Biomass to Biochar
Water Filtration Report

Assessment of Test Results for Biochar Trials

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1.0 Introduction

Charcoal is an established filter medium for water quality improvement[1] and this trial seeks to explore the effectiveness of biochar made from rushes and from woodchip as part of the Biomass to Biochar trail process; and to assess potential differences in effectiveness between woodchip char and rush char.

Four different trials were set up as part of this experiment, including a filter system for septic tank effluent; rush char additions to a domestic well; rush char additions to a farm pond and a comparative filter media trail for domestic grey water via different media types, including both biochar types. This report describes and discusses the results obtained as part of the trial process.

2.0 Experimental Set-up

2.1 Well water set-up

For this element of the trails samples were taken from a shallow stone well at Knocknaskeagh, Lahinch, Co. Clare. Analysis was carried out for three weeks on the well water to establish a control, and then rush biochar (10 litres) was added to the well in a jute sack and the sampling continued for a further two weeks to assess before and after figures. The capacity of the well is *c*. 200 litres, providing a ratio of char to water of *c*. 1:20.

2.2 Farm pond set-up

Samples were taken from a farm pond at Caheraduff, Kilshanny, Co. Clare. Analysis was carried out for three weeks on the pond water to establish a control, and then rush biochar (20 litres) was added to the inlet to the pond in two jute sacks and the sampling continued for a further three weeks. The pond volume is *c*. 200 m^3, providing a ratio of char to water of *c*. 1:10,000. The pond has been excavated within a farm drain, so water throughput is present.

2.3 Septic tank effluent filter

This process involved a standard septic tank with a woodchip filter system located immediately after the tank. For the first three weeks of the trial the effluent quality into and out of the woodchip filter was assessed. For the second half of the trial a 75mm deep layer of rush char was added on top of the woodchip media and the assessment of effluent quality into and out of the woodchip filter tank was continued, to compare before and after figures for the effluent quality.

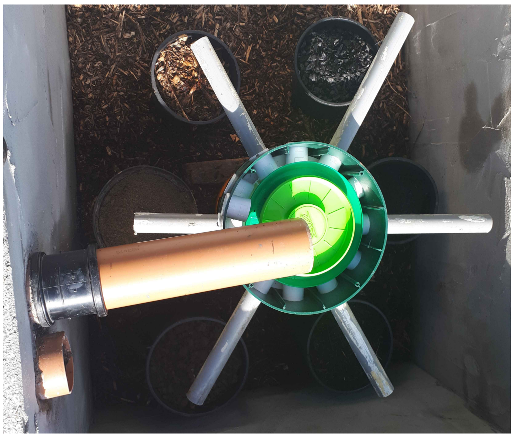
Fig. 2.3.1. Woodchip filter taking effluent from a domestic septic tank; shown here with 75mm of rush char added as a layer over the woodchip filter media. Ribbit splitter shown to the left of the photo added over the char to provide effective 12-way splitting of liquid into the filter tank.

[1] Gwenzi W, N Chaukura, N Chicgoua, FND Mukome (2017) *Biochar-based water treatment systems as a potential low-cost and sustainable technology for clean water provision*. Journal of Environmental Management, 197: 732-749.

2.4 Filter media comparisons

A final experimental set-up involved splitting a domestic grey water line from a single dwelling and dividing it 6 ways to assess the comparative effectiveness of rush char, woodchip char, soil, quarry grit and a control with no filtration. A series of 5-litre pots were used underneath different splitter outfalls and the filtrate was collected in 500ml containers for analysis. This was carried out on only a single sample date, following *c*. 1 month of filter system maturation.

Fig. 2.4.1 – Splitter system and filter media set up



3.0 Analysis Results and Discussion

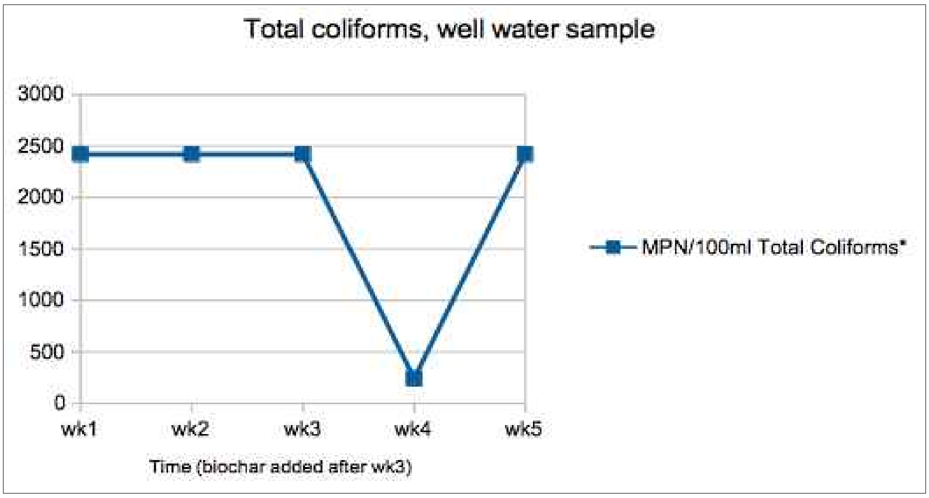
3.1 Well water analysis

These samples were taken from a shallow stone well. Rush biochar was added to the well in a jute sack after wk 3, and *c*. two weeks elapsed between addition of the char and taking the wk 4 sample. Drinking water limits are shown in red below.

