/g dry matter and that no sample contains more than 500 *E. coli* per g of dry matter. The dry matter content of the urine and leachate were 28 000 mg/L and 8 200 mg/L or 2.8 g and 0.82 g dry matter per 100 mL for the August 2008 sample (the material applied to land). If this sample contained 100 *E. coli*/100 mL, for example (measurements indicated <19 orgs per 100 mL for urine and 131 orgs/100 mL for leachate), this converts to 36 and 122 *E. coli* per g dry matter in urine and leachate respectively. This material was taken straight from the storage tanks, which had been subject to immediately recent additions of faecal matter and fresh urine. The less than 20 *E. coli*/100 mL detected in the samples after storage in this experiment would equate to less than 7 and less than 24 *E. coli*/g dry matter in urine and leachate respectively. If, alternatively, the biosolids guideline is interpreted as directly applying to the urine and leachate considering all the material to be “dry solids”, the guideline would become 10 000 *E. coli*/100 g or 10 000 *E. coli*/100 mL. This would be an unacceptable level of bacterial contamination but one that all samples would have met. A further interpretation of the guideline would be that it should be 100 orgs/mL in which case the highest count for urine of 82 orgs/100 mL and 131 orgs/100 mL for leachate become <1 and 1 orgs/mL respectively, well within this interpretation.

Schönning, in presenting work from Höglund (2001), noted several conclusions in relation to typical indicator bacteria presence in urine and their usefulness in predicting the possible presence of pathogens. Firstly, *E. coli* are not a good indicator, as they are present in low numbers in urine and do not survive. Experiments in diluted and undiluted urine at pH 4.5 to 9 showed that *E. coli* reductions of several $\log_{10}$ occurred within a few days, with die-off being faster at 20 degrees Celsius than at 4 degrees Celsius. Various *Salmonella*, *Pseudomonas* and *Aeoromonas* species had survival times not dissimilar to *E. coli*. Total coliforms are not a good indicator of possible pathogens because of their widespread presence in the environment. Faecal *Streptococci* were present in high numbers and survived longer with die off of one $\log_{10}$ occurring taking up to 35 days. *Clostridia perfringens* spores showed no inactivation over 80 days. Survival of bacteria appeared to be longer at lower pH, thought to be due to higher ammonia concentrations at high pH. This work also looked at survival of *Cryptosporidium* and viruses and concluded that storage of urine at 20 degrees Celsius for more than 6 months would probably destroy all pathogens.

7.11.5 Swedish Guidelines for Urine Reuse

Schönning C and Stenström (2004) authored a guideline for safe use of urine and faeces, which also forms the basis of urine guidelines published by the WHO (Schönning). Table 6 from this guideline is reproduced below as it provides the only guidance currently available.

“Table 6. Recommended Swedish guideline storage times for urine mixture [a] based on estimated pathogen content[b] and recommended crop for larger systems[c]. (Adapted from Jönsson et al., 2000 and Höglund, 2001)

Storage temperature	Storage time	Possible pathogens in the urine mixture after storage	Recommended crops
4°C	≥1 month	Viruses, protozoa	Food and fodder crops that are to be processed
4°C	≥6 months	Viruses	Food crops that are to be processed, fodder crops[d]
20°C	≥1 month	Viruses	Food crops that are to be processed, fodder crops[d]
20°C	≥6 months	Probably none	All crops[e]

[a] Urine or urine and water. When diluted it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/l.

[b] Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognized for causing any of the infections of concern.

[c] A larger system in this case is a system where the urine mixture is used to fertilize crops that will be consumed by individuals other than members of the household from which the urine was collected.

[d] Not grasslands for production of fodder.

[e] For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.”

These guidelines are based on the work by Höglund, which appears to be the only source of testing and risk-based microbiological guidance setting.

7.11.6 Conclusions

Overall, it is concluded that the bacteriological testing carried out was insufficiently reliable to draw useful conclusions on health risk. However, if it is assumed that the consistently fairly low concentrations of *E. coli* and Faecal *Streptococci* detected, especially after storage away from new additions, are representative of actual contamination present, it could be concluded that the biosolids guidelines may be met by storage for several months at approximately ambient temperature. Furthermore, the results do not conflict with and, in terms of indicator bacteria monitored, support the conclusions of Höglund (2001) about the effectiveness of storage of urine in destroying bacteria and probably pathogens.

There was also no loss of ammonia or total nitrogen during these tests. It is also noted that the seeding with faecal matter added most nitrogen as ammonia. This does not confirm that storage of urine and leachate does not lead to loss of ammonia in the open storage tanks, as the bottles were sealed. The fact that the analysis of urine after storage in open tanks gave phosphorus concentrations similar to those published by other researchers, but total nitrogen concentrations were a little over half those published by other researchers, suggests that there was probably significant ammonia loss. It is concluded that the storage of urine in a bladder, as in the Queensland trials reported by Hood et. al. (2009), would be more advantageous than storage in a tank. The higher ammonia resulting may have a more bactericidal effect and keep the pH higher, which Schönning reports as being more effective in destroying pathogens.

Further investigation of the fate of bacteria, including indicators of faecal contamination, would be needed to determine the most appropriate storage arrangements and temperatures, unless the work of Höglund and the Swedish and WHO guidelines as proposed by Schönning are accepted as sufficient.

If it is considered necessary in Australia to do further work on pathogen destruction, some validation of the bacteriological test methods in urine would be desirable to gain an appreciation of reliability. It may be necessary to develop specific test methods, such as performing all tests on samples aseptically diluted in sterile water to the same salt concentration. It would probably be best to undertake some strictly controlled trials in a laboratory using fresh urine and diluted urine both with and without added faecal matter, with appropriate replicates and spiking with different starting concentrations of the bacteria monitored. Parallel but also replicated trials (similar to those carried out in this experiment) using the collected leachate and urine stored on site would be desirable. Following successful completion of such testing, some trials with pathogen spiking and bacteria phages would be appropriate, both in fresh urine in laboratory trials and in field trials.

The study team consider that a better alternative to such research would be to adopt the Swedish guidance of providing at least 6 months storage of urine and leachate (during which there are no new additions) and run further agricultural application demonstration trials. The applied urine and leachate would be monitored for selected indicator bacteria and pathogens, as would be the soil and crops. The health of those involved in the process should also be monitored. Since pathogens are unlikely to be present (at least most of the time) in fresh urine and leachate, it would be appropriate to spike part of the urine (and leachate) with indicators and pathogens before placing in storage and apply this spiked material to separate plots. Such a practical demonstration would probably be more convincing than repeating the type or work reported by Schönning and Höglund.

8. Communications Program

Various actions have been taken since February 2007 to publicise the demonstration project, but these have been limited due to student misuse of the installation. The closure of the toilets by the school between mid-May and mid-August 2007 meant that planned press releases were delayed. In addition, the reluctance of the school to hold publicity events and open days earlier on in the project due to issues with student behaviour severely limited the publicity given to the project.

GHD has maintained information on its website up to date and the current information on the site will be updated shortly with new wording that has been prepared to include the latest information in this report.

Four papers/talks have so far been written and presented:

- 23 September 2008, Sustainable Buildings 2008 Conference, Melbourne (SB08) September: Paper presented
- 24 September 2008 short presentation to the Sustainable Cities Round Table at the University of Melbourne Victorian Eco-Innovation Laboratory (VEIL), Australian Centre for Science, Innovation and Society (ACSIS)
- A paper was published in “Water” the Journal of the Australian Water Association Vol 36, No 1, February 2009.
- A poster presentation given on the project at the OzWater ’09 Conference in Melbourne in March 2009 that is included in the proceedings of that conference.

