A review of nature-based systems available to treat blueberry irrigation run-off

Mark Bayley, Mark Bayley Consulting & Diana Unsworth, David Cordina, David Mitchell & Melinda Simpson, NSW DPI

- The Clean Coastal Catchments (CCC) Research project is assessing the effectiveness of nature-based systems for the removal of nitrogen from crop irrigation runoff at the Wollongbar Primary Industries Institute
- The bioreactors are showing excellent nitrate reduction, based on the water quality data observed during the sampling (spring 2023) season
- The reed bed also demonstrated effective nitrogen reduction where the hydraulic retention time was at least 4-5 days

The two most adopted nature-based technologies for reducing nitrogen levels from wastewater are constructed wetlands (reed beds) and denitrification bioreactors (wood chip bioreactors). In this trial, three bioreactors and one reed bed were installed at the Wollongbar Blueberry Nutrition Research Facility to treat nutrient rich runoff from 300 potted blueberry plants.

The project adopted common design and operational elements from existing denitrifying bioreactors and reed beds within Australia and across the world. Once installed the efficacy of the bioreactors and the reed bed to reduce the nitrogen (volume and quality) of the irrigation runoff water was measured.

This activity will provide basic design and construction schematics of the bioreactors and reed bed to assist growers from across the intensive horticulture industry to incorporate the technology, appropriately scaled, into their farming systems.

Background

Nitrate applied as fertiliser, either prior to crop planting or during crop production is highly mobile and leaches easily from shallow soil layers to lower soil layers. In areas of shallow groundwater this can result in the nitrate entering the local groundwater. Additionally, the mobility of nitrate means that in some cases surface runoff water can contain a significant amount of nitrate and this runoff water can cause negative off farm impacts.

Bioreactors and wetlands create the required conditions for the rapid conversion of water-soluble nitrates into dinitrogen (N_2, a gas), providing a viable method for reducing excess nitrogen in water flowing from intensive horticultural operations, including hydroponic fertigation systems. This occurs via the relatively simple heterotrophic microbial mediated 'denitrification' reaction (Kadlec, 2009), which converts water soluble nitrate to dinitrogen gas (N_2). However, it is important to get the conditions right, such as sufficient capacity to meet minimum retention times based on the flow rate and nitrogen concentration of the irrigation runoff, for this technology to be effective and efficient.

Experimental Design

Irrigation runoff water is collected from the substrate blueberry drain system into a common collection sump (~200L), prior to being dosed to either the bioreactor trial or the reed bed trial; Sampling schematic (Figure 1) actual setup (Figure 2).