Table 3.1.1 – Well water results before and after biochar addition

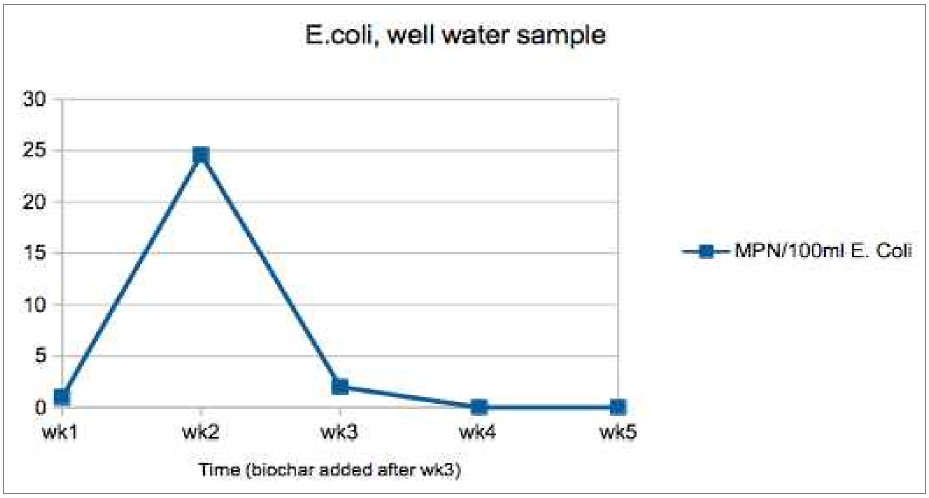
Unit	Parameter	05/05/22	12/05/22	19/05/22	02/06/22	09/06/22	Limits
		Well	Well	Well	Well	Well	
μg/l	Aluminium	31	105	16	35	13	200
mg/l NH_4	Ammonium	0.32	0.26	0.28	0.08	0.12	0.3
mg/l	Calcium	120.3	52.5	114.6	121	110.1	-
mg/l Pt-Co	Colour	9.8	130.3	17.1	9.3	17.1	-
μS/cm 20°C	Conductivity	673	377	740	694	650	2500
MPN/100ml	E. Coli	1	24.6	2	0	0	0
μg/l	Iron	245	226	99	123	120	200
mg/l	Magnesium	7.4	4.9	9.27	8	6.89	-
μg/l	Manganese	253	40	384	125	286	50
mg/l NO_3	Nitrate	2.2	2.2	2.2	2.2	2.2	50
mg/l NO_2	Nitrite	0.03	0.03	0.03	0.03	0.03	0.5
ph units	pH	6.9	6.7	7.1	7.1	7.1	6.5<pH<9.5
mg/l	Sulphate	18.02	44.04	25.43	16.2	20.74	250
MPN/100ml	otal Coliform	2420	2420	2420	240	2420	0
mg/l $CaCO_3$	otal Hardnes	330.6	151.3	324.3	335.1	303.3	-
mg/l N	Oxidised Nitr	0.5	0.5	0.5	0.5	0.5	-
NTU	Turbidity	1.27	1.74	0.78	0.02	0.79	-

Figure 3.1.1 – Total coliform concentrations in well water samples



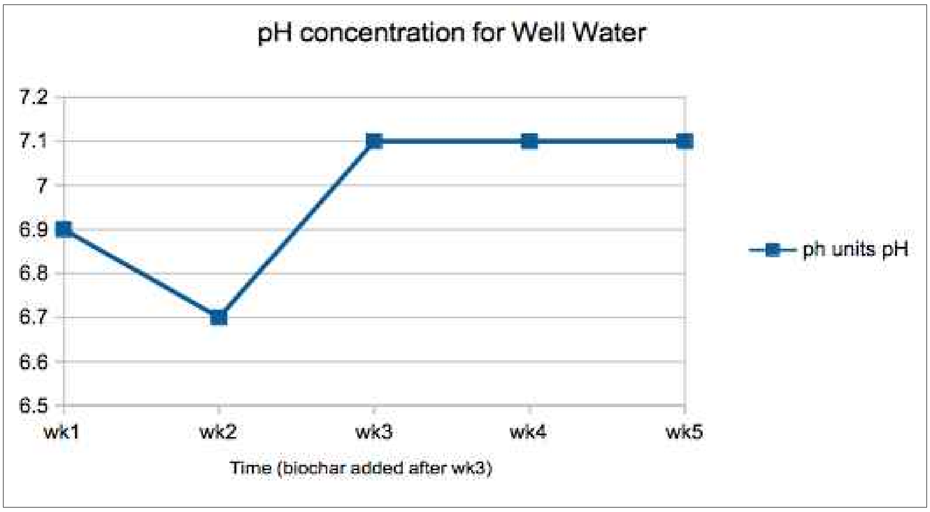
Coliforms were detected in abundance (up to the lab upper limit of 2500MPN/100ml) for all weeks except wk 4, which was the first week after addition of biochar, suggesting possible correlation between char and reduction in coliforms in the well. However for wk 5 the samples were back over the measurement threshold of 250MPN/100ml, indicating that the effectiveness of the biochar was short lived or else the biochar was not the determining factor in wk 4 coliform reductions.

Figure 3.1.2 – E.coli concentrations in well water samples



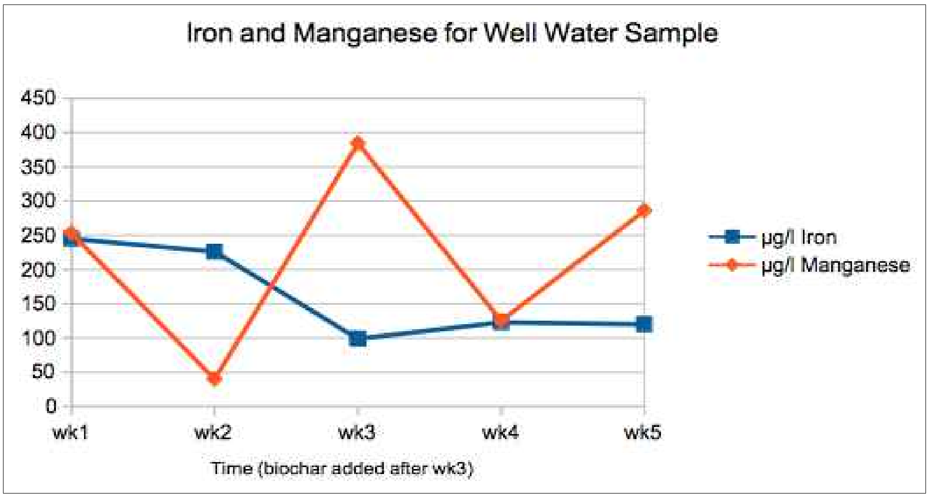
E.coli were detected in weeks 1, 2 and 3, and absent thereafter, following addition of biochar, suggesting possible correlation between char and reduction in coliforms in the well. Note that the levels were relatively variable in the first three samples; being as low as 1MPN/100ml in wk1.

