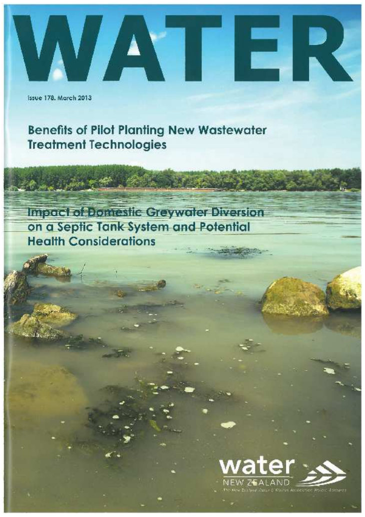

Impact of domestic greywater diversion on a septic tank system and potential health considerations

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The problem

In rural New Zealand, domestic wastewater is typically treated on-site. Many new property developments are investing in advanced wastewater treatment systems although an estimated 270,000 existing properties still operate a traditional primary treatment septic tank. Failure rates of these systems are high (15-50%) and it is generally accepted that many older septic tanks do not have sufficient capacity to process and dispose of the volumes of domestic wastewater produced by modern lifestyles. Also, many rural properties experience extreme changes in occupancy, which may be sporadic and seasonal e.g. the family holiday home. Both on-going and temporarily elevated loading rates result in a decreased hydraulic retention time of wastewater in a septic tank system and poorer settling of suspended solids. This leads to clogging of the soakage area, increased discharge of microbial and chemical contaminants to groundwater and potential surface ponding of poorly treated wastewater, which has environmental and public health risk implications.

A potential solution

There are two main options to remedy this failing situation: (1) replace/modify the existing septic tank to meet the new hydraulic requirements of the property or (2) reduce the volume of wastewater requiring treatment by the septic tank system. The costs associated with re-designing or replacing existing septic tanks is dependent on the regional requirements, but could be up to NZ$18,000 per unit and would need to be financed by the homeowner. Many homeowners are unwilling or unable to finance a system upgrade, particularly for rural holiday homes that are not a primary residence and have intermittent use. Consequently, unregulated greywater diversion is practiced extensively in rural New Zealand as a means of relieving the hydraulic burden on failing septic tanks and the receiving environment. Greywater (domestic wastewater originating from laundry, shower, bath and bathroom sink) can account for 50-75% of the wastewater produced by a household (according to AS/NZS 1547: 2012). As such, its separation and diversion should increase the septic tank hydraulic retention time and theoretically improve the quality of the septic system effluent, thereby prolonging the life-span of the soakage area, lessen the impact on the receiving environment and reduce the public health risks.

However, greywater itself is a potentially hazardous wastewater stream, reported to contain a high microbial (bacterial and viral) and chemical (pharmaceuticals and household cleaning products) load. If greywater does not actually improve the treatment efficiency of a domestic septic system, then the unregulated use of a diversion/disposal system may in fact increase the exposure of the residents to potential public health risks, and further increase risks to the receiving environment.

Although the use of a greywater system for the purpose of relieving the hydraulic burden on a septic tank has not been previously investigated, many rural homeowners are nonetheless practising greywater diversion for this purpose. There are anecdotal reports that a growing number of households are using some form of unregulated and unreported greywater disposal system. This was confirmed by a recent survey of a small coastal settlement (to be published shortly), which identified a high proportion (ca. 44%) of properties that were undertaking greywater disposal measures. These disposal methods are typically basic, with no flow regulation, and may be as simple as pipes from washing machines going through a window and directly onto a lawn area. This in itself has implications for public health as well as environmental contamination concerns.

The research

The Centre for Integrated Biowaste Research (CIBR)* set out to fill this knowledge gap by carrying out a study that investigated the use of greywater diversion as a means of reducing the volume of wastewater directed to a domestic septic tank, and to determine if there were any associated environmental and public health risks from such a practice. Two domestic properties kindly agreed to participate in an 8-week study; site-1 is located in Paekakariki on the Kapiti Coast, and site-2 is located in West Melton, Christchurch. Both properties had two permanent residents, were served by a reticulated water supply, and operated a single chamber septic tank and a Watersmart® greywater system, which diverts untreated greywater for irrigation, with no storage capacity. It should be noted that septic tank at site-1 was overdue for regular maintenance and a pump-out of the accumulated solids, which were clearly visible, and was therefore considered to be a “worst case” scenario. Site-2 had a larger tank that was well maintained and was operating more efficiently. This configuration enabled us to ascertain if, in addition to improving the functioning of an underperforming septic tank, greywater diversion would not be detrimental to the operation of a well-functioning system.