The International Water Association also published a short news item on the project during 2008, which lead to several enquiries.

An abstract has been submitted for an International Water Association conference on ecological sanitation in late 2009.

A case study on the project is also being prepared for publication in the Royal Australian Institute of Architects BEDP Environment Design Guide, which is jointly produced with Engineers Australia, the Association of Consulting Engineers and other organisations. http://www.environmentdesignguide.net.au

GHD staff members presented talks to students at the school on four separate occasions: in February 2007, in August 2007, in May 2008 and in June 2008.

An ‘open morning’ was held at the installation on 8 December 2009. The event was attended by representatives from the Maryborough Education Centre, the EPA Bendigo office, Central Highlands Water and Central Goldfields Shire Council. The GHD project leader gave a short presentation on the project and conducted a tour of the installation.

A database of contacts has been prepared listing all external parties who have enquired about the project. This is included in Appendix L. Information on the trial progress has been provided to the majority of these contacts. In addition, a number of GHD staff members have contacted the study team for information. All people making enquiries have been directed to the information already on the GHD website.

9. Expenditure

9.1 Capital Costs

Table 16 sets out the estimated and actual costs for the installation and the capital cost per fixture, disregarding costs which are equivalent for composting and conventional toilets (e.g. toilet room, hand wash basins, lighting, water supply). The actual costs include costs of monitoring equipment purchased purely for the trial and water metering to the hand-wash basins and to another toilet block in the school to allow comparison of water use. Because of the way building works were put out to tender and prices then negotiated with the selected builder to substitute urine-separating composting toilets for conventional toilets, there are many uncertainties in the estimate of the actual cost for 8 fixtures. In particular, the only information available from the builder and architect was the additional cost on top of a lump sum price for the school with all-conventional toilets. This means that it has been necessary to add an allowance for the cost of the conventional toilet building in order to estimate the total cost.

Table 16 Estimated and Actual Capital Costs (AUD)

	Urine-Separating Composting Toilets			
	Estimate for proposed design of school (slab on ground) (20 fixtures)	Actual (8 fixtures)	Estimated Minimum for building on sloping site (20 fixtures)	**Estimate for Conventional Toilet Option (20 fixtures)**
Total Capital Cost including design	318 000	335 000	211 000	100 000 (Estimated)
Capital Cost per Fixture	15 900	41 900	10 600	5 000

From Table 16, prior to construction it was estimated that the urine-separating composting toilets would cost around 11 000 AUD more per fixture than conventional water-flushed toilets. It was also estimated that, if the building arrangement had been different, this difference could reduce to around 5 600 AUD. Following completion it turned out that the actual cost was 36 900 AUD per fixture (that is 41 900 – 5000) more than conventional toilets.

From the available records and estimates by the authors, the total cost of 335 000 AUD was made up of:

Item	**AUD 2007**
Rotaloo® Maxi 2000 Units, urinals and pedestals	20 166
Fabricated PVC leachate tank	5 602
Rotomold HDPE urine tank	3 361
Odour biofilter	5 602
Sun Lizard and ducting	6 722
Sump pump system for basement	5 602
Building works as tendered by builder (in addition to tender for conventional toilets)	124 678
Variation to building works including water metering, hand basin and hot water, additional pipework and electrics	53 616
Monitoring equipment, electric heater and signage	7 574
Total contract cost	225 347
Design and supervision	30 000
Total additional capital cost	**255 347**
Add estimated cost of conventional toilet building (without toilets)	80 000
Total estimated cost of actual installation	**335 347**

From this summary, it can be seen that the cost of the Rotaloo® Maxi 2000 composter units, pedestals and urinals only made up around 20 000 AUD of this total capital cost and, together with the leachate and urine tanks, the odour control biofilter and the Sun Lizard and air ducting, the total installed price of equipment for the toilets was around 41 500 AUD. Special monitoring equipment, an electric heater and signage that would not be required in a normal installation cost a further 7 500 AUD.

The capital cost of the installation was higher than initially estimated, for a number of reasons. The pricing for the installation was finalised with the builder after the construction contract had been awarded, which meant that there was no competition in pricing. Structural costs were high as the building was constructed on rock as a slab-on-ground structure. The building was also complex because of the need to fit it to an existing building design and site layout and because possible economies, such as sloping the walls of the basement area, were not adopted. The cost of constructing and providing drainage to the equipment basement was significant and could have been reduced if the building was constructed on sloping ground on piers, allowing sufficient under-floor space. This would have been feasible on the site but design of the buildings had progressed significantly before the trial was proposed and adopted. The leachate tank was custom-built by the contractor rather than using standard plastic tanks or bladders. Experience to date suggests that the greenhouse structure could have been simplified and made smaller and a smaller basement could have been built if the urine and leachate tanks had been constructed below the ground outside the building. As well as this, a number of items were included specifically for the trial including the monitoring equipment and additional electrical supply, provision to convert to water-flush toilets at a later date, a natural gas supply for possible future heating and hot and cold water plumbing to a hand-wash basin in the basement. The result of this was that the additional capital cost when compared to conventional toilets (which include an allowance for design and project management costs) for each pedestal and urinal was around 37 000 AUD compared to the maximum 10 000 AUD per fixture estimated previously (GHD 2003). Thus the conclusion from earlier work by GHD that the cost of dry sanitation overall (after allowing for sewerage system and water supply cost savings) should be no more than conventional sewerage remains to be proven in practice.

However, the authors are of the opinion that a satisfactory building could have been provided for around one third of the cost of the building actually provided. If building costs are reduced by this amount and the cost of monitoring equipment is removed, the total capital cost of the installation would have been around 240 000 AUD or around 30 000 AUD per fixture, which would be 25 000 AUD more than the cost of conventional toilets per-fixture. With ongoing development and simplification plus wider use, it would still not be unreasonable to conclude that the additional cost per fixture for urine-separating composting or desiccating toilets could be brought down to the range of 5 000 to 10 000 AUD per fixture additional to conventional toilets. Considering the fact that there is a saving in infrastructure for sewerage and for water supply, the conclusion in the report by GHD (2003) that this form of sanitation is potentially no more costly than conventional sewerage overall may still be reasonable. Nevertheless, it is suggested that for the present it would be wise for any future such demonstration projects to allow ample additional cost for new installations, probably of the order of 10 000 to 15 000 AUD per fixture on top of conventional toilets or 15 000 to 20 000 total cost per fixture in total to allow for equipment and additional building costs. This additional cost will present a major hurdle for wider use unless there is some encouragement from Government and Water Authorities to adopt alternative sanitation for its overall benefits.

9.2 Project Expenditure Against Budget

To the end of May 2009, GHD's recorded times and costs on the project were as follows:

Total GHD time input:	915 hrs
(GHD time cost at standard hourly rates:	$163 000)
GHD time cost at rates adopted for the project:	$97 800
GHD disbursements (including travel costs):	$7 700
Capital paid to Department of Education and Early Childhood Development (DEECD)	$74 175
Monitoring equipment capital	$6 775
Total GHD expenditure to date at rates adopted for the project including payment of capital to DEECD:	**$186 450**
(Total GHD expenditure at standard hourly rates:	**$251 650 A**

In kind contributions from Oaten Stanistreet, Connor Pincus & Saunders and Environment Equipment (recorded in Milestone 3 Report):	$24 690
Project expenditure by parties excluding the school and DEECD:	**$187 842**

Total payments claimed from to date from SWF:	$147 400
Milestone 6 Payment to be Claimed:	$25 700
Total to be claimed to Milestone 6:	**$173 100 B**
(In kind contribution from GHD (A-B):	**$78 550)**

The original project budget was as follows:

GHD time input anticipated:	354 hrs
(GHD estimated time cost:	$61 000)
In kind contribution by GHD:	$23 540
In kind contribution by others:	$13 190
In kind contribution by DEECD:	$60 800
Total in-kind contributions:	$97 530
Total Project Cost Estimated:	$290 900
Balance (Funding from SWF):	$193 370

It can be seen from the above that GHD’s in-kind contribution to date of over $78 000 far exceeds that proposed in original project plan accepted by SWF. In addition, the in-kind contribution from GHD as recorded above did not include time input by the project leader to complete this report, estimated at a further 100 hours.