Figure 3.1.3 – pH concentrations in well water samples



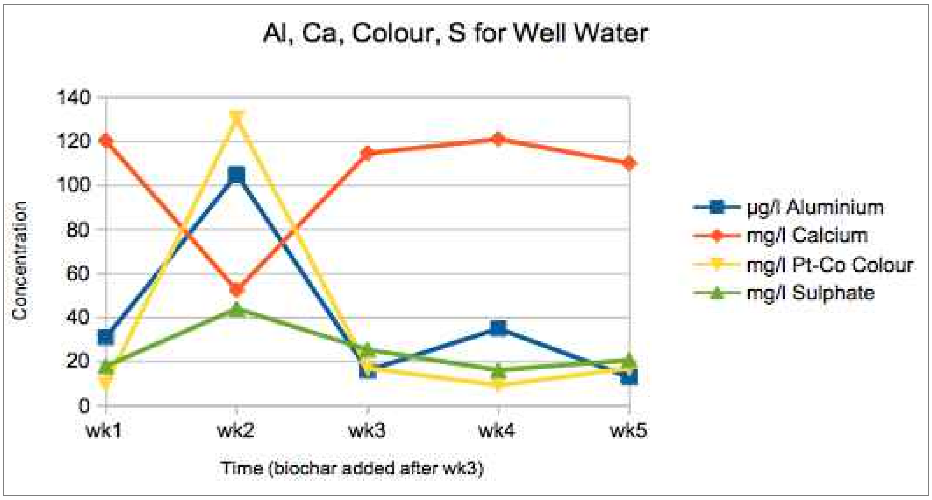
pH concentration showed a move towards more alkaline conditions, however the variability is slight and coincides with 7.1 during wk3 prior to biochar addition, so no correlation may exist.

Figure 3.1.4 – Iron and Manganese concentrations in well water samples



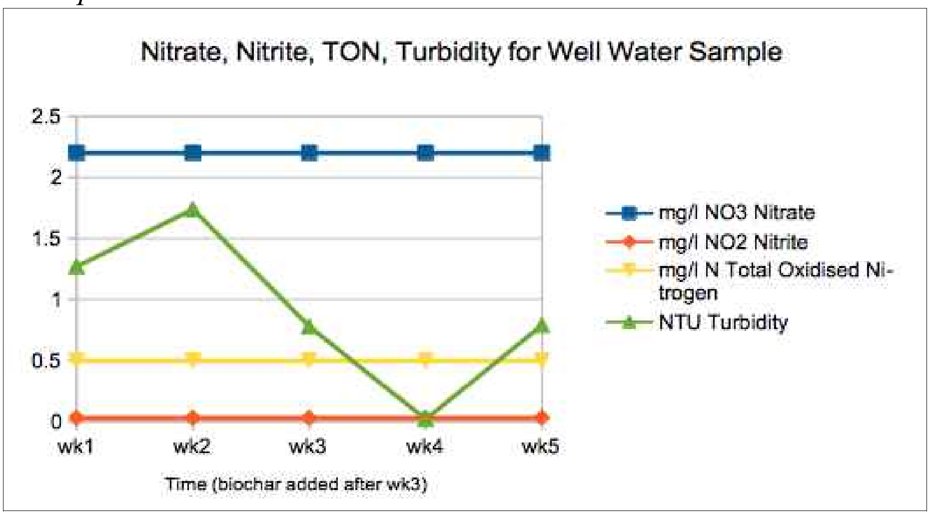
Iron levels dropped to 100ug/l in wk3 prior to addition of biochar, so the lower averages for wk4 and wk5 may not be attributed to the biochar. Similarly the manganese concentrations were quite variable in the samples leading up to the addition of biochar, so no correlation is clear.

Figure 3.1.5 – Aluminium, calcium and sulphur concentrations in well water samples



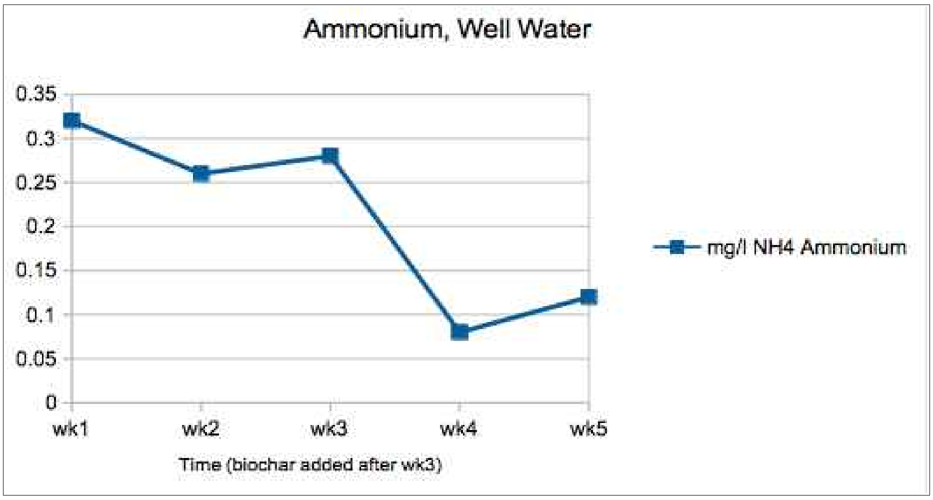
Aluminium, colour and sulphate all appear to show a downward trend across the sampling period. However this trend started prior to the addition of biochar after wk3, so although the average concentrations drop, it is difficult to conclude that they are due to the biochar.

Figure 3.1.1 – Nitrate, nitrite, total organic nitrogen and turbidity concentrations in well water samples



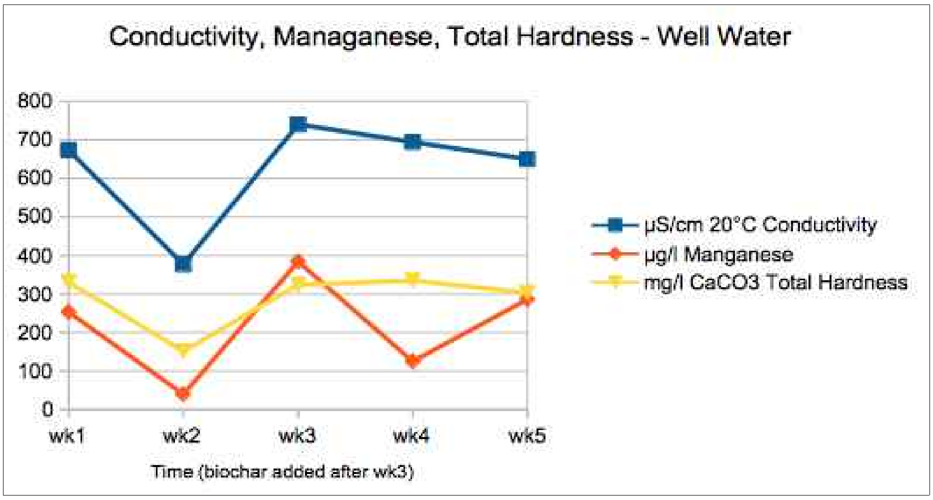
Results for Nitrate, Nitrite and Total Oxidised Nitrogen were all below the limit of detection both before and after addition of biochar, so no discernable difference is present. Turbidity appears to show a reduction after biochar, and yet this downward trend commenced in wk3, prior to addition of biochar, so remains inconclusive.