From weeks 1 to 4, all domestic wastewater was directed to the septic tank and triplicate samples were taken weekly from the septic tank effluent discharge pipe. From weeks 5 to 8, the greywater stream was diverted to irrigation, and the greywater was sampled in triplicate in addition to the on-going septic tank effluent sampling. Sub-samples were analysed by ESR for pH, total suspended solids, human polyomavirus and adenovirus, while Environmental Laboratory Services (ELS, Lower Hutt, Wellington) carried out analysis for BOD_5, alkalinity, *Escherichia. coli (E. coli)*, Total Kjeldahl Nitrogen (TKN), ammonia, nitrate, nitrite, total phosphorus, dissolved reactive phosphorus (DRP), sodium, calcium and magnesium.

Loading rates applied to the septic soakage field before and after greywater diversion, and the loading rate of the greywater stream, were determined. These calculations were based on averages of the weekly triplicate samples taken over four weeks, and the volume of wastewater was estimated by an expected two person household water consumption of 0.4 m^3 d^{-1}, with greywater diversion accounting for 50% (0.2 m^3 d^{-1}) of the total wastewater stream, according to AS/NZS 1547.

Physical indicator of effluent quality

Total suspended solids (TSS) are one of the key factors to determine if a septic tank is operating beyond its hydraulic capacity. Insufficient settling time increases the level of solids expelled from the septic tank, and decreases the lifespan of the soakage field and/or impact on the receiving environment. There was a significant difference in the TSS levels of the septic tank effluent between both sites during the first 3 weeks ($p < 0.05$), with TSS of up to 190 g m^{-3} observed at site-1 (Fig. 1). This clearly shows that the septic tank at site-2 is operating more efficiently than that at site-1. Following diversion of the greywater stream, and for the remainder of the study, the TSS values of both sites were consistently between 120-140 g m^{-3} (Fig. 1). It appears that rather than causing a decrease in TSS as a rule, the diversion of greywater stabilises the TSS levels of the septic tank effluent. Also, at both sites we observed an overall decrease in the average daily TSS levels applied to the septic tank soakage area following greywater diversion, from 57 to 25 g/day at site-1 and from 30 to 26 g/day at site-2 (Table 1).