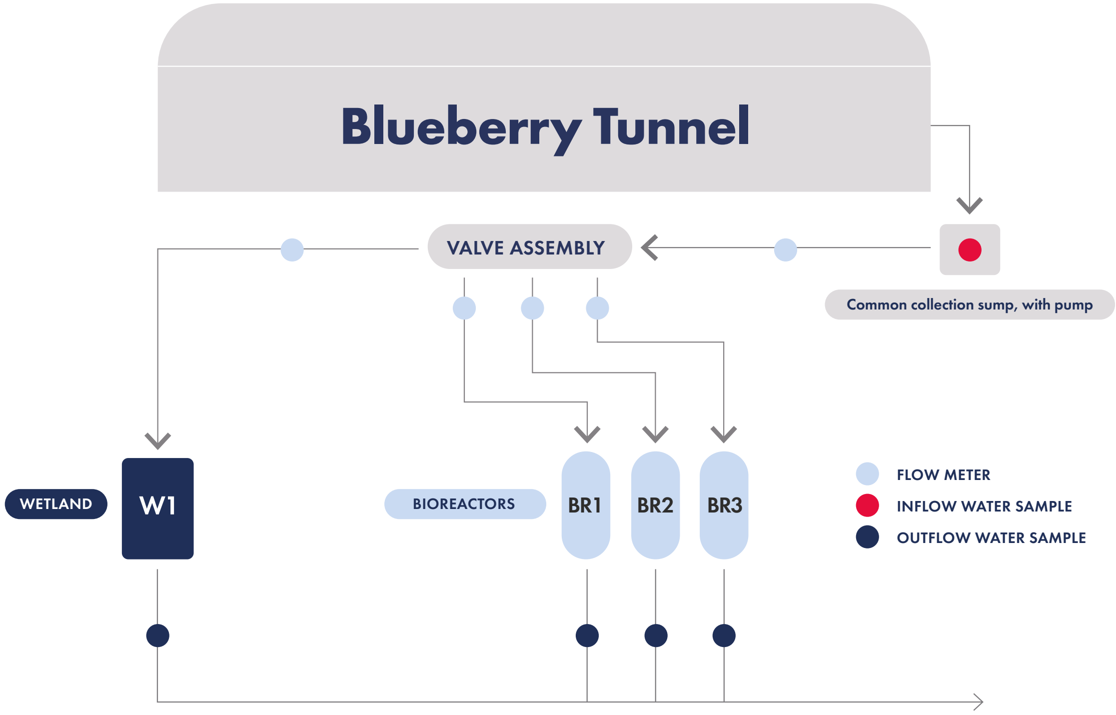

Figure 1. Bioreactor and wetland schematic design Source: Mark Bayley Consulting

Figure 1 shows a schematic design of the three bioreactors and one wetland, location of the common collection sump, valve assembly, flow meters and sampling points in relation to the blueberry tunnel and the trial bioreactors and wetland. It also lists the analytes to be monitored which are also shown in Table 1.

Figure 2. Reed bed in foreground and bioreactors in background

Source: Mark Bayley Consulting, November 2023

The photo in Figure 2 shows the bioreactors and wetland in situ. The wetland is a rectangular reed bed (sub-surface flow) in the foreground, lined with impermeable membrane. The bioreactors are seen by the three green square 750 litre containers behind the reed bed and in front of the valve assembly. The bottom corner of the blueberry tunnels is seen in the background immediately behind valve assembly.

One of the benefits of bioreactors is that the reduction of nitrate from agricultural runoff water occurs in a relatively short time frame following their construction.

Reed beds, on the other hand, require more time (12-18 months) before their optimum denitrification potential is achieved. As such, the trial commenced with the bioreactors while the reed bed undergoes its 'maturation phase'.

Trial methods and interim results

Flow Monitoring

The flow of irrigation runoff water into each of the bioreactors and reedbed is measured using a 25 mm inline flow meter. Manual readings are taken on the day of water sample collection.

A water-level sensor is located within the irrigation collection sump, with the water level being logged every 2.5 minutes. This logger counts the number of pump cycles delivered to the treatment systems and therefore an overall daily flow rate can be calculated.

Water quality monitoring

Water samples were collected from the common inlet and each outlet of the three bioreactors / reed bed three days a week of the respective sampling periods and analysed for the analytes (Table 1).

Table 1. Water sampling analytes

Water sampling analytes
Total Nitrogen (TN)
Ammonium
Nitrate + Nitrite
Total Phosphorus
Free reactive phosphorus
Dissolved Organic Carbon
Total organic carbon
pH
Temperature
Conductivity
Dissolved oxygen
Redox potential

Interim results

Bioreactors

Initially, irrigation runoff to the bioreactors was variable, resulting in irregular flows for the first 3 sampling dates, ranging from ~250 L/day to 15 L/day and a mixture of hydraulic retention times for the irrigation water within the bioreactors. This stabilised by mid-August 2023 where the average flow to the bioreactors was 42.35 L/day with standard deviation of 6.39.

Figure 3 and Figure 4 show that once the flow rates stabilised, nitrate removal across all three bioreactors was extremely high, with removal efficiencies exceeding 95% across this time series.

While there was an overall Total Nitrogen (TN) reduction within the bioreactors, ammonium (NH_4-N) increased in all reactors in comparison to the sump in the last six sampling events.