Figure 3.1.1 – Ammonium concentrations in well water samples



Ammonium figures show a clear drop in concentration after wk3, correlating directly with the addition of biochar.

Figure 3.1.1 – Conductivity, manganese and total hardness concentrations in well water samples



Conductivity, manganese and total hardness all show significant variation prior to addition of biochar. As such it is difficult to assess the impact of the biochar on the well water quality for these parameters.

Well water summary: For most parameters there is no dramatic correlation between biochar addition and water quality, however ammonia, turbidity, Total Coliforms and *E. coli* all show notable reductions in concentration after addition of biochar, which suggests that there may be direct improvement in well water quality as a result of the rush char additions.

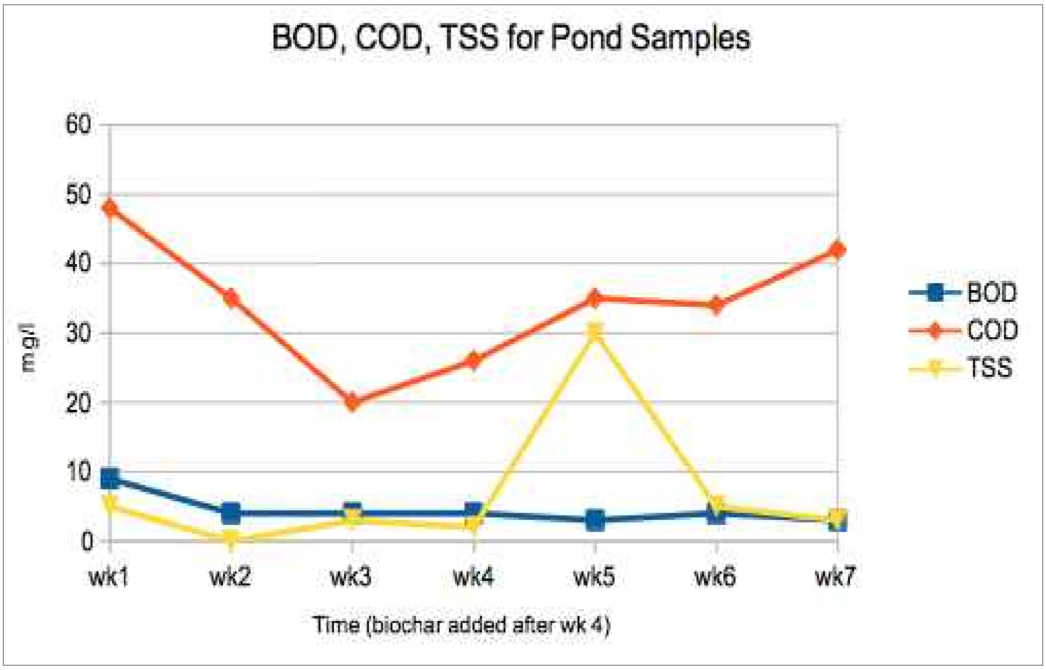
3.2 Pond water analysis

The pond is *c*. 20m x 40m in area and *c*. 600mm deep on average; totalling *c*. 500m^3 in overall volume. It is an in-channel pond as part of a farm drainage network, receiving inputs from neighbouring farms upstream, and so is influenced by both weather and local land management. Biochar was added in two jute sacks to the pond at the point where the drain enters, to maximise the mixing of water through the char.

Table 3.2.1 – Pond water samples before and after rush char addition

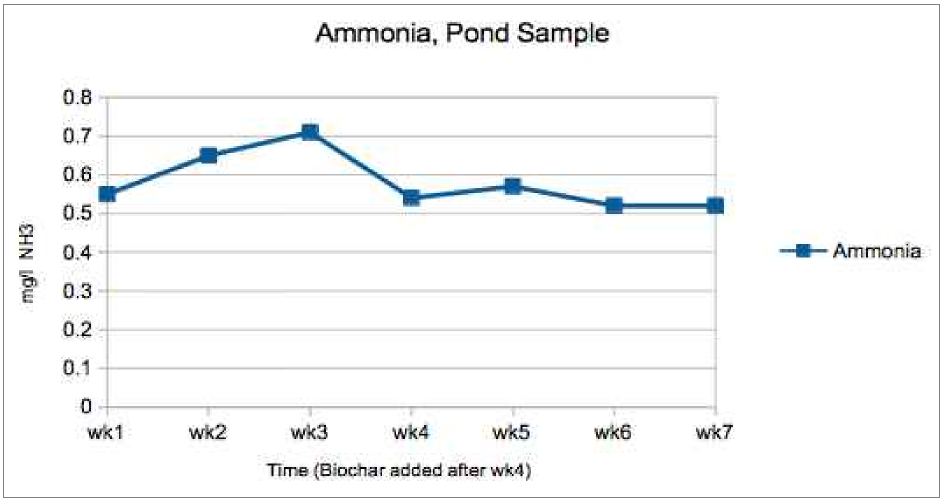
	BOD	COD	TSS	TP	Nitrate	Nitrite	Ammonia
wk1	9	48	5	0.07	2.2	0.03	0.55
wk2	4	35	0	0.05	2.2	0	0.65
wk3	4	20	3	0.17	-	0.03	0.71
wk4	4	26	2	0.13	2.2	0	0.54
wk5	3	35	30	2.05	2.2	0.03	0.57
wk6	4	34	5	0.13	2.2	0.03	0.52
wk7	3	42	3	0.15	2.2	0.03	0.52