10. Energy Use in Dry Toilet-Based Sanitation

In its report to the Smart Water Fund in 2003, GHD presented results of energy use estimates for a sanitation system based on urine-separating dry composting toilets and conventional sewerage for household grey water and compared this estimate to energy use in conventional water-born sanitation systems. The former included cost of cartage of residues to agricultural land as well as grey water pumping and treatment and the latter included energy use for sewage pumping and treatment plus the energy embodied in fertiliser equivalent to that contained in dry residues that would be available from urine-separating dry toilets and not available from conventional sewerage systems. It was assumed that energy use in dry toilets for ventilation fans was 4 W per household. This is lower than used at Maryborough but it was concluded in Section 5.4 that lower ventilation energy use, around 6 W or lower, should be satisfactory. The previous work also allowed for supplementary heating to maintain compost temperature equivalent to around 9 W of primary energy use for a household installation. The overall conclusion from this current study is that supplementary heating of on site composting toilets is probably unnecessary and if a central composting facility is used it should also be unnecessary. Therefore, it would be reasonable to adjust the energy use allowance to say 6 W of electrical energy per household (assumed to be 2.25 people per household as used in the 2003 GHD work). Allowing for the low efficiency of brown coal power generation in Victoria of 25%, this equates to primary energy use for a household installation of 303 MJ/c.yr. This compares to up to 358 MJ/c.yr for ventilation and supplemental heating estimated in the 2003 GHD work for 4 W fans and some supplementary heating.

Other assumptions made in the 2003 GHD work included:

- A total average pumping lift in the sewerage system of 50 m has been assumed for the sewerage energy calculations and this is probably low for many systems.
- Wastewater sludge is transported 25 km from the treatment plant.
- Compost and urine carried 40 km from the source to the reuse site (plus the return journey) in a five tonne truck carrying only 2.5 tonne of material. If larger trucks were used then the relative energy use for trucking would decrease substantially. However, if uptake of dry composting toilets were dispersed over a wide area then the transport distances and utilisation of load capacity of the vehicles would be reduced.

Table 17 sets out revised calculations of annual energy use per capita for the conventional and dry sanitation options.

The energy use estimates indicate there is potential for a sanitation system based on dry composting toilets to use more or less energy than conventional sanitation. This demonstration project has provided some support for the previous assumptions about energy use for ventilation and supplementary heating and the transport distance for residues in tis case, a 40 km round trip, was less than assumed in the 2003 GHD study. The confirmation that energy use in the on-site installation can be less than previously assumed appears to give dry sanitation a potential advantage over conventional sanitation, especially if on-site energy is reduced to zero by use of solar and wind-driven ventilation which is commonly used in such dry toilet systems in remote areas. As noted in the earlier study, a conventional toilet system could be penalised by assuming there is also a ventilation fan in the toilet.

Table 17 Estimated Primary Energy Use per Capita Per Year for collection, Treatment and Land Application of Excreta (Modified from GHD 2003)

Energy-using operation	Conventional Sewerage (WC waste and flushing water)	Composting Toilet
Ventilation MJ/c.yr	0	0 - 303
Transport MJ/c.yr	105	202
Treatment and Reuse of Residues MJ/c.yr	142 – 434	39
Embodied energy in fertiliser saved MJ/c.yr (negative = saving)	Negligible	- 70
TOTAL MJ/c.yr	**248 - 540**	**171 - 474**
Equivalent diesel fuel use (L/c.yr)[1]	6 - 14	4 - 13
Approximate GHG Emissions CO_2-e kg/c.yr	19 – 42	13 - 34
Lifetime Emissions (50 years) tonnes CO_2-e kg/c.yr	**1.0 – 2.1**	**0.7 – 1.7**

Note 1 MJ is equivalent to the energy available from combustion of about 26 mL of diesel fuel

As was noted in the GHD work in 2003, the above estimates support conclusions on urine transport reached by Jonsson (2001). Jonsson found, in a combined study of information from five different installations of urine separating toilets, that 24 MJ per person per year was required for transporting and spreading the separated urine at a farm site 33 km away from the installation. When taking into account the decreased nutrient load on the sewage system, 31 MJ per person per year was saved. Also, by taking into account the replacement value of the source separated urine, a further 75 MJ per person per year was saved by not producing the mineral fertilisers. These data are of a similar order to the figures derived in this feasibility study but suggest that the 70 MJ/person.yr of embodied energy in fertilisers saved may be conservative and illustrate that energy use for transport can be substantially less if distance to the reuse site is reduced and/or economy of scale for a larger operation is allowed for.

11. Concept for a Urine-Separating Desiccating System

An important conclusion from this project is that urine-separation facilitates the desiccation of faecal matter and toilet paper. Desiccation appears to eliminate fly breeding and also reduces the potential for odour. Thus, it has some distinct advantages over on-site composting. Absence of flies means an absence of cobwebs in vent ducts, which can be a problem requiring frequent duct cleaning in composting facilities. The disadvantages of desiccation are that there will be a fire risk and, because the solids will not heat up due to composting, there may be higher concentrations of some pathogens in desiccated solids than in effectively composted material. However, partial or full desiccation of solids in a dry toilet does not preclude off-site composting or other processing. Also, since ambient air in a dry climate will provide adequate desiccation for much of the year, facilities such as the greenhouse system used at Maryborough would not be necessary. The more compact Sun Lizard used at Maryborough would be useful to warm the air and assist in desiccation and is simple to mount on a roof.

Figure 18 shows a conceptual cross section of a urine-separating desiccating toilet system that would have worked as well as the Rotaloo® Maxi 2000 system at Maryborough and would have been substantially less costly to install. Rather than the Rotaloo® composters, the solids would discharge into a perforated bin, similar to the Rotaloo® compost bins but round, which would be located in a relatively shallow (say 750 mm deep) space below the floor. There would be a drain in the floor of this space to a leachate collection bladder and the space would be sealed and ventilated via a 5 to 10 Watt (per pedestal) solar/battery or mains-operated fan to a roof vent equipped with a wind-turbine-driven fan/cowl above the roof. This type of cowl provides adequate ventilation on windy days without the electric fan. A system could be set up to detect airflow in the vent or wind speed and only turn on the electric fan when necessary. The solids bin would be removed and replaced with an empty bin every few days, weeks or months depending on usage. The solids would be either taken to a composting building serving a number of such toilets or it could be disposed of as solid waste or by on-site burial with at least 50 mm of soil cover. The health risk from handling the desiccated solids should be minimal, especially if a mask and gloves are used. This sort of installation is similar in concept to the large number (in the hundreds of thousands) of such systems being installed in Africa.