This is most likely the result of Dissimilatory Nitrate Reduction (DNRA) – where nitrate is reduced to ammonium by obligate anaerobes in low oxygen conditions (Redox Potentials below 0 mV) (Reddy and DeLaune, 2008).

Redox Potential reduced to less than 0mV by 18 August, which corresponds to the increase in ammonium in that and all subsequent sampling events (Figure 4).

Denitrification is a more conservative, energy efficient molecular pathway for nitrate loss (Reddy and DeLaune, 2008), therefore while some DNRA may be observed, denitrification is expected to remain the dominant pathway for nitrate loss within the bioreactors.

Reed bed

Reed bed monitoring data was collected for the period 20 September 2023 to 16 October 2023 and water quality results of the reed bed trial for both nitrogen and phosphorus species were measured (Figure 5, Figure 6).

During the sampling period, the irrigation runoff delivered to the reed bed was around 200 litres per day at the beginning of the sampling period, and then after dropping to around 50 litres per day, was increased to around 400 litres per day for the final two sampling events (**red** line Figure 5, Figure 6). Increased flow results in a reduced amount of time water are held within the reed bed (HRT) and hence a reduced treatment time, shown as the **green** line (Figure 5 and Figure 6).

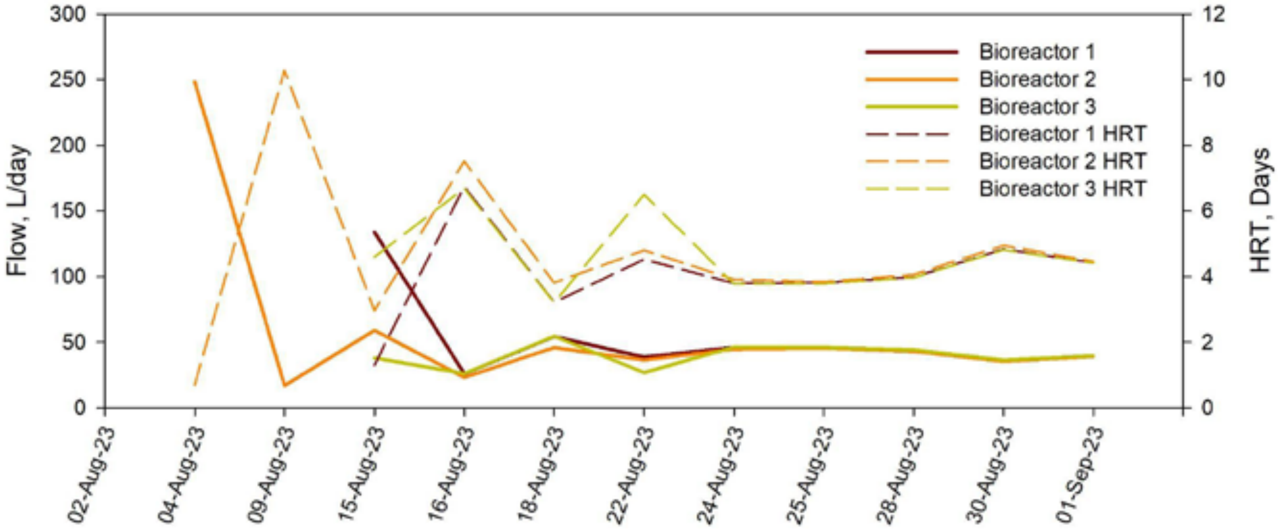

Figure 3. Bioreactor flow and Hydraulic Retention Time (HRT), August 2023

Source: Mark Bayley Consulting

Figure 3 shows a plot of daily flow rates, and daily hydraulic retention times (HRT) for the three bioreactors for 11 sample dates between 2 August 2023 and 30 August 2023. The plots show considerable variability in both flow and HRT between 2 August and 22 August (typically, when flow is high, HRT is low and vice versa). From 22 August, the plots stabilise to around just under 42 litres per day flow and 4 days HRT.