Figure 3.2.1 – BOD, COD and suspended solids concentrations in pond samples



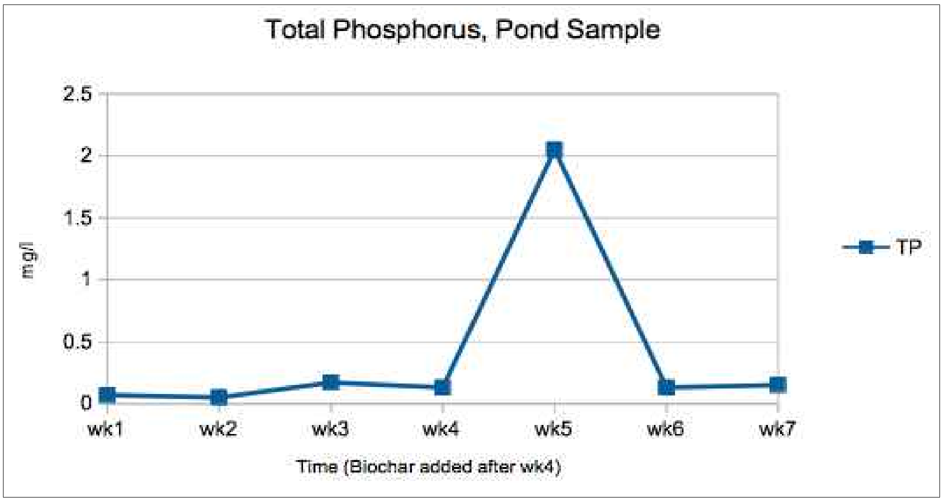
Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) were assessed over a seven week period, with 4no. samples prior to biochar input and 3no. samples afterwards. Results for BOD shows a slight decline in concentration across the study period, from 9mg/l at the beginning of the study to 3mg/l at the end. However this cannot necessarily be attributed to the biochar since after wk1 results oscillate between 3 and 4mg/l, both before and after addition of char. COD similarly shows an initial decline after wk1, extending to wk3, and then rises slowly thereafter, even after char inputs. TSS shows the same trend in dropping from wk1 to wk2, but then remains relatively low with the exception of a spike to >30mg/l in wk5 which may correlate with wet weather in the preceding week.

Figure 3.2.2 – Ammonia concentrations in pond samples



Ammonia concentrations vary little throughout the study period, from 0.52 to 0.71; and show a slight tendency towards lower concentrations after addition of biochar, although not exclusively so, making conclusions about the biochar effectiveness difficult to draw with confidence.

Figure 3.2.3 – Phosphorus concentrations in pond samples



Phosphorus concentrations remain low for most of the study, with the exception of wk5 where a spike of >2mg/l can be seen. This correlates with the spike in TSS, so this phosphorus may be sediment related, from upstream activity. Overall the char does not appear to positively influence water quality where phosphorus is concerned.

Pond water summary: No notable shift in concentrations can be concluded for the pond samples for the pre- and post-sampling times. The habitat is likely to be influenced more by weather and landuse than by the presence or absence of the relatively small quantity of biochar added. It would be interesting to assess this water quality again with a through-put filter rather than the jute sacking. Note that for wider application, through-put filtration is generally not feasible for such situations due to the risk of clogging and inundation by storm events. Thus this study assessed the most probable scenario rather than an ideal situation from a filtration perspective.

3.3 Septic tank woodchip/biochar filter analysis

Woodchip/Biochar Filter: Samples were taken from a woodchip filter following a domestic septic tank. Rush biochar was added as a 75mm deep layer over the woodchip surface after the wk4 sampling to assess the relative difference between woodchips and biochar – or more specifically the difference between woodchips alone and woodchips with a biochar layer overlaying them. Inlet sampling commenced on wk3 to provide inlet/outlet comparisons as well as before/after timeline comparisons.

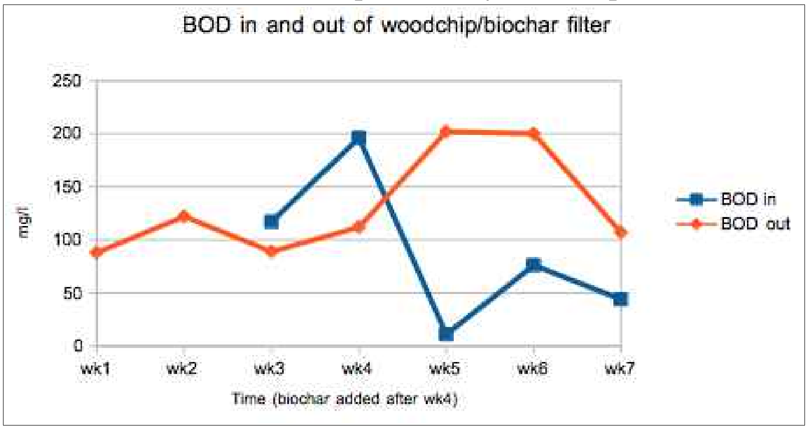
Table 3.3.1 – Inlet to woodchip filter

	BOD in	COD in	TSS in	TP In	Nitrate in	Nitrite in	Ammonia in
wk1	-	-	-	-	-	-	-
wk2	-	-	-	-	-	-	-
wk3	117	355	58	21.2	1.2	-	152.32
wk4	196	429	118	26.8	2.2	-	152.46
wk5	11	46	4	0.13	14.34	0.4	10.32
wk6	76	252	57	30.1	62.7	14.49	135.94
wk7	44	206	37	23.1	177.72	14.95	85.45

Table 3.3.2 – Outlet from woodchip filter

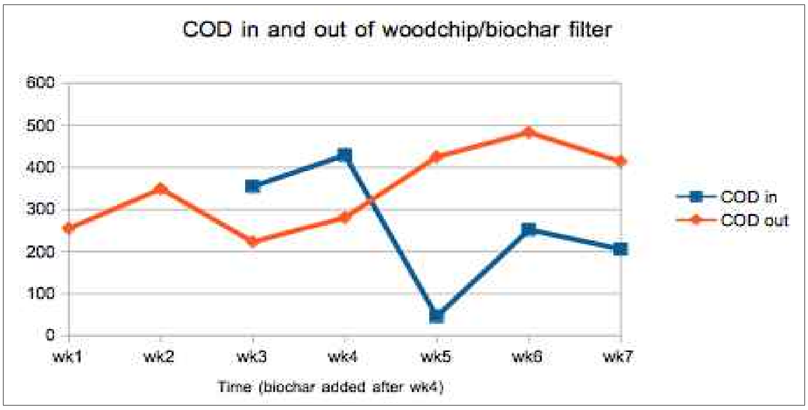
	BOD out	COD out	TSS out	TP out	Nitrate out	Nitrite out	Ammonia out
wk1	88	255	43	20.9	8.76	0.2	110.34
wk2	122	349	85	0.06	5.81	-	138.27
wk3	89	223	44	20.2	92.18	-	115.25
wk4	112	281	28	25.6	101.11	-	132.14
wk5	202	425	110	27.3	2.2	0.03	158.75
wk6	200	483	80	32.9	2.2	0.03	174.89
wk7	107	414	73	29.6	2.2	0.03	200.3