Collected urine would also flow to a bladder. The use of bladders for urine and leachate should avoid the need for a biofilter on the vents from tanks although tanks with a biofilter on the vent could also be used. The bladders would be emptied by eductor truck every 6 months to a year and the contents placed in a storage tank or tanks for at least 6 months at an agricultural reuse site before spreading by trickle bar from a tanker in dry weather late in Summer or in Autumn.

If the installation was on a sloping site or if the building had a sub floor space, the need to provide below-ground space for the bins and bladders may be avoided.

The arrangement would suit any number of pedestals and waterless urinals. It could also be adapted to high rise buildings since the bins could be quite shallow and would require little clearance beneath the toilet, even down to the extent of fitting directly beneath the pedestal on the normal floor level (the author has such a small system in a boat and the pan takes more than a week of use to fill with solids when being used by two people even though it only holds around 15 L. However, with a very small shallow pan the solids will be less desiccated and would also need perhaps daily removal in a heavily used installation. There would also be a possibility of using drop chutes in high-rise buildings as proposed by GHD (2003).

Urine and leachate pipework could be constructed largely or completely in flexible tube that could be pulled out for cleaning. This may be more practical than providing multiple entry pipe entry points for cleaning of fixed pipework.

A Sun Lizard, which consists of a solar-panel-driven fan and a flat panel heat exchanger, could be added to provide warm air to the sub-floor space during sunny periods.

A separate composting system could serve a single house, a public facility, a school or institution or a large number of installations. Co-composting with green waste would probably be beneficial. Urine and/or leachate could be used in the composting process as a source of additional nitrogen and moisture if necessary. The main advantage of separate composting is that an appropriate insulated aerobic composting vessel (or a large aerated pile) could be used, moisture could be controlled, the insulated vessel should not require any separate heating since composting could be optimised and quality of the compost could be properly controlled.

This approach has the advantage of producing easy-to-handle urine and leachate for agriculture with the significant nutrient recovery this allows, plus good quality compost; all with minimum on-site building and equipment cost, minimum energy use and a high level of health protection. Certainly, regular removal of full bins would involve significant manual labour but this should be regarded as a benefit within a household or community rather than an imposition.

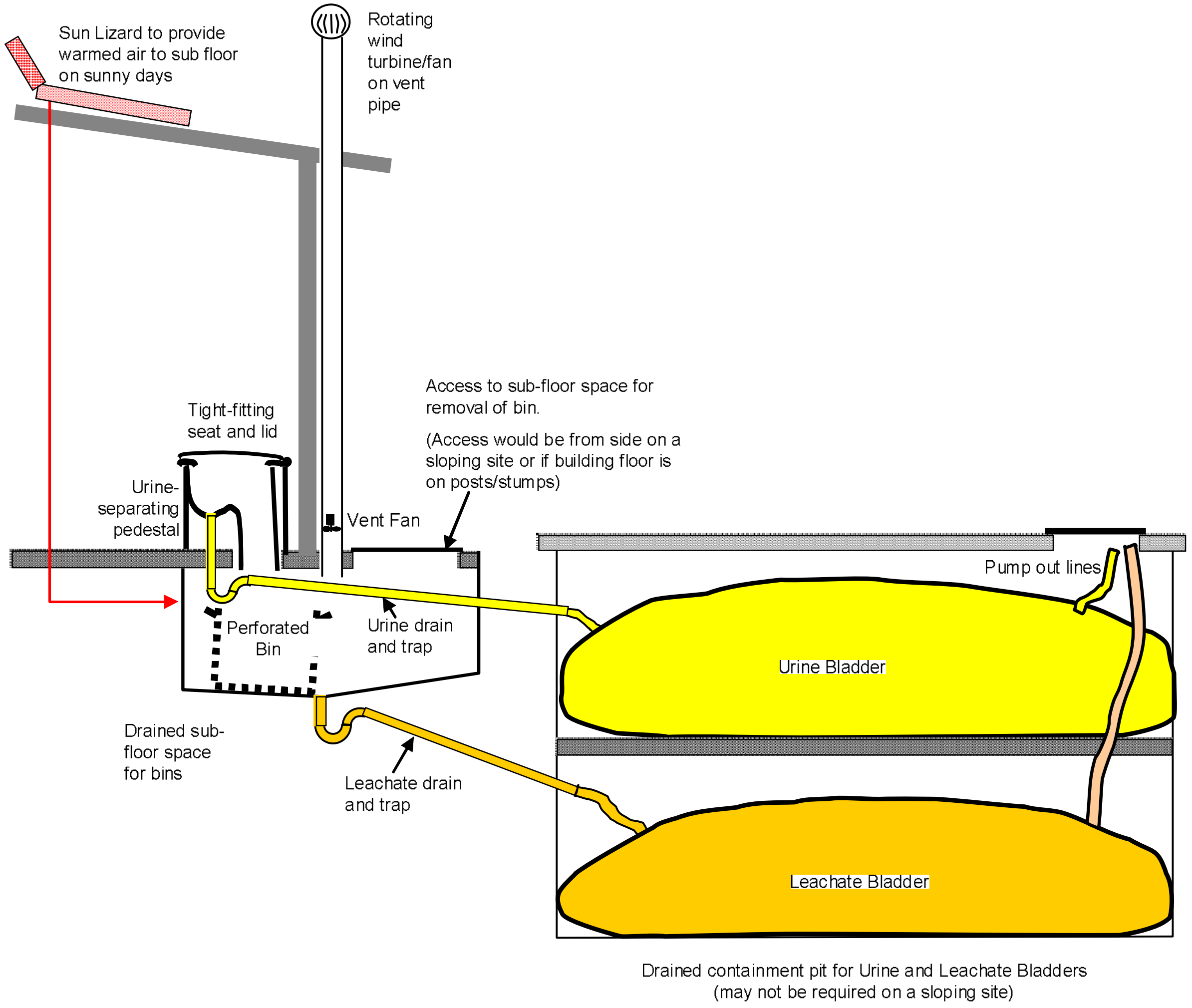

Figure 18 Concept Layout for a Urine-Separating Desiccating Dry Toilet Installation

12. Recommendations

12.1 Introduction

The recommendations made in this section relate mainly to the ways in which the installation at the Maryborough school could be improved. However, many of the recommendations would apply to the Rotaloo® Maxi 2000 equipment used in general and some would apply to any sort of urine-separating dry toilet system. Some recommendations are also made for possible further investigation at the Maryborough installation and for investigations of other urine-separating desiccating or composting toilets.

12.2 Issues with the Design of the Installation

12.2.1 Composters

Based on the experiences with this under-laded facility, the design of the composting system in the Rotaloo® Maxi 2000 could be improved in the following ways:

- Inclusion of a sloping floor to drain leachate direct to a small outlet sump whilst keeping the carrousel flat. This relates to systems where leachate is to be recovered rather than evaporated, where the flat floor assists.
- Provision of rigid frames around the access hatch and hatchway so that the access doors seal properly against flies.
- Provision of a toilet seat (or redesigning the top of the pedestal) so that the lid of the seat seals off the pedestals from access by flies (and also reduces air flow when seats are closed).
- Better insulation of the composters and redesign of the air flow pattern to limit airflow around and over the compost bins so as to reduce evaporative cooling.
- Indirect heating of an insulated composter space (for example by means of circulating hot water or air within a heat exchanger in the space) may be feasible and would be preferable to passing warmed air directly over the compost.
- Provision of high airflow capacity, easily accessible and removable fine mesh insect screens on the inlets and outlets to limit the risk of access by small flies.
- In a school or public toilet, a means of automatically controlling moisture level in urine-separating composting or desiccating toilets is desirable to minimise the risk of fire in the compost bins.