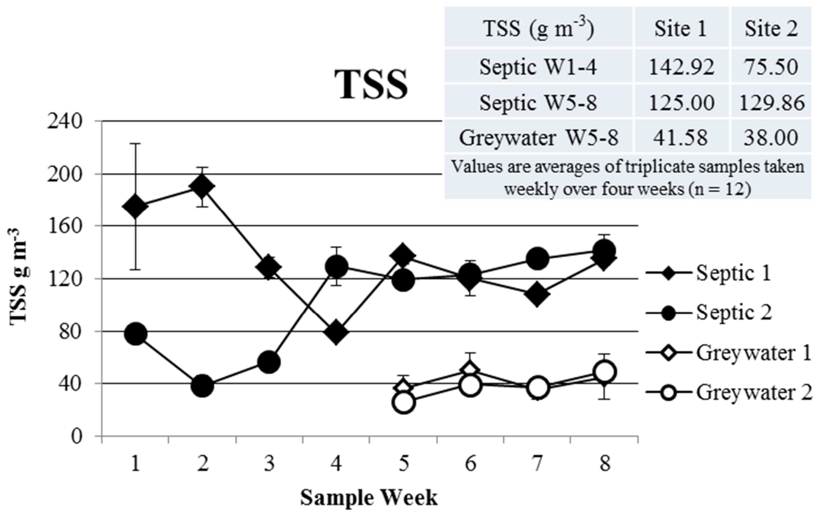


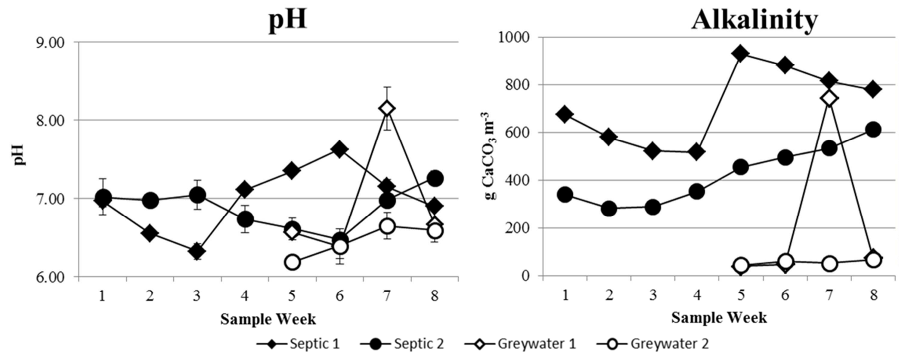
Figure 1. **Graph:** Measured TSS (g m^{-3}) of septic tank effluent and greywater at sites 1 and 2; **Table**: average TSS values of septic tank effluent pre-diversion (Weeks 1-4) and post diversion (Weeks 5-8) and average TSS values of greywater (Weeks 5-8).

Table 1. Average daily loading rates applied to septic tank soakage area. Calculated on the assumption that a two-person household produces approximately 0.4 m^{-3} wastewater/day, of which, greywater should account for approximately 50%, according to AS/NZS 1547. (♦) denotes significant difference in the septic tank effluent between W1-4 and W5-8 ($p < 0.05$).

		TSS (g/day)	Alkalinity (g/day)	BOD_5 (g/day)	TKN (g/day)	Total P (g/day)	*E. coli* (MPN/day)
Site-1	Septic W1-4	57	229	119	56	6.5	3.1×10^9
	Septic W5-8	25♦	170♦	48♦	42♦	4.6♦	5.6×10^8♦
	Greywater W5-8	8	46	13	1	0.4	7.3×10^6
Site-2	Septic W1-4	30	127	175	27	4.5	4.8×10^9
	Septic W5-8	26	105♦	62	23♦	3.8	3.4×10^9
	Greywater W5-8	8	12	14	1	0.3	6.8×10^7

Chemical indicators of effluent quality

The pH values demonstrated the variability of the greywater stream, which is believed to be dependent on the personal habits of the homeowners and the activities carried out in the property at the time of sampling. As an example, although the greywater sampled from both properties was generally slightly acidic (6.1 – 6.7), an average value of 8.2 was recorded at site-1 on week 7 (Fig. 2). Septic tank effluent values were typically in the range of 6.3 – 7.6 (Fig. 2).

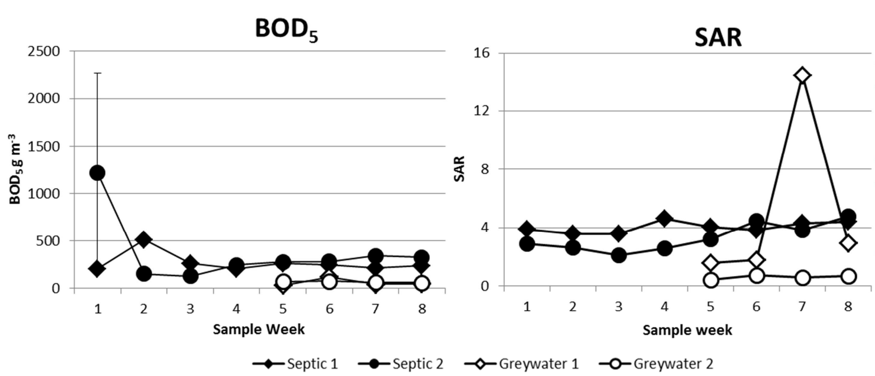


		Site 1	Site 2
pH	Septic W1-4	6.74	6.95
	Septic W5-8	7.25	6.83
	Greywater W5-8	6.94	6.46
Alkalinity	Septic W1-4	573	317
	Septic W5-8	851	524
	Greywater W5-8	228	58

Values are averages of triplicate samples taken weekly over four weeks (n = 12)

Figure 2. **Graph:** pH and alkalinity of septic tank effluent and greywater at sites 1 and 2; **Table**: average pH and alkalinity values of septic tank effluent pre-diversion (Weeks 1-4) and post diversion (Weeks 5-8) and average pH and alkalinity values of greywater (Weeks 5-8).