Figure 3.3.2 – BOD concentrations in woodchip/biochar filter samples



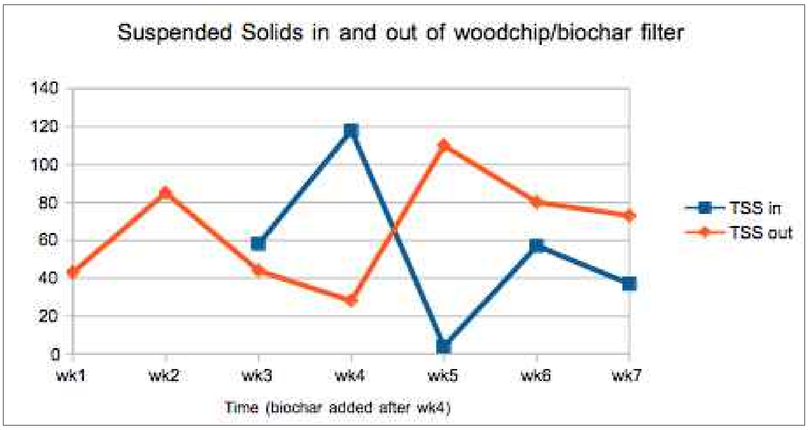
Biochemical Oxygen Demand (BOD) shows somewhat anomalous results insofar as the concentrations rise after addition of biochar and are also higher than the input values exiting the septic tank. There was elevated usage in the house that correlates to the elevated input figures for week 4, which may have then translated as a delayed elevation in output concentrations in subsequent weeks.

Figure 3.3.3 – COD concentrations in woodchip/biochar filter samples



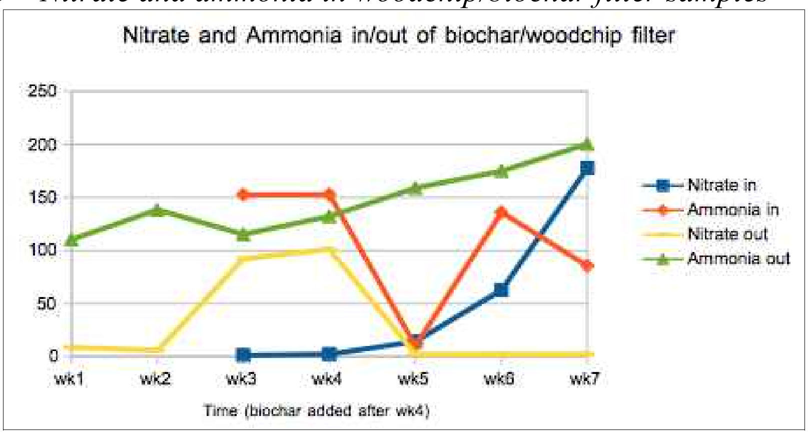
Chemical Oxygen Demand (COD) shows the same trend, directly mirroring the BOD figures with higher figures after addition of char and higher figures exiting the filter than entering from the septic tank. As with BOD, elevated usage in the lead-up to wk 4 may have influenced output concentrations for subsequent weeks.

Figure 3.3.4 – Suspended solids concentrations in woodchip/biochar filter samples



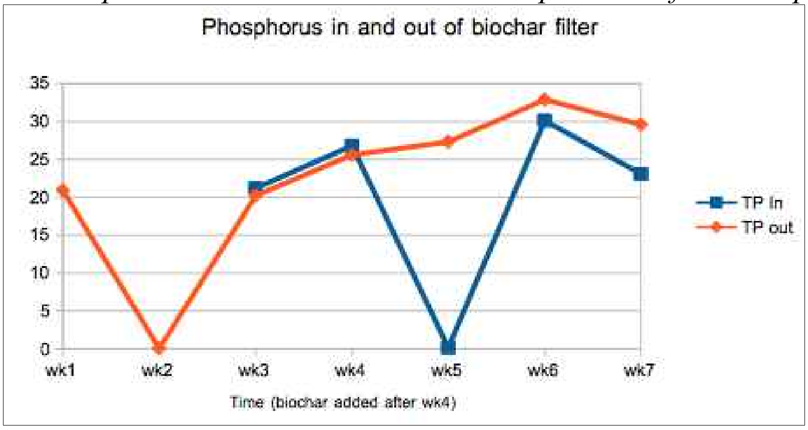
TSS shows the same trend as do both of the oxygen demand results. Again the high input results for wk4 may follow busy usage for the septic tank at that time.

Figure 3.3.5 – Nitrate and ammonia in woodchip/biochar filter samples



Ammonia concentrations show a common trend with the previous results. The aeration that would be expected from the filtration process (with or without the biochar added to the woodchip media) would be expected to reduce the ammonia concentrations, while in fact the opposite is the case. Nitrate also shows a similarly anomalous result insofar as the expected trajectory would lead to an elevation in concentrations following the aeration phase of a filter system (increasing the NO_3 as a result of oxygen input, as the nitrogen changes in form from ammonia (NH_3) to nitrate (NO_3) as part of the treatment process). Here instead there is a lower nitrate output exiting the woodchip filter than the concentrations in the input from the septic tank.

Figure 3.3.6 – Phosphorus concentrations in woodchip/biochar filter samples



Phosphorus similarly shows that as time progresses the exit concentrations appear to rise, despite addition of rush biochar.

Woodchip/Biochar Summary: There are two elements to the above results that appear anomalous. Firstly the output concentrations are generally higher than the input concentrations. Secondly the output concentrations appear to rise after addition of the biochar following wk3.

One explantation for the rise in concentrations after addition of biochar is that the char itself may be a source of oxygen demand, suspended solids and nutrients. The elevation in concentrations from inlet to outlet may be explained by the woodchip media also contributing contaminants to the effluent en route through the filter. These are unlikely however since the biochar is freshly made and relatively uncontaminated biochar that should be essentially devoid of contamination and also woodchip filter tanks have been shown in other trials[2] to reduce contaminants.