12.2.2 Liquid System

- Smaller bore (that is less than 100 mm and probably 50 mm) pipework could probably be used for separated urine but large outlets on the base of the composters (75 to 100 mm) for leachate are probably desirable to limit the impact of scale build-up.
- The use of bladders rather than tanks could be considered but may be less secure. They should avoid the need for the biofilter on the storage vent system.
- The biofilter needs to be protected from stormwater inflow.

- Use of standard plastic tanks for urine and leachate should be possible provided any metal parts (if metal is essential) are a suitable grade of stainless steel (preferably 316).
- The external educt couplings and pipework are unnecessary, as it is simpler to educt directly from the tanks in the basement.
- The urinals should not have removable covers over the oil seals on the outlets as this invites removal.

12.2.3 Ventilation System

- Provision of access points for inspection and cleaning any cobwebs that may exist.
- Provision of a means of easily removing fans for replacement (this relates to the way the system was piped up).
- Provision of reliable time clocks for control of fans to minimise energy use.
- A small reduction in airflow rate to limit necessary fan power.
- Use of solar/battery fans to avoid the need for external power for fans (this is an option currently available with the system although users have reported failures of the standard system).

12.2.4 Building Design

- The basement design could be improved and simplified and the cost reduced significantly by using sloping concrete-sprayed walls in the basement or building the toilet block on stumps. Location on a slope where available to allow easier access would also be desirable.
- The greenhouse structure is capable of trapping useful heat in winter but this needs to be transferred to some form or heat storage such as a hot water tank or stone storage through which air (or water) can be circulated to warm it. As noted above, indirect heating of an insulated composter space may be feasible and would be preferable to passing warmed air directly over the compost.
- The greenhouse needs to be properly insulated and sealed from drafts and this would assist to prevent dust build-up.
- The composting toilets should have used exactly the same floor covering as other toilets to make them of equivalent standard and appearance.
- Door locks and all other parts of the design such as fencing need to be vandal-proof and this needs to be included in the contract.
- The door locks on access to the basement need to be of a type that makes it impossible for a person outside to lock a person inside.
- Gravity rather than pumped drainage of the basement would be preferable.
- Low headroom in the basement around the composters and leachate tank makes working difficult.

12.3 Recommendations for Further Investigations

12.3.1 Further Work at Maryborough

In order to further demonstrate and develop urine-separation and dry toilet technology, a number of further projects would be appropriate. These could include projects focussing on both composting on-site as was intended at Maryborough and development of the desiccating concept with centralised composting.

Whilst further work at the Maryborough Education Centre would be desirable, there is no point in doing more until usage of the toilets increases. This would require a change in student behaviour, which is probably unlikely without major efforts by staff and parents. It is understood that there is a possibility of establishing community use of the oval that is adjacent to the toilets. If this does occur then the toilets would be the most convenient and usage and usage patterns would change. If this occurs, a further round of monitoring for a year would be desirable. The lead investigator on this project does intend to remain involved and in contact with the school and may participate in such further work. However, it would need funding to be worthwhile as further analysis of compost and investigation of health and agricultural issues would be necessary.

The lead investigator will also be arranging for ongoing use of urine and leachate on farmland so that the school has a route for reuse of these materials, which will continue to collect at significant rates. At current usage it will be several years before there is sufficient compost to warrant a trial application to land and litter in the compost may prevent such use. However, removal of compost will be necessary in future if the toilets remain in operation.

The focus of further investigation at the school, if usage increases, should be on:

a. Quantities, characteristics and composition of compost

b. Evidence of composting with or without temperature elevation taking place

c. Fly breeding and odour

d. Usage counting, probably by survey using volunteers

e. Practical observations of benefits of agricultural application of residues

Further intensive soil testing or crop response testing is not warranted with the small quantities being produced and in the absence of some interest by regulators and governments in use of excreta as a fertiliser.

12.3.2 Opportunities and Needs for Further Investigations

Several research questions that were not answered by this investigation would benefit from intensive investigation elsewhere. The opportunities and needs for further investigation are summarised below.

Whether composting can be achieved where urine separation is included

The issue is whether the lower water content and nitrogen: carbon ratio helps or inhibits composting. It is known that urine separation has worked together with worm growing at CERES in Brunswick and the operation of this facility was reviewed in GHD's 2003 report. It is uncertain however whether any composting can be achieved when urine is separated in high use facilities. In theory, the dryer material with lower N:C ratio achieved with urine separation should compost more readily. To answer this question, a first step should be to review performance at CERES and at other facilities such as Cardinia Reservoir (a Rotaloo® installation near Melbourne) where there is no urine separation and to include logging of compost temperature. A sub-question specific to the Rotaloo® system is whether composting with urine separation continues in the bins no longer under drop pipes. It is also uncertain whether compost reaches disinfecting temperatures at other large installations such as Charles Sturt University at Thurgoona NSW. Some initial survey by measurement of operating temperatures at several installations would answer this last question.

Optimum conditions for composting

If composting with temperature elevation can indeed be achieved at one or more of the existing installations it would be useful to carry out some optimisation experiments as were proposed at Maryborough and to record useful information such as moisture content, temperature versus time, bulk density and nutrient and indicator bacteria content of finished compost. Temperature monitoring using a similar type of canister logger as used at Maryborough (OneTemp UA-001-64 pendant data logger) would be a useful part of such investigations. Such a study should involve a number of existing installations of different types.

If no temperature elevation is achieved by composting at any installation then construction of a new facility drawing on the heating and ventilating results from this investigation would be desirable so that design and operating requirements to achieve composting can be determined.

Development and trial of urine-separation and desiccation

Whether or not it is concluded that urine separation inhibits composting, it would be desirable to pursue the desiccating concept presented in the Section 11 as it potentially offers significant cost advantages over on-site composting. This would require construction of such a facility, preferably on a large scale with an associated composting facility and agricultural trial.

Flies, Spiders and Odour

At all existing and any new facilities, it would be desirable to monitor fly breeding and spider nuisance as well as odour complaints and pedestal cleaning.

Implementing large-scale urine separation

It is apparent both from this trial and from generally good experience with the many waterless urinals now installed around Australia, that a large scale installation of urine separation and an associated large scale and long term trial of agricultural use of urine would be desirable. It is suggested that this could best be established in a new residential apartment block or large office where there can be good management of maintenance and control of urine collection. There is not need for this trial to include composting or desiccation of solids.

The only reason not to use urine separation in all or most new w buildings or refits of old buildings is the lack of an established urine collection and reuse pathway and associated health and environmental safeguards. Therefore, a priority of government should be to establish this pathway and regulatory system as soon as possible. It is suggested that this does not need significant additional research of health risks as, at least initially, adoption of the draft Swedish and UN guidelines for reuse of urine included in Section 7.11.5 would provide adequate safeguards. The initial effort should be to find willing farmers and horticulturalists and to educate agricultural scientists and regulators on the topic. Detailed investigation of health effects and effects on crops, livestock, soil and groundwater will be far more productive if significant use is established first.

Flushing or no-flushing in urine separation

There is some uncertainty whether it is necessary to use flush water in urine collection. The experience in this investigation and from waterless urinal use is that it is unnecessary provided toilet pedestals are wiped over daily. Clearly, no flush urinals are desirable both to save water and to reduce cartage cost for collected urine.