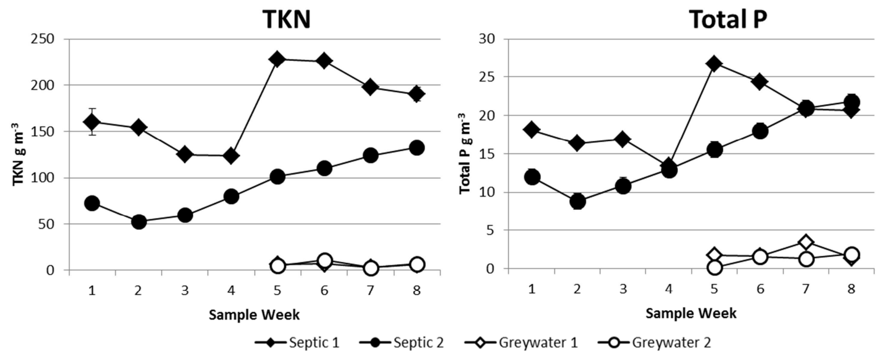
The remaining chemical indicators monitored included alkalinity (Fig. 2; a measure of the acid neutralizing ability, or buffering capacity, of a sample, which can be the result of several ions in solution), BOD_5 (Fig. 3; a measurement of the dissolved oxygen used by microorganisms in the oxidation of organic matter in sewage in five days), the cations sodium, magnesium and calcium, which are used to determine the sodium adsorption ratio (SAR; Fig. 3) and various forms of nitrogen and phosphorus (Fig. 4).



		Site 1	Site 2
BOD5	Septic W1-4	296.58	436.42
	Septic W5-8	241.17	307.83
	Greywater W5-8	63.08	69.00
SAR	Septic W1-4	3.91	2.55
	Septic W5-8	4.14	4.08
	Greywater W5-8	5.20	0.60

Figure 3. **Graph:** BOD_5 and Sodium Adsorption Ratio of septic tank effluent and greywater at sites 1 and 2; **Table**: average BOD_5 and SAR values of septic tank effluent pre-diversion (Weeks 1-4) and post diversion (Weeks 5-8) and average BOD_5 and SAR values of greywater (Weeks 5-8).

For all parameters, except BOD_5 and pH, the diversion of greywater corresponded to an increase in the average concentration of each chemical indicator in the septic tank effluent at both sites (Figs. 2-4). However, the lower volume of septic tank effluent produced as a result of greywater diversion means that overall there was a reduction in the mass load discharge of chemical components such as nitrogen and phosphorus entering the soakage area (Table 1).



		Site 1	Site 2
TKN	Septic W1-4	140.67	66.34
	Septic W5-8	210.25	117.08
	Greywater W5-8	5.70	6.32
Total P	Septic W1-4	16.18	11.19
	Septic W5-8	23.13	19.08
	Greywater W5-8	2.08	1.26

Figure 4. **Graph:** Total Kjeldahl Nitrogen and Total Phosphorus of septic tank effluent and greywater at sites 1 and 2; **Table**: average Total Kjeldahl Nitrogen and Total Phosphorus values of septic tank effluent pre-diversion (Weeks 1-4) and post diversion (Weeks 5-8) and average TKN and TP values of greywater (Weeks 5-8).