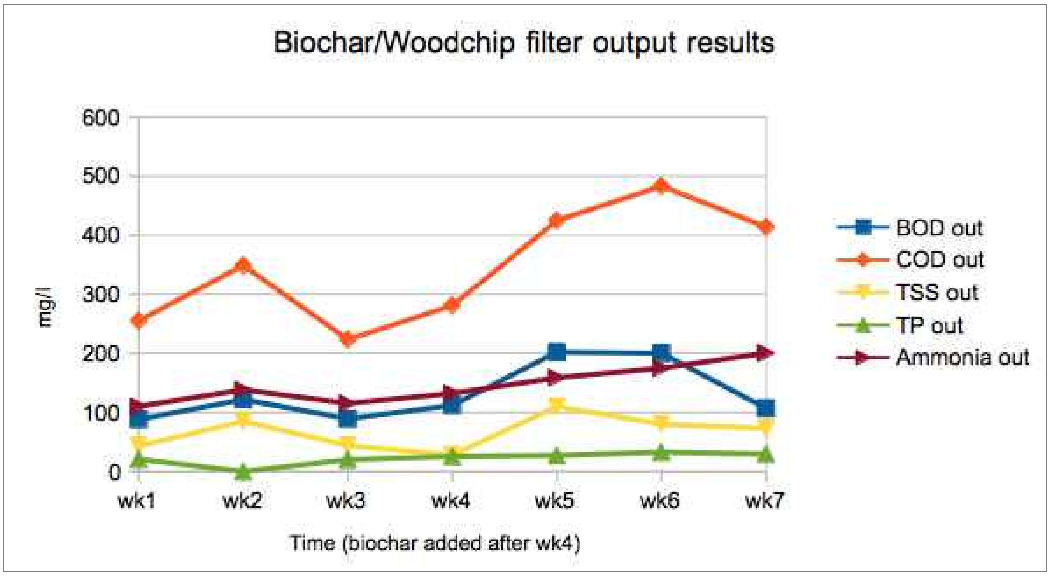
Another possible cause for the anomalous results is lab error or mixed samples, but this is also unlikely due to the fact that the results are so consistent in their anomaly. They are exactly the opposite of what may reasonably be expected, for all of wk4, 5 and 6 rather than swinging widely within that time, which would be expected from a lab or sampling error.

The final and arguably most likely cause is a shift in the population size contributing to the septic tank. The source of the effluent is a cabin with typically a single occupant, however early in the sampling process a weekend course used the cabin for toilet facilities for the event for *c*. 25 people. This may have led to a significant rise in septic tank contaminants during that event which then contributed to a stored load of oxygen demand, solids and nutrients in the biochar filter. This final explanation does not account for the absence of a rise in nitrate concentrations that would be expected from an aeration phase within the system, so is not an entirely satisfactory explanation.

[2] Eday A (2014) *Green Light at the End of the Tunnel - Learning the art of living well without causing harm to our planet and ourselves.* Trailblazers Press, MA, USA.

Overall the results from this phase of the study are unsatisfactory and do not have a suitable explanation for the fact that results that are so completely the opposite of the expected outcome. Further assessment is recommended in a follow-up trial to assess whether the results obtained are accurate and what the cause may be.

Figure 3.3.7 – Outlet results for the woodchip/biochar filter for multiple parameters



Summary figures above show a generally consistent trend over time, showing that most parameters show a slight rise in concentrations for wk 5 and 6 with a drop in wk7. It would be interesting to have extended the study to assess whether the rise was attributable to elevated user numbers in earlier weeks.

3.4 Filter media comparison analysis

Different media types were compared for filter effectiveness using domestic grey water as the effluent type. Four filter media types were selected for analysis as follows:

1. Rush char
2. Woodchip char
3. Quarry grit
4. Soil
5. A control was also used, where grey water was collected but not filtered

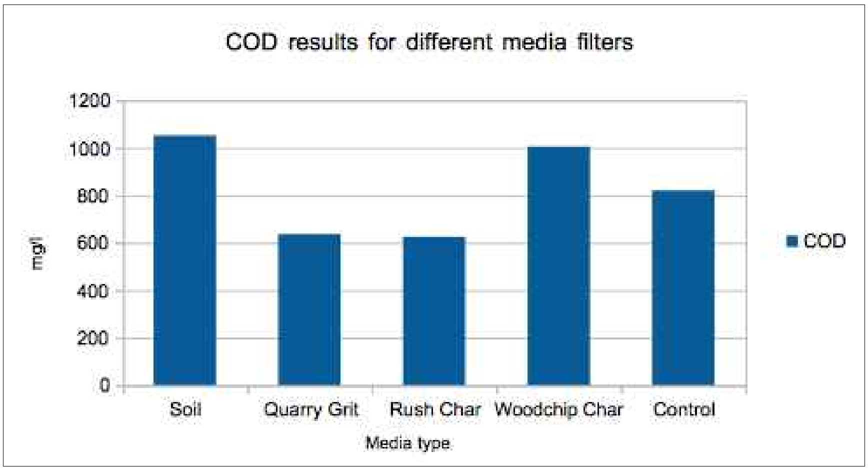
Analysis was carried out for COD, Ammonia and Total Phosphorus. Other parameters were omitted since it was found that during the previous sampling events, BOD and COD followed a similar trend and so could be used interchangeably to determine relative oxygen demand levels. Similarly TSS followed a similar trend to oxygen demand figures and as such was also not deemed to be necessary for relative comparisons between media types. Of the nitrogenous compounds ammonia was retained as this was deemed to be the most suitable indicator of water quality.

The different media types were added to 5 litre plant pots, and the effluent was drained from the base over a light sheet of plastic; routed into 500 ml containers for collection for analysis. A single sample was taken from each to compare results, as set out below.

Table 3.4.1 - Results of analysis for different media filter types

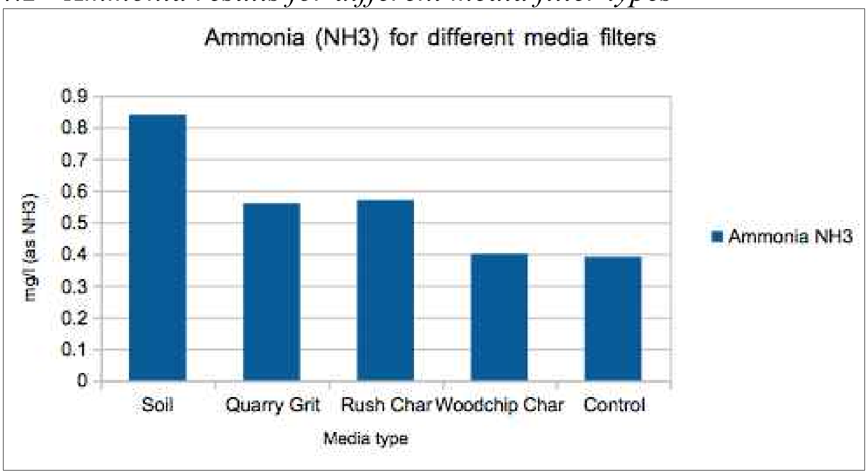
	Soil	Quarry Grit	Rush Char	Woodchip Char	Control
COD (mg/l)	1052	636	625	1006	820
Ammonia (mg/l NH3)	0.84	0.56	0.57	0.4	0.39
TP (mg/l P)	0.7	0.44	0.63	0.59	0.51

Figure 3.4.1. COD results for different media filter types



Overall COD figures varied from 625 to 1052mg/l, with the control roughly midway between these figures. These results were significantly higher than the sewage effluent and pond samples. Note that the rush char and woodchip char, which are both carbonaceous biochar products, produced almost the lowest and highest COD outputs respectively. The soil filter and woodchip char filters both produced a higher COD than the control, so it is difficult to extrapolate a clear pattern of the filter system effectiveness based on COD.