Total nitrogen loss across the sampling period averaged ~40% removal under a Hydraulic Retention Time (HRT) of approximately 4 days, with the exception of the last two monitoring rounds where flow to the reed bed significantly increased and the HRT of the reed bed reduced to around 2 days (Figure 5, Figure 6). Removal of NO_3-N averaged around ~25%, with NH_4-N reduction approximately ~66% across the sampling period (ignoring the last two sampling regimes where there was excessive flow through the reed bed).

Phosphorus removal within the reed bed was high, at ~41%, however this is not expected to persist as one of the main mechanisms for phosphorus removal within reed beds is the adsorption of PO_4-P onto the surface of the substrate. It is expected that over time phosphorus reduction will decrease and be limited to that which is taken up by the plant and microbial community.

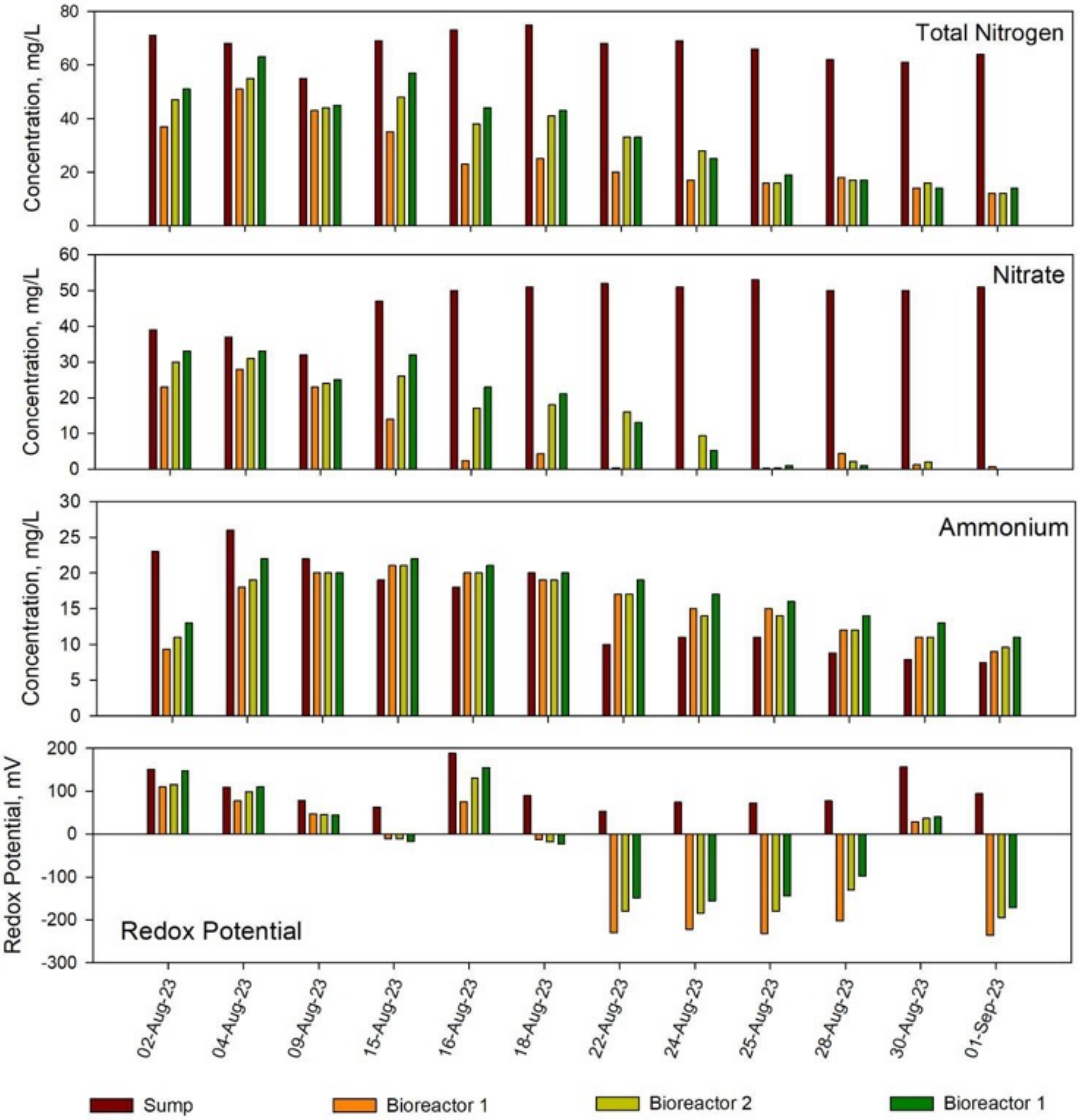

Figure 4. Bioreactor water quality results, August 2023

Source: Mark Bayley Consulting

Figure 4 shows a series of plots of daily concentrations for (1) Total Nitrogen, (2) Nitrate, (3) Ammonium and (4) Redox Potential. Corresponding with the date (22 August) in Figure 2 when flow rates into the bioreactors stabilises, the data show that total nitrogen and nitrate is significantly reduced by all three bioreactors compared to the concentrations in the sump (pre-bioreactor). During the same period, ammonium concentration increases compared to the concentrations in the sump (by up to 8 mg/L) and the redox potential moves to below 0mV.