Biological indicators of effluent quality

Organisms, such as total and faecal coliforms and *E. coli,* are commonly used to indicate the density and reduction of pathogenic bacteria and viruses in waste water. In this study *E. coli* levels at both sites were monitored and remained at approximately 10^6 MPN/100ml throughout our study (Fig. 5). Greywater diversion did not appear to impact the concentration of *E. coli* in the septic tank effluent, and the levels of *E. coli* in the greywater stream were typically 2 orders of magnitude lower than the septic tank effluent. Again, the lower volume of septic tank effluent being produced following greywater diversion resulted in a reduced numbers of *E. coli* entering the septic tank soakage area on a daily basis (Table 1).

E. coli (MPN/100ml)	Site 1	Site 2
Septic W1-4	7.7×10^5	1.2×10^6
Septic W5-8	2.8×10^5	1.7×10^6
Greywater W5-8	3.7×10^3	3.4×10^4

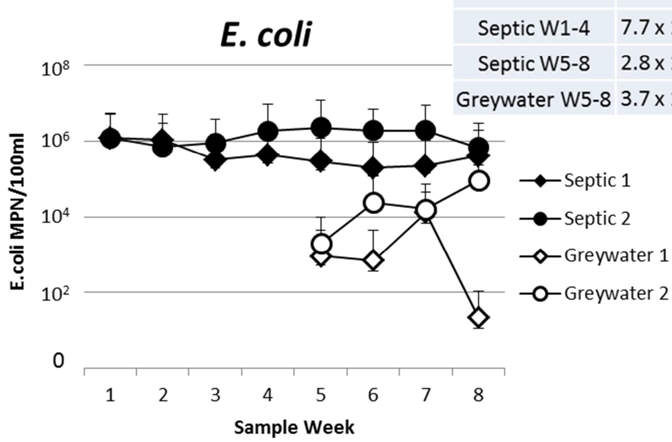


Figure 5. **Graph.** *E. coli* levels of septic tank effluent and greywater at sites 1 and 2; **Table**: average *E. coli* values of septic tank effluent pre-diversion (Weeks 1-4) and post diversion (Weeks 5-8) and average *E. coli* values of greywater (Weeks 5-8).

Pathogens from poorly functioning septic tank systems have frequently been linked to outbreaks of human illnesses when these pathogens are transferred to nearby groundwater or drinking water supply sources. Therefore, a reduction in the numbers of *E. coli* entering the environment may be indicative of reductions in the numbers of pathogens, which would in turn indicate a reduction in the public health risks associated with the discharge of pathogens from septic tank systems. However, it has been widely demonstrated that coliform bacteria do not adequately reflect the occurrence and survival of pathogens in treated sewage and wastewater, and it is thus important to monitor a suite of organisms including a subset of pathogens). For this reason virology analysis was carried out at the Environmental and Food Virology Laboratory, ESR for human polyomavirus (HPyV) and adenovirus (HAdV). These viruses have been suggested as suitable human pollution indicators (faecal and urine) because of their prevalence in influent wastewater.

Table 2. Virology analysis of samples collected throughout the study. Human polyomavirus (HPyV) and adenovirus (HAdV) were targeted. (-) denotes weeks where samples were not collected for virology analysis. +(F) indicates the species of HAdV detected in the sample. Values given are genomes copies/L.

	Week	Site 1		Site 2	
		HPyV	HAdV	HPyV	HAdV
Septic tank	1	5.6×10^5	Neg	2.4×10^4	Neg
	2	7.3×10^3	Neg	2.0×10^4	Neg
	3	-	-	-	-
	4	1.9×10^4	+ (F)	Neg	Neg
	5	5.2×10^3	+ (F)	1.5×10^5	Neg
	6	3.3×10^8	+ (F)	Neg	Neg
	7	1.6×10^9	+ (F)	-	-
	8	Neg	Neg	Neg	Neg
Greywater	5	Neg	Neg	Neg	Neg
	6	Neg	Neg	3.9×10^3	Neg
	7	-	-	-	-
	8	6.0×10^3	Neg	Neg	Neg

HPyV was detected in 6 out of 7 septic tank effluent samples collected from site-1, and in 3 out of 6 septic tank effluent samples collected from site-2. It was also detected sporadically in the greywater stream from both sites. HAdV was detected less frequently – in 4 out of 7 septic tank effluent samples collected from site-1, but was not detected in the septic tank effluent of site-2 or in the greywater stream from either site.