Figure 3.4.2 - Ammonia results for different media filter types

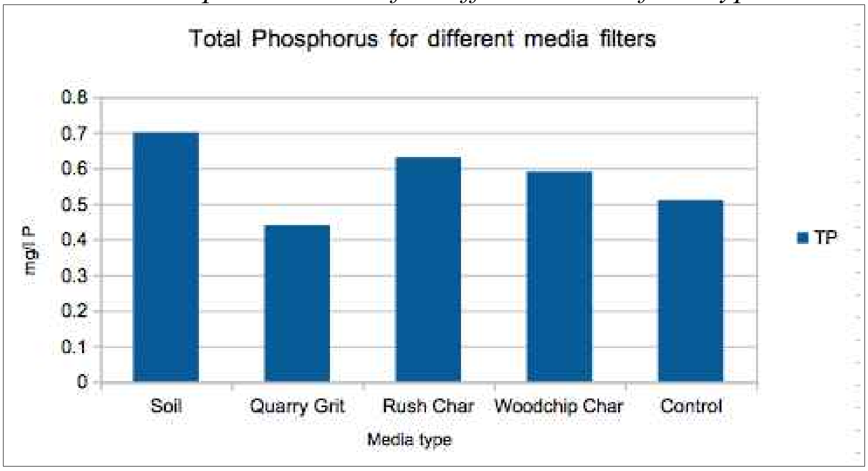


Ammonia results are lowest for the control but all figures are within such a narrow range that differentiation between results is difficult to assess with any certainty. The aeration typically associated with vertical flow reed beds is generally shown to be an effective way to reduce ammonia concentrations in effluent[3] and yet here the opposite appears to be the case, with the aeration through the filters leading to elevated levels. The control sample was taken from the same effluent timeline as the other samples –

[3] Kayser, K and S Kunst, S. (2005). *Processes in vertical-flow reed beds: Nitrification, oxygen transfer and soil clogging.* Water Science and Technology, 51(9): 177-184.

split evenly between the filters and control, so it is unlikely that different inputs account for the low control concentration shown here. Note that typical sewage effluent will have a much higher ammonia concentration than grey water, so it is possible that the difference (from <0.4 mg/l to <0.85 mg/l) is a negligible difference and the results this low cannot be accurately compared.

Figure 3.4.3 - Total Phosphorus results for different media filter types



Phosphorus concentrations are also a lot lower than for standard sewage effluent and may thus be similarly difficult to compare with any degree of certainty.

Media Filter Comparison Summary: While it is difficult to see whether the results provide any improvement compared with the control in this instance, it is interesting to look at the results in overview. The soil filter consistently produced the highest concentration of each parameter, indicating that residual oxygen demand, ammonia and phosphorus in the soil may have had a bearing on the final results. Other than for soil however the results become difficult to decipher for consistent patterns. This may be due to the low input values for ammonia and phosphorus in the grey water inputs from the dwelling, or may be due to a lack of maturity in the filter media substrates, leading in turn to leaching from the filters into the sample. Indeed, ammonia concentration is lowest for the control, indicating that residual nitrogen compounds, and ammonia in particular, may be present in the different media used, and contaminating the samples. Similarly for the phosphorus samples, the only media type with a lower phosphorus concentration than the control was for quarry grit. This is a limestone grit, which is likely to have provided adsorptive binding of phosphorus and thus reduced the outlet concentrations, whereas the other media appear to have contributed phosphorus to the liquid en route through the filter.

All in all it is recommended that further research be carried out with the following changes:

1. Is proposed that a more mature filter be used, such that contamination from media washing is ruled out as a possible source of contamination. This may be carried out by allowing a longer lead-in time between first adding the filter media and starting into the water sampling. In this instance the filters were set up in early July and the samples taken in late July, allowing *c*.4 weeks lead-in time.

2. Secondly it is proposed that septic tank effluent be used as the inlet feed rather than grey water. For this set of analysis the infrastructure at the site facilitated easy monitoring of grey water, whereas black water analysis would have required excavation and new tanks being built which was outside the scope and budget of the trail. Sewage effluent would provide higher input concentrations for all ammonia and phosphorus and thus potentially have shown greater reductions through each media filter type.

4.0 Summary of Findings

For the well water ammonia, turbidity, Total Coliforms and *E. coli* all showed reductions in concentration after addition of biochar, suggesting that there may be direct improvement in well water quality as a result of the rush char additions. Other parameters did not show a discernable change.

In the farm pond, no notable shift in concentrations can be concluded for pre- and post-sampling times. Weather and landuse are likely to be larger factors in determining water quality than the presence of a relatively small volume of rush char for such a situation.

The woodchip/biochar filter after the septic tank showed results that appear anomalous, with higher output concentrations compared with input concentrations; and higher output concentrations following addition of rush char. The most likely reason for this may be elevated population usage early in the study followed by reduced numbers thereafter, which may have skewed the results in the direction shown.

For the media filter comparison study the results were also anomalous, with higher input concentrations for some media types than the control, which was unexpected. This may have been due to contamination from the filter media itself or to the low input concentrations leading to results that lacked sufficient difference to be meaningful or clear.

5.0 Conclusion

This study set out to assess the difference in water filtration effectiveness between rush biochar and woodchip biochar; and between biochar and a control. In general terms the results from the different analyses yielded relatively inconclusive results in terms of comparing rush char with woodchip char, or either with a control. There were improvements for some of the test scenarios and the opposite for others. This makes it difficult to draw satisfactory conclusions but it does not necessarily mean that the char was ineffective. Rather further research is recommended over a longer time period to adequately assess the different factors that influence water quality for each scenario.

That said, the improvement in ammonia, turbidity, total coliforms and E. coli in the well water after addition of rush char is well worth following up on with additional study. Microbial reductions in particular were not assessed for the other test scenarios and may well yield positive results if assessed in more detail.