Energy and cost of dry sanitation

Further detailed study of the energy and resource implications of urine separation and dry toilet use compared to conventional sanitation and chemical fertiliser use will be essential to avoid increasing energy use overall. There has been sufficient work done to suggest that sanitation based on dry toilets could save energy. Similarly, further investigation of costs will be necessary to make sure that capital and operating cost is minimised. The work done previously suggests that a dry sanitation option may be no more costly overall but this remains to be proven.

Community acceptance

There is still a low level of knowledge of the advantages of urine separation and dry sanitation in the Australian community and there is a high level of resistance to change in most groups within society. Thus, for any large scale adoption to occur, it will be necessary for leaders and decision-makers to take some risks and for there to be a significant effort to publicise the concepts and advantages in the community. Adoption of dry sanitation is just one small but possible part of what must be done in the next decade or less to change our lifestyle and practices if we are to avoid catastrophic climate change.

13. Conclusions

Overall Conclusions

1. The low usage of the toilets (under 7 uses per day for urination and under 2 uses per day for defecation on average compared to an initial expectation of around 200 uses per day) has meant that completion of the originally proposed application of compost to land and detailed investigation of the solids composting process was not possible. Desiccation of the compost also inhibited any composting that may otherwise have occurred and no elevation of temperature was noted within the compost at any stage.
2. At most installations reviewed by the authors as well as at the Maryborough installation, there is no evidence that often-mentioned temperature elevation necessary to inactivate pathogens occurs. Whilst there is a need to further investigate temperature changes in operating composting toilets before concluding that temperature elevation cannot be relied upon to inactivate pathogens, it is probable that it cannot. This lends support to separating or centralising the composting process in a location where it can be controlled.
3. Despite the low usage and behaviour issues that have lead to some damage, it is reasonable to conclude that urine-separating dry composting toilets do function effectively in a secondary school environment. Furthermore there is good evidence that any aesthetic objections such as smell and unsightliness are unfounded and are more a matter of prejudice than fact. The trial has provided some evidence that odour within the toilet rooms of mechanically ventilated dry toilets is less likely than within conventional toilet blocks.
4. The recovery of nutrients in urine and leachate for use as fertiliser in agriculture has been shown to be readily achieved with no apparent health or environmental risks that could not be managed.
5. It would be preferable for future demonstrations of dry sanitation to be carried out in establishments where the occupiers have some interest in and commitment to success of the trial and this is likely to be difficult to achieve in a school. A “green” high, medium of low-density residential development or possibly a commercial development would be a preferable site for further demonstration projects and the work under way with urine separation in Queensland is one good example.
6. For any large-scale adoption to occur, it will be necessary for leaders and decision-makers to take some risks and for there to be a significant effort to publicise the concepts and advantages in the wide community. Adoption of dry sanitation is just one possible but admittedly small part of what must be done in the next decade or less to change our lifestyle and practices if we are to avoid catastrophic climate change.

Health, Aesthetic and Nuisance Issues

7. Health risk to users from using the toilets is negligible as the toilet pedestals have proved to be easy to keep clean and the incidence of fly breeding has been negligible. The absence of soap (and to a lesser extent, paper towels) in all student toilets at the school discourages normal hygiene and was undesirable but the misuse of towel and soap when provided illustrates one of the practical difficulties in running a school or public facility.
8. Health risk to the transporter and person applying urine and leachate to agricultural land is probably low if the low *E.coli* concentrations in the materials are used as a measure of risk. The *E.coli* content

in the urine and leachate after storage would typically be well below the EPA Victoria Biosolids guideline of 100 organisms/g of dry matter although this guideline is probably not appropriate for a concentrated liquid. The study team members were exposed to faecal matter, urine, leachate and spray mist from urine and leachate at various times during the trial. Whilst precautions were taken to use plastic or rubber gloves, initially to use facemasks when opening composters, and to wash hands using a disinfectant soap, there could well have been some inhalation and ingestion of minor quantities of the waste materials. No ill effects were noted. This is not any proof of safety but does add a small additional piece of information supporting the contention that risk of disease transfer from a normal (that is, healthy) school population to workers on this sort of installation is probably low.

9. No problems were experienced with blockage or scaling in the urine or leachate systems but higher usage may have increased this risk, particularly in the leachate outlets which tend to be dry much of the time and which have been found to block in other installations. The biofilter on urine and leachate tank vents coupled with water seals on tank overflows prevented any release of odour from the composters.
10. Fly breeding has not been a problem to date although small vinegar flies have been noted on one occasion for a limited period. It is likely that fly breeding would have been more of a problem with greater usage and it is concluded that better screening of vents and changes in user practices (closing of seat lids after use) would be necessary to manage the problem. The desiccated nature of the compost most of the time is the probably reason for lack of fly breeding.
11. Spiders did not colonise the inside of the composters or vents. This is probably because of the lack of flies. Therefore, if usage was greater and compost remained wet sufficient for flies to breed, it is likely that spiders would appear as they do in other installations.
12. Desiccation of the faecal matter and toilet paper generates a risk of fire, as dropping of cigarette butts and lighted material will always be a possibility, even in a private installation. Thus, equipping any dry toilet that is likely to desiccate the solids with automatic wetting sprays (coupled to smoke detectors within the solids storage space) would be desirable and should probably be a requirement. This is clearly an additional cost and also will require use of a small amount of water, which slightly reduces the advantage of the waterless toilet concept.

Composter Ventilation System

13. Air velocity into the open pedestals was measured on several occasions and was estimated to be typically around 0.24 m/s (range 0.18 to 0.3 m/s), which equates to airflow of 23 m^3/hr down the 185 mm diameter pedestal outlet. It is considered that a lower velocity of around 0.1 m/s would probably be sufficient to prevent odour release during use and this would reduce the necessary fan power.
14. Fan power was measured at 22 W per Rotaloo® Maxi 2000 or 11 W per pedestal. The use of time clocks reduced the average power input over a day to 12.6 W or around 6.5 W per pedestal and it is considered likely that this could be reduced substantially and still control odour.
15. The air handling system ran at under 0.5 mm of water vacuum, probably no more than around 0.1 mm of water, within the composters when lids on pedestals were closed.

Efficiency of Nutrient Capture

16. Based on the mass of nitrogen in leachate collected versus the mass of nitrogen in urine collected, it appears that over 90% of urine contributed is captured by the waterless urinals and the urine

collectors in pedestals. However, based on leachate volume collected before water addition started, the percentage of urine captured as urine is likely to be closer to 70% or less which is closer to literature values of 60%. Nevertheless, since both leachate and urine are collected at the installation, the full nutrient contribution from urine can be utilised (less any loss by volatilisation). For a urine separating toilet incorporating flushing of solids to sewer (where there is no leachate), the literature figure of 60% urine capture is possibly conservative but is supported, as a reasonable estimate, by some of the data collected at Maryborough.

Separated Urine Contributions per use

17. The best estimate that can be made from the data collected of the volume of separated urine collected per use is between 150 and 300 mL/use, which is consistent with the order of magnitude of published urination volumes. No information can be derived from the data on the number of uses made per student per day but it is likely in a normal situation to be 2 or 3. Thus, it is estimated that a secondary student is likely to contribute between 400 and 900 mL of urine per day whilst at school and that around 60% to 70% of this can be collected in urine separating devices.

18. If 150 mL per use is adopted as the volume of separated urine collected per use, the trial indicated that the probable contributions per use of N, P and K were 0.8 g N, 0.05 g P and 0.4 g K. If a use generates 300 mL these increase to 1.7 g N, 0.1 g P and 0.8 g K.