So what does it all mean?

The septic tank at site-one would not be described as “failing” as there were no visible signs of system failure at the property, e.g. surface ponding of partially treated effluent. However, prior to sampling at the property, the homeowner informed us that he was aware that the tank was overdue for a scheduled pump-out. This was apparent on visual inspection of the septic tank, and the homeowner agreed to delay his regular maintenance until sampling was complete. This tank, in effect, acted as a poorly performing system for the purposes of this study, and this was also evident in the elevated TSS, alkalinity and ammonia levels detected during the initial weeks of sampling. This site strongly benefited from the reduced hydraulic loading that resulted from greywater diversion. TSS, alkalinity, BOD_5, N, P and *E. coli* mass loading applied to the septic tank soakage area were all significantly lower in weeks 5-8 than in weeks 1-4 ($p < 0.05$). This should have a strongly positive impact on the life-span of the soakage area, thereby reducing the potential environmental and public health risks associated with the failure of an on-site septic tank system.

In contrast, the septic tank at site-2 had been pumped out more recently and there was no visible accumulation of solids in the tank. This tank was included in the study to determine if the reduced hydraulic loading to the septic tank as a result of greywater diversion would have a detrimental impact on a well functioning system. This did not appear to be the case – concentrations of TSS, BOD_5, total P and *E. coli* applied daily to the soakage area were not significantly affected by the commencement of greywater diversion ($p > 0.05$), although TKN and alkalinity levels were reduced.

This study suggests that the use of a greywater diversion system may be a suitable cost effective way to extend the life-span of a septic tank soakage area and thereby improve the function of an under-performing system; being older systems with reduced hydraulic retention capacities. Additionally, greywater diversion resulted in a decreased loading of factors such as *E. coli* and specific viruses to the environment, and does not appear to result in an increased risk to public health.

It should be noted that our research emphasises the necessity for certain precautions to be implemented with regard to the on-site use of untreated greywater. We can observe from our data that levels of *E. coli* in greywater were typically less than 2 orders of magnitude lower than that of the septic tank effluent, and were frequently $>10^4$ MPN/100ml. Also, we detected the intermittent presence of the HPyV virus in the greywater streams of both sites, which is emerging as a potential indicator of contamination by human biowastes. As such, despite the benefits on the performance of septic tanks, greywater in itself may be considered to be a public health risk and its use should be carefully considered with design undertaken and matched to the site conditions and receiving environment. There are currently no nationally applicable guidelines for the safe reuse of untreated domestic greywater. Most Councils recommend that untreated greywater is used for sub-surface irrigation ($\geq$ 10cm depth) of non-food chain plants, such as borders and shrubberies, and that its use should be restricted to areas where children are unlikely to come into contact with the soil. Greywater should not be applied in areas with a shallow depth to the groundwater table, or on soil susceptible to clogging or excessive leaching, to minimise the environmental risks associated with its dispersal. Some councils, such as Kapiti Coast District Council and Gisborne District Council, have developed specific guidelines for greywater use in their region. However there is typically extensive variation between different councils, causing confusion and tension between engineers, system suppliers, and local government.

The requirement for national guidelines is increasing and will likely need to be addressed in the near future. There are increasing demands for greywater systems as the general public become more water conscious; particularly as water metering is introduced throughout New Zealand. The CIBR is working towards collating scientific information that may form the basis of a New Zealand specific Greywater Guideline that takes into account New Zealand's unique soils and climate.

If you have any queries about this study or on-going greywater research at the CIBR, or would like to be involved in any future greywater research, please contact alma.siggins@esr.cri.nz

* The Centre for Integrated Biowaste Research is a multidisciplinary collaboration between 10 New Zealand research institutes, universities and research partners dedicated to developing appropriate and sustainable solutions that maximise the benefits and minimise the risks of reusing biowastes (www.CIBR.co.nz)

Acknowledgments

The authors would like to thank:
The homeowners who took part in this study
The Ministry of Business, Innovation & Employment for funding this research via ESR core-funding.
Brent Hawthron (Innoflow) for advice with experimental design

Morkel Zaayman and Lisa Daniel for their assistance with field sampling