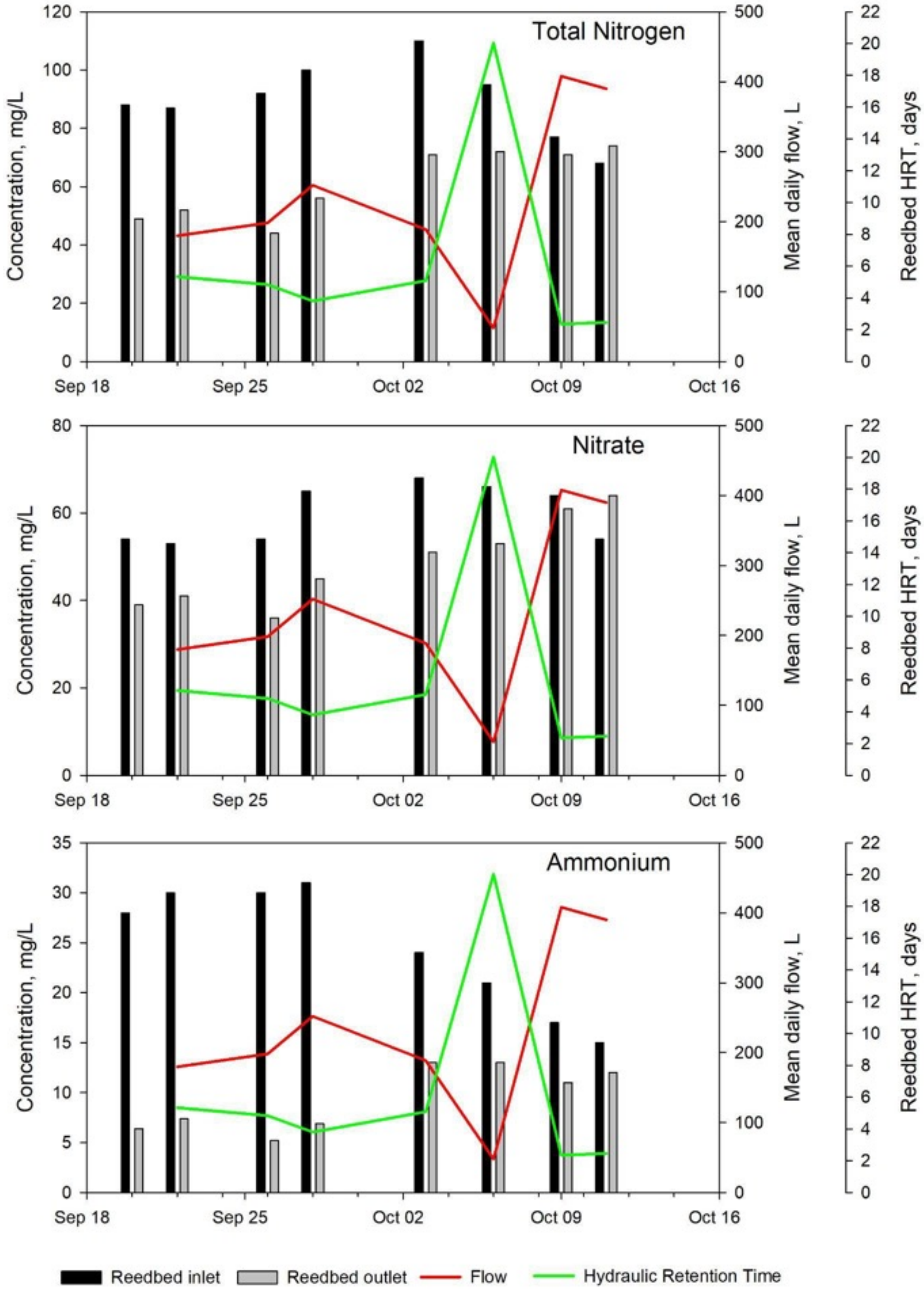

Figure 5. Reed bed water quality results for Nitrogen, including flow and HRT data
Source: Mark Bayley Consulting

Figure 5 contains three graphs showing daily concentrations of (1) Total Nitrogen, (2) Nitrate and (3) Ammonium in both the sump (pre-reed bed) and the reed bed, as well as daily flow (litres per day) and HRT (days) for 8 sampling days between 20 September 2023 and 11 October 2023. The graphs show that the reduction in total nitrogen, nitrate and ammonia was effective while the daily flow and HRT was around 100 L/day and 4 days HRT, respectively. It also shows the reed bed was less effective in reducing these when the flow rate was around 400 litres per day and the HRT only 2 days.