19. However, in the absence of good data on student use of toilets and better data on volume per use it may be more appropriate, at least for estimating maximum likely contributions, to use literature data that suggests contribution from a single student or staff use (around 300 mL compared to the 150 mL used to estimate usage) would typically be 2.2 g N, 0.2 g P and 0.8 g K based on a published data adjusted to account for the high K measurements at Maryborough.

20. If leachate is also collected for use then these mass loadings of N, P and K per use should be increased by a factor of about 1.4.

Urine and Leachate Composition and Characteristics

21. The estimated composition of urine is as expected from published literature and the data obtained so presents a wider range of analytes, including metals, than is currently available in the literature.

22. The metals analyses indicate that there is no hazard from metals likely to arise from use of urine in agriculture, that the nutrients nitrogen, phosphorus and potassium are significant as expected and there is a potential hazard from salts, particularly sodium and chloride, which may need management. The bacterial results indicate that both urine and leachate may potentially contain pathogens.

23. In relation to metals in urine, is it suggested that because concentrations are so low, further consideration of the impact of metals on soils is unnecessary.

24. As expected due to water addition to the composters for moisture control, leachate is more dilute than urine and may contain higher counts of *E. coli*. However, absence of detectable *E. coli* and Faecal *Streptococci* in some sampling of urine and leachate suggests that these indicators of faecal pollution do not necessarily survive for long in these liquids. Measured *E. coli* ranged between <10 orgs/100 mL and 131 orgs/100 mL in the three samples of each material measured. However, Faecal *Streptococci*, were detected at much higher counts, in urine samples, up to 230 000 orgs/100 mL.

Heat and Water Balances and Need for Composter Heating

25. Supplementary heating of composters is probably unnecessary, at least if urine separation is included, since achieving adequate moisture control for effective composting in ventilated systems such as the one tried is probably difficult. However, a trial with high usage would be desirable to determine the feasibility of on-site aerobic composting with Rotaloo® Maxi 2000 toilets without supplementary heating in temperate climates.

26. Heat and water balances over the composters indicate that the general effect of ventilation, even with warmed air, is to cool and desiccate the compost by evaporation. The heat transfer and water transfer to and from the compost during the day is highly dependent on air temperature, humidity and the effectiveness of the Sun Lizard in transferring warm air which varies rapidly with passing full sun and shade from clouds as well as slowly over a day. The greenhouse proved to be relatively ineffective in maintaining the compost warm as evidenced by composter and compost temperature following the diurnal temperature variation fairly closely. At times air temperature into the composters reached 60°C due to the combined heating effect of the greenhouse and Sun Lizard.

27. Provision of 500 W of heating on the inlet air to an insulated composter proved sufficient to maintain the compost mass and air temperature close to 20°C throughout the year, it is likely that less than this would suffice.

28. The highest heat input achieved to the composters from the greenhouse and Sun Lizard system was measured to be around 330 W, although this was not on a very hot day when short-term heat input may well be several times this amount.

29. Estimated heat losses by evaporation may be up to 400 W per Rotaloo® Maxi 2000 composter and heat losses due to radiation and convection are estimated to be around 600 W or more per composter if there is no insulation. These losses compare to a maximum likely heat generation from composting within one fairly full Rotaloo® Maxi 2000 of around 300 W. This shows a high potential for failure to establish thermophilic composting if there is a small volume of compost, no additional heat input and if the composters are not insulated.

30. The indication that achieving thermophilic composting may be difficult in the Rotaloo® Maxi 2000 is consistent with earlier investigations by the authors (GHD 2003) and further interviews of operators during this project, that indicated most operators of composting toilets of various kinds did not note high composting temperatures in temperate climates.

31. It would be desirable to monitor temperature in number of operating composting toilets in Australia in order to determine whether thermophilic composting is ever achieved and if so under what conditions.

32. Daily water loss from within the compost bins in a Rotaloo® Maxi 2000 was measured to be at up to a rate of 6.6 L/d with only limited dry compost in two of eight bins and little (if any) liquid in the base of the composters. With more compost, higher evaporation (and hence possibly more evaporative cooling) is likely. On a daily basis, loss of 2 to 3 L/d of water from the compost was measured both during summer and winter and this could be higher with more compost. This significant evaporation resulted in desiccation of the compost both in summer and winter.

Water Usage in Dry versus Conventional Toilets

33. Water usage in the dry composting toilet installation for hand washing was an estimated 1.5 to 2.5 L per use compared to total water usage in a conventional toilet block estimated as 4.2 L per use

(which is lower than expected and indicates that not all users flush or wash hands). However, the inability to count uses in this trial limits the reliability of this estimate. The use of water (3 to 6 L/d) to keep compost moist so as to reduce the risk of fire caused by cigarette butts meant that overall use in the composting toilets was more significant. However, the low usage was probably the primary cause of this need for additional water so it is not particularly relevant to water usage estimates.

34. It was estimated with reasonable accuracy that total conventional toilet block water use within the secondary school is of the order of 3.8 kL/d out of a total water use for all purposes (including summer evaporative cooling) of 6.5 kL/d (which should be accurate). As there were 1370 students and staff in the secondary school, estimated average use per person in toilets was 2.8 L/student and staff member per day out of a total use was around 7.1 L/d per student and staff member. All these estimates are based on use being assumed to be spread only over operating school days. This low estimated use per person in toilets suggests flushing, hand washing and even use of the toilets are not universally practiced. The long period of Stage 4 water restrictions in Maryborough have probably encouraged very active water saving practices.

Outcomes of the Agricultural Trial

35. The lack of rainfall during Spring 2008 limited the potential for the agricultural trial to show whether application of a urine/leachate mixture was as effective, more effective or less effective than application of chemical fertiliser in improving crop yield. There is some indication that urine/leachate application was effective in improving canola plant growth and the number of seeds per pod compared to the unfertilised control plot and possibly was more effective than chemical application. However, soil tests indicate that, whilst urine/leachate fertilised plots had elevated levels of nitrate nitrogen, its application may have reduce the availability of phosphorus and also chloride levels were higher on completion of the trial, which could possibly have a negative effect on plant growth.

36. For the pasture plots, the conclusions are similar to that for the canola plots. Visual observations suggest that application of the urine/leachate mixture did not have any detrimental effect and may have had a slightly beneficial effect similar to that from the chemical application.

37. An eductor truck using a 75 mm suction hose readily emptied urine and leachate tanks and no odour complaints were generated. Because the volume removed was low (around 600L) the volume of air displaced within the tanker may not have been sufficient to cause odour and in any case perfumed masking oil was injected into the vacuum pump on the truck. A full volume pump out would be expected to release some odour although it would be possible to discharge vented air from the truck via the biofilter.

38. The urine/leachate mixture was easily handled in the agricultural trial. On a larger scale, distribution direct from the truck via a trickle bar would be preferable to the water pump and fire hose used. The water pump did block with solids at one stage.

39. Spraying of urine/leachate did generate significant down-wind odour. Use of a trickle bar may reduce this by minimising fine spray but it is expected that application will be odorous and should not be carried out close to habitation. However, the odour disappeared within an hour of spraying.

40. The procedure adopted of spraying the vegetation with an equal volume of water after urine/leachate application prevented any observable damage to plant foliage. Application to bare soil or dormant pasture in autumn would be the preferred application approach.

41. No health issues were noted during the application and the urine/leachate probably met bacteriological criteria for biosolids if these are interpreted either as organisms/mL or organisms/g of dry solids contained in the urine.

42. The metal content in the urine/leachate mixture was so low that it would not be expected to increase metal content measurably even with annual application for 100 years and it is concluded that monitoring of metals in urine/leachate and in soils should not be required in future trials beyond pre-trial tests and then after many years of trial.

