Performance comparison of five alternative wetland-based ecotechnologies for on-site and decentralised wastewater treatment.

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Keywords: constructed wetland, nutrient removal, disinfection

Disposal of poorly-treated wastewaters from households and communities can pollute ground- and surface-waters, reducing water quality, and creating risks for human health and negative impacts on aquatic ecosystems. Constructed wetlands have the potential to reliably treat septic tank effluents to advanced secondary or tertiary standards with nil or low requirements for energy or mechanical equipment. Because they harness robust natural treatment processes and have extended residence times, they are likely to be more able to deal with fluctuations in usage and loading than mechanised package treatment plants (particularly those based on activated sludge processes), nd be less reliant on technical maintenance. However, they do tend to require larger land areas than mechanised treatment plants. In recent years a wide range of different constructed wetland formats have been developed, each with differing performance attributes, area requirements and establishment costs. Development and testing of these systems has generally been carried out at diverse locations under differing local conditions, so that comparative performance is hard to evaluate.

The present study compares the treatment performance over an annual period of five different wetland-based treatment trains comprised of different combinations of horizontal and/or vertical-flow constructed wetlands, attached-growth bioreactors and carbonaceous media filters. The components of the five treatment trains were optimised based on the results of preliminary testing over the two previous years in a multi-component testing facility in Hamilton, New Zealand. This allowed side-by-side comparison of 6 different treatment trains, comprising 20 discrete treatment units, belonging to five different ecotechnology categories. A prime focus of system optimisation was enhancement of nitrogen removal, as this is a key diffuse pollution issue for on-site wastewater management that significantly influences disposal and reuse options.

The five post-septic tank treatment trains compared in the present study were:

- *HG*, **H**orizontal subsurface-flow **G**ravel media wetland
- *VG+C*, **V**ertical-flow **G**ravel media wetland and **C**arbonaceous media filter
- *VS+C*, **V**ertical-flow **S**and media wetland and **C**arbonaceous media filter
- *R(HG+VS)*, **R**ecirculating **H**orizontal subsurface-flow **G**ravel and **V**ertical flow **S**and media wetland
- *R(A+VS)+C,* **R**ecirculating submerged **A**ttached-growth bioreactor and **V**ertical flow **S**and media wetland, followed by a single-pass **C**arbonaceous media filter

Each system received hourly doses of primary screened and settled sewage from a municipal treatment plant, which was similar in composition to septic tank effluent. Flow meters were used to monitor and adjust influent rates. Both recirculating

systems employed a 4:1 recirculation ratio. Performance was compared over an annual period with grab samples taken monthly from inflows (in common), outflows and intermediate points. Temperature, pH, dissolved oxygen and conductivity was measured in the field using calibrated meters, and samples returned directly to the lab and analysed for Total Suspended Solids (TSS), five day Carbonaceous Biochemical Oxygen Demand ($CBOD_5$), Total Kjeldahl Nitrogen (TKN), ammonium-N, nitrate/nitrite-N, Total P (TP), Dissolved Reactive P (DRP), alkalinity, and *E.coli* using standard methods.

All the wetland-based treatment systems were able to substantially reduce TSS and $CBOD_5$ (Table 1). NH_4-N and TN removal were substantially higher in the pulse-dosed vertical-flow wetland systems, with removals of 95% recorded for the R(A+VS)+C system with recirculating components followed by carbonaceous media filters. Both nitrification and denitrification appeared to be limiting in the simplest HG system which recorded a mean TN reduction of 38%, whilst denitrification stages appeared to be limited in the VS+C and R(HG+VS) systems. Best TP and DRP removal (>50%) was recorded overall for the HG and VS+C systems. Faecal indicator bacteria were reduced by 2.9 to 4.8 log units with best performance in the VS+C and R(A+VS)+C systems.

Table 1 Summary of annual treatment performance for the 5 alternative treatment systems.

		TSS	$CBOD_5$	TN	NH_4-N	NO_x-N	TP	DRP	*E.coli* (CFU
		g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	/100mL)
Inflow	**Mean or *median**	**72.2**	**111.3**	**42.5**	**33.5**	**0.2**	**5.2**	**3.5**	***3400000**
	Std Dev or *75%ile	32.8	47.6	9.3	6.4	0.5	1.4	1.2	*4800000
Outflows									
HG	**Mean or *median**	**2.1**	**1.8**	**26.2**	**11.3**	**13.7**	**1.8**	**1.7**	***2200**
	Std Dev or *75%ile	1.67	1.06	15.99	6.62	19.42	1.33	1.37	*12500
	% or log removal	*97%*	*98%*	*38%*	*66%*		*66%*	*51%*	*3.2 log*
VG+C	**Mean or *median**	**3.0**	**1.6**	**7.5**	**0.2**	**6.2**	**2.3**	**2.2**	***510**
	Std Dev or *75%ile	2.14	1.09	5.45	0.23	5.70	0.47	0.58	*5300
	% or log removal	*96%*	*99%*	*82%*	*99.5%*		*57%*	*36%*	*3.8 log*
VS+C	**Mean or *median**	**4.5**	**1.0**	**16.5**	**0.3**	**15.2**	**1.7**	**1.5**	***100**
	Std Dev or *75%ile	5.25	0.51	7.32	0.56	7.24	0.38	0.37	*540
	% or log removal	*94%*	*99%*	*61%*	*99%*		*68%*	*56%*	*4.5 log*
R(HG+VS)	**Mean or *median**	**2.9**	**1.9**	**11.6**	**0.3**	**10.1**	**2.9**	**2.7**	***4000**
	Std Dev or *75%ile	1.73	0.50	3.95	0.10	3.78	1.32	1.23	*40000
	% or log removal	*96%*	*98%*	*73%*	*99%*		*44%*	*21%*	*2.9 log*
R(A+VS)+C	**Mean or *median**	**1.5**	**2.2**	**2.3**	**0.6**	**0.8**	**3.2**	**3.2**	***49**
	Std Dev or *75%ile	0.00	2.06	2.22	0.30	2.11	0.67	0.65	*127
	% or log removal	*98%*	*98%*	*95%*	*98%*		*40%*	*9%*	*4.8 log*

The results of this study show that wetland-based treatment systems can achieve substantial improvements in effluent quality approaching or exceeding treatment levels achieved in mechanised package treatment plants. Use of such hybrid systems will reduce the land areas required to sustainably dispose and assimilate wastewaters from households and communities. This will reduce impacts on sensitive groundwaters and aquatic ecosystems, whist reducing human health risks from discharge of faecal microbiological pollutants. These systems have relevance for decentralised wastewater management, particularly in remote situations and where there is fluctuating usage (e.g. marae and camping grounds). Full results of the study have been submitted for publication in Ecological Engineering, and investigations are continuing to assess the effects of shock loadings and intermittent usage on treatment performance.