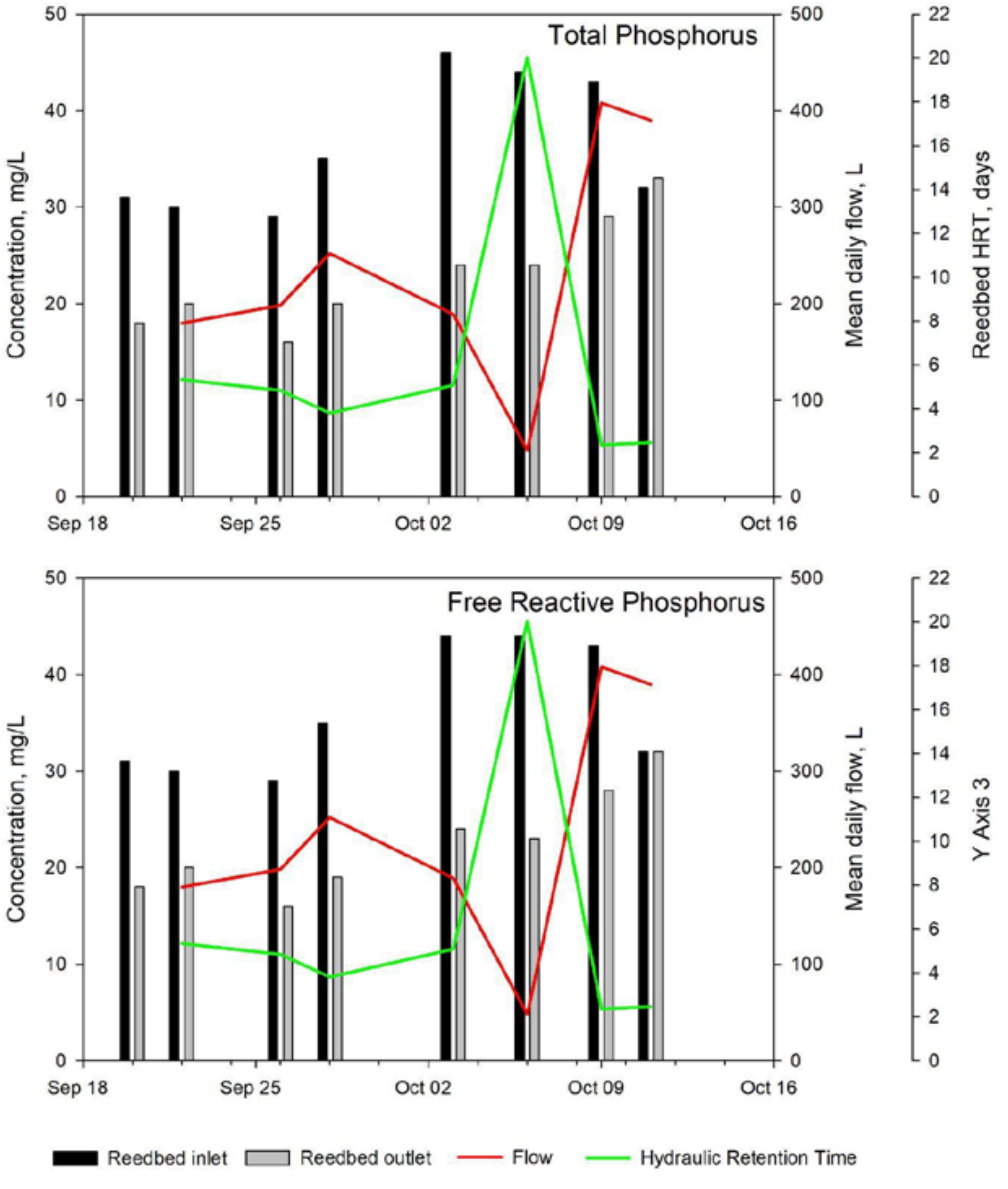

Figure 6. Reed bed water quality results for Phosphorus, including flow and HRT data

Source: Mark Bayley Consulting

Figure 6 contains two graphs showing daily concentrations of (1) Total Phosphorus and (2) Free Reactive Phosphorus (FRP) in both the sump (pre-reed bed) and the reed bed, as well as daily flow (litres per day) and HRT (days) for 8 sampling days between 20 September 2023 and 11 October 2023. The graphs show that the reduction in total phosphorus and FRP was effective while the daily flow and HRT was around 100 L/day and 4 days HRT, respectively. It also shows the reed bed was less effective in reducing these when the flow rate was around 400 litres per day and the HRT only 2 days.

Conclusions and recommendations

The bioreactors are showing excellent nitrate reduction, based on the water quality data observed during the sampling (spring 2023) season. Continued monitoring may show that increased irrigation rates through the warmer months results in higher hydraulic loading and potentially lower nitrate removal rates. However, at this stage, there appears to be sufficient capacity within the bioreactors suggesting that no major changes to the experimental design will be required. Once this is established, design parameters can be confirmed and scalable solutions for intensive horticulture can be specified.

The reed bed also demonstrated effective nitrogen reduction where the hydraulic retention time was at least 4-5 days. When Nitrogen is in high concentrations (>80 mg/L), the data suggests that there is a rapid reduction in nitrogen with-in the first 4-5 days, however this rate of loss appears to slow significantly as the HRT increases. As inflow increased and HRT dropped below 2.5 days, significantly less nitrogen reduction occurred.

This suggests that the reed bed is best designed to cater for the largest anticipated inflows targeting an HRT of at least 4-5 days. Further monitoring of the reed bed will help quantify and explain these observations.

While significant reduction in phosphorus levels were observed, this was attributed to absorption onto the surface of the new substrate. As the reed bed matures, absorption by the substrate is expected to decrease and phosphorus loss will be limited to that which is taken up by the plant and microbial community.

Acknowledgements

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