43. The high SAR did not have an observable effect on soil structure or crop growth.

44. The extensive soil testing carried out prior to and at the end of the agricultural trial showed impacts on the soil consistent with the applied urine/leachate and fertiliser after allowing for the complexities of transformations that take place in soils. Sodium, chloride and EC increased as a result of urine/leachate addition and chemical fertiliser addition but the increase was greater for chloride and sodium on the urine/leachate plot. Sodium concentration appeared to increase in the top 100 mm by the amount expected on the urine/leachate plot. Nitrate nitrogen in the urine/leachate plots increased over the trial more in the canola plot than in the pasture plot.

Value of Nutrients in Urine and Compost

45. The prices of nitrogen, phosphorus and potassium fertiliser varied significantly over the period of the trial. At the peak of the cycle in December 2008, the value of these nutrients in urine totalled around 20 AUD per kL and the value in compost (assuming 28% moisture in the compost) totalled around 160 AUD/tonne wet basis. However by April 2009 these values had dropped to around 13 AUD/kL and 110 AUD/tonne wet basis respectively.

46. Unless cost of cartage is under say 10 AUD/tonne or kL, use of urine as a fertiliser may not be an economical practice at current fertiliser prices. However, as urine contains the majority of the nutrients in excreta, its use may become financially attractive if, as seems likely, prices of fertiliser continue to increase and provided cost of transport is reduced by economies of scale. These values do not take into account the value of organic matter in the compost and this could be considerable.

47. By contrast, the cost of conventional chemical fertilisers at the peak prices in December 2008 were around: 1 035 AUD/tonne for urea containing 45% N, 590 AUD/tonne for single superphosphate containing 8.8% P and 1 500 AUD/tonne for potassium chloride (muriate of potash) containing 50% K.

48. Recovery of all nutrients in human excreta in dry toilets would only provide around 11.5% of typical current nitrogen in fertiliser used in Australia. For phosphorus and potassium, recovered excreta would provide 3.0% and 11 % of P and K in chemical fertiliser currently used. Whilst these percentages appear to be low, it must be remembered that Australia exports much of its produce from chemically fertilised land, for example around 65% of the wheat crop is typically exported. Thus, human excreta can potentially provide a significant proportion of agricultural fertiliser needs to sustain a population.

49. Total chemical fertiliser use in Australia leads to application of N, P and K in the ratio 100:51:21. The ratios of N:P:K in urine of 100:7:50 are such that applying sufficient for nitrogen needs will over-apply potassium and under-apply phosphorus. In compost the N:P:K ratio of 100:67:78 will mean application of the required nitrogen will over-apply both phosphorus and particularly potassium. For

these reasons, farmers may wish to apply mixes of these materials and chemicals and this will reduce their willingness to pay transport costs.

User Attitude

50. Females were more averse to using the toilets than males. In an initial survey prior to commissioning, 28% females and 46% of males said they would not avoid using the toilets. In the second survey, only 25% of all respondents indicated they had used the toilets, this percentage being made up of 17% of female respondents and 35% of male respondents (mainly students).
51. Most users (74%) were either pleasantly surprised or considered the toilets were not as bad as they expected after using the facility. 35% of female respondents who used the toilets were pleasantly surprised whereas a lesser percentage of male respondents (23%) were pleasantly surprised. Only 10% of female respondents reported they did not like the experience whereas 23% of male respondents reported they did not like the experience.

Cost of the Installation

52. The total cost of the trial installation at Maryborough was very high, around 235 000 AUD or nearly 42 000 per fixture. This is nearly 37 000 AUD per fixture more than for conventional toilets. This additional cost is to cover the building works necessary to house the toilets as well as monitoring and other equipment and facilities specific for the trial. Only a minor fraction (around 12%) of this cost is the equipment itself.
53. The very high costs at Maryborough arose form the design of the school with slab-on-ground construction on a flat area of rock, the generally expensive design of the building and the fact that the price for the installation was negotiated with the builder after award of the contract for construction of the school.
54. If reasonable adjustments are made to the costs at Maryborough, it is estimated that the total cost for what was actually built should have been substantially less and the additional cost per fixture could have been brought down to around 25 000 AUD compared to conventional toilets. With construction on a sloping site and with further development and economies of scale, the previous GHD estimate that urine-separating composting toilets could be installed for a cost additional to that for conventional toilets in the range of 5 000 to 10 000 AUD may still be achievable. This is a reasonable additional cost bearing in mind that it provides a processing and storage system for excreta on site, allows substantial resource recovery and reduces the capacity required in municipal sewerage systems.
55. It is suggested that for the present it would be wise for any future such demonstration projects to allow ample additional cost for new installations, probably of the order of 10 000 to 15 000 AUD per fixture on top of conventional toilets or 15 000 to 20 000 total cost per fixture in total to allow for equipment and building costs.
56. Maintenance and cleaning costs were no higher than for conventional toilets if the cost of cartage of urine and leachate is excluded.

Project Costs

57. The Smart Water Fund contributed a total of about 173 000 AUD to the project of which around 117 000 AUD was a contribution to capital cost. The participants GHD, Oaten Stanistreet Architects, Environment Equipment Pty Ltd and Connor Pincus & Saunders as well as the Department of Education and Early Childhood Development Victoria contributed an estimated 104 000 AUD of in-

kind support, giving a total cost for the project of around 280 000 AUD. Total project cost including the capital costs, engineering, supervision, monitoring, investigation and reporting costs were around 500 000 AUD. This does not include unrecorded time spent by study team members, which was considerable.

58. Costs of such studies are easily underestimated at the start of a project. An example is that the project plan assumed that mainly the operator could do investigation work with only three visits by the study team. In the end, whilst the cleaner provided some monitoring and recording, the study team members made some 15 visits to site during the project.

Energy and Dry Sanitation

59. The study provided some additional support to earlier investigations by GHD in 2003 and by other workers that dry sanitation could be implemented on a medium to large scale with lesser or similar overall primary energy use per capita than conventional sanitation. The estimated per-capita primary energy use for conventional sanitation is 248 to 540 MJ/c.yr and for dry sanitation assuming heating of composters is not required it is 171 to 474 MJ/c-yr. This comparison allows for embodied energy in fertiliser saved with dry sanitation compared to conventional sanitation amounting to 70 MJ/c.yr. Thus, it appears that sanitation based on urine separation and dry toilets could reduce overall energy use.

Further investigation at Maryborough

60. If usage of the toilets increases then further investigation would be worthwhile focussing on composting, fly nuisance, compost use and health issues.
61. Ongoing application of residues to dry land farms in the area should continue with sufficient record keeping to track effectiveness and areas used.

Recommendations for Further Development Demonstration Projects

62. Further demonstration on a large scale of urine separation, on site composting, on site desiccation with off site composting and agricultural use of residues should be a priority for government. Such projects will require substantial funding assistance, encouragement and regulatory support and ideally should be located in large high or medium density residential or commercial developments where users have an interest in the success of the trial.
63. Future demonstration projects in schools are not recommended because of the difficulties encountered but there is no reason not to actually use dry toilets in schools if there is support from the school community.
64. Development of a dry toilet based on urine separation and desiccation with centralised composting or co-composting of solids is recommended as a potentially lower cost and more easily operated approach to dry sanitation than urine separating dry composting toilets.
65. Further comparison of low-flush urine separating toilet and waterless urine separating toilets is necessary but indications are that the waterless option is acceptable.
66. Specific regulations and approval processes for such demonstration projects are needed.

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