REDUCING NITROGEN IN WATERWAYS

Constructing a bioreactor on a farm

Thinking about installing a bioreactor on your property? This guide covers key aspects and some tips from on-farm experience over the last two years.

Pipe drainage is common on farms in low land areas like the Ruamahanga river basin. Known as “tile drains” they take excess water away quickly to prevent waterlogging of soil so that plants keep growing. These pipe drains have drained wetlands which used to provide a system for cleaning water on its way to Lake Wairarapa by removing sediment and some dissolved nutrients.

The risk of contaminants such as nitrogen entering the waterways from farm drainage systems is recognised as an issue facing the agricultural industry. Pipe and open (surface) drain systems typically carry water which has elevated levels of Nitrate-Nitrogen ($NO_{3-}N$) caused by urine patches[1] from sheep and cattle. NO_3-N is an important plant fertiliser, but it is highly soluble and leaches through soils, particularly after heavy rainfall. Dairy cows deposit large quantities of urine onto pasture, equating to 700 to 1000 kg N/ha under a urine patch. Reducing nitrogen in the feed and/or removing cows from grazing when the soil is wet reduces the risk to waterways. However these options are not always available, practical or economic.

A bioreactor at the end of a pipe drain is an option that can significantly reduce nitrate in drainage water. It is known as an “edge of field mitigation”.

This guide provides practical advice on installation, check with your local authorities for any requirements thay may have.

1 The urea nitrogen in urine is naturally converted to ammonium-N, and then into nitrate-N.

WHAT IS A BIOREACTOR?

A swimming pool size pit in the ground filled with wood chip. Water from pipe drains with high nitrate concentration flows in one end and as it moves along the length of the pit, nitrate is removed by natural processes resulting in significantly lower concentrations at the outlet. Usually it sits below the level of the pipe drain.

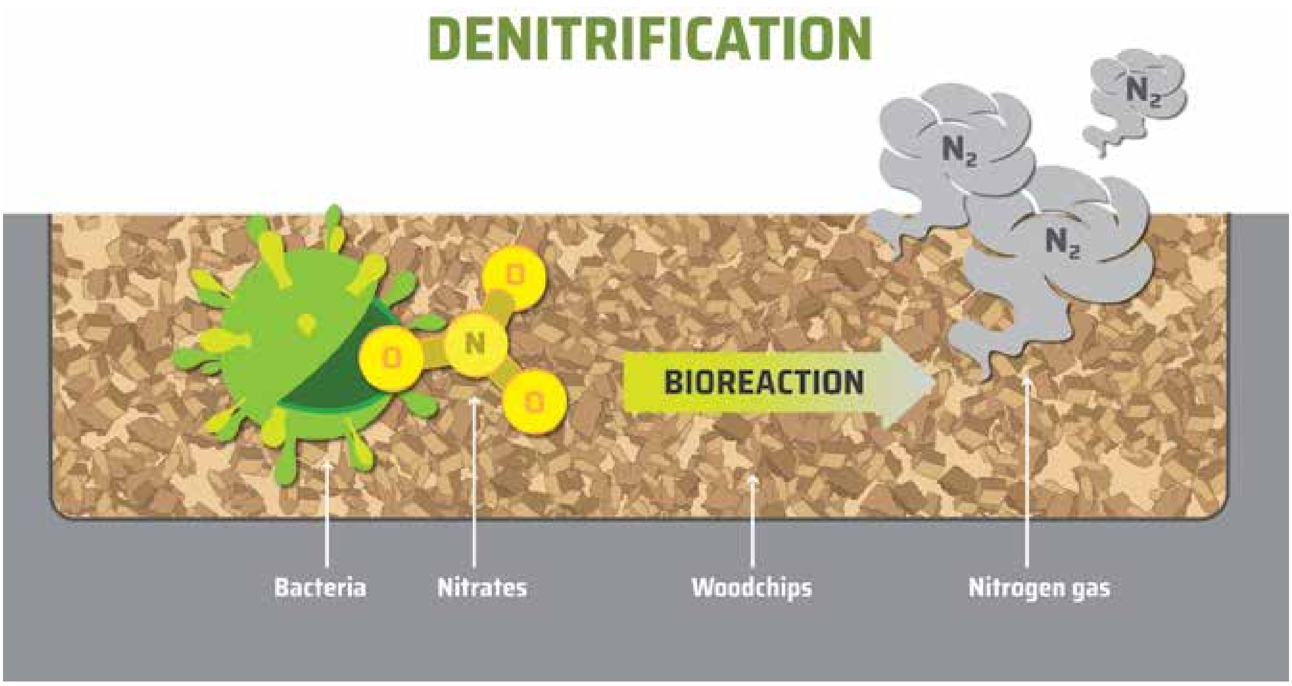
How does it work, what goes on in a bioreactor?

A bioreactor provides a suitable environment for bacteria to convert potentially harmful Nitrate (NO_3-N) to harmless Nitrogen gas (N_2) removing it from drainage water. This process is known as denitrification and occurs in the absence of oxygen.

Denitrification is carried out by bacteria which thrive in environments where oxygen levels are very low and there is organic carbon for energy.

The Science

The process is a type of respiration that reduces[2] NO_3-N ultimately producing N_2, completing the nitrogen cycle. Since denitrification can remove NO_3-N, reducing its discharge to surface water. The process of denitrificaton can be strategically used to treat agricultural drainage water and is an instrumental process in bioreactors and constructed wetlands.



2 Oxidized forms of nitrogen include nitrate (NO_3-), nitrite (NO_2-), nitric oxide (NO), nitrous oxide (N_2O) and dinitrogen (N_2) which are 'reduced" in response to the oxidation of an electron donor such as organic matter. These forms of nitrogen can be used as a substitute terminal electron acceptor instead of oxygen (O_2) which get reduced in the reaction by receiving electrons.

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Bioreactors installed on a farm in the Wairarapa reduced the loss of nitrate from pipe drains by 46%[3].

In order to design and install a bioreactor to remove as much nitrogen as possible you should:

- **Assess the quality of water flowing from your pipe drains. If nitrate levels average 2g/m^3 (2ppm) or more then a bioreactor could significantly reduce N losses from the farm.**
- **Prioritise the most active pipe drains – avoid pipe drains which seldom flow.**
- **Take care to source only woodchips, no bark or other organic matter.**
- **Get the site's hydrology fundamentals right – especially pipe flow rates and pipe levels. Use an experienced drainage contractor to help with design elements such as slope or fall across the site.**
- **Consider access to the site for trucks and earthmoving equipment and alignment of fencelines and open drains. Ideally bioreactors should be close to the discharge points of pipe drains.**
- **Carry out the installation in summer when the water table is low to make site work more efficient. For example getting truck and trailer loads of woodchip to the site requires dry conditions.**
- **Materials needed include piping and fittings, Geotech cloth liner, silage cover for plastic liner (double thickness). Note the size which these come in. For example a 15m wide silage cover would suit a 5.5m width bioreactor to minimise waste[4].**
- **Geotech liner is required on top of woodchips to allow the escape of N_2 gas.**

GET TO KNOW YOUR DRAINAGE WATER

Hydrology is a key factor for success in a bioreactor. Key aspects are nitrate concentration in the drainage water and flow rate from pipe drains. You need to know these aspects in order to calculate the size of your bioreactor.

Nitrate concentration – Some farms have analysed the quality of water coming from their pipe drains. They will likely know what range in NO_3-N concentration to expect. Usually this will range between 2 and 8g/m^3. An average NO_3-N concentration might be 5g/m^3. If you don't know the range of nitrates in your drainage water; arrange water sampling from your pipe drains to establish what your levels are. It is recommended that you take samples three times; early, mid and late, over the drainage season which is usually mid-June to mid-October. Once you know the average NO_3-N concentration and water flow; the volume of woodchips needed can be calculated from an expected removal rate of around 2gm N per cubic metre of woodchips per day[5].

This design targets 50% removal of nitrates.

3 Average removal from June to October 2019

4 Total width of liner will need to be 7.5m (1m down one side, 5.5m across base and 1m up other side) x 2 for double thickness = 15m

5 Based on work to date at University of Waikato, Aqualink and in the U.S.

Drain flow rate - Maximum flow is likely to be around 3 litres per second for standard 110mm Novaflow type pipe[6]. Peak or maximum drain flow is likely to occur only once or twice a year, usually when local flooding is reported. Designing a bioreactor to cope with full flow will be relatively expensive. We suggest you design/size your bioreactor to remove 50% of nitrate from average or normal flow. Observe the flow every 10 days or so during the drainage season to gauge the average discharge flow. Measure what appears to be the average flow as it exits the drainage pipe into the open drain by catching the discharge in a 10 litre bucket and record how long it takes to fill. Divide 10 litres by the time taken, say 11 seconds. This equates to a flow of 0.9 litres/second (10/11=0.9). Do this on at least three occasions to estimate average flow.

'BIOREACTOR' Size calculator

Litres in bucket ÷ Seconds taken to fill bucket x Conversion Factor 86.4[7] x Average Nitrate Conc g/m³ ÷ Removal Rate gms N/day/m³

=

___m³ Woodchips

For example

10L ÷ 11Sec x 43.2 x 5 g/m³ ÷ 2 gm/N/day/m³

=

98m³ Woodchips

So for a drain flow of 0.9 litres/second and an average nitrate concentration of 5 g/m³ in the drainage water, a volume of 98m³ of woodchips would be required to remove 50% of N from the drainage water. A practical size might be 1m deep x 5.5m wide x 18 m long.

6 Based on the assumption that farm pipe drains are typically installed with a fall of 1% (1m drop in 100m). At the same fall 65mm drainage pipe will have a maximum flow of 0.6 litres/second and 160mm pipe will flow at 9 litres/second

7 Convert litres/second to m³/day for 50% nitrate removal

Tips for installation

Usually pipe drains are placed between 600 and 900mm below the soil surface, the bioreactor is usually installed below this level to use gravity to provide flow.

Engage an experienced drainage contractor with a laser level to excavate the cavity for the woodchips. If practical place the bottom end of the bioreactor about 6m from the open drain.

For example the start or top end of the bioreactor will be 24 m up from the discharge point, for an 18m long bioreactor.

Locate the existing drainage pipe about 29m up the discharge point and establish the depth of the bottom of the drainage pipe. This will be where you can divert flow from the drainage pipe into the bioreactor. The depth to the top of the woodchips should be about 60mm lower than the bottom of the drainage pipe for the suggested layout in Figure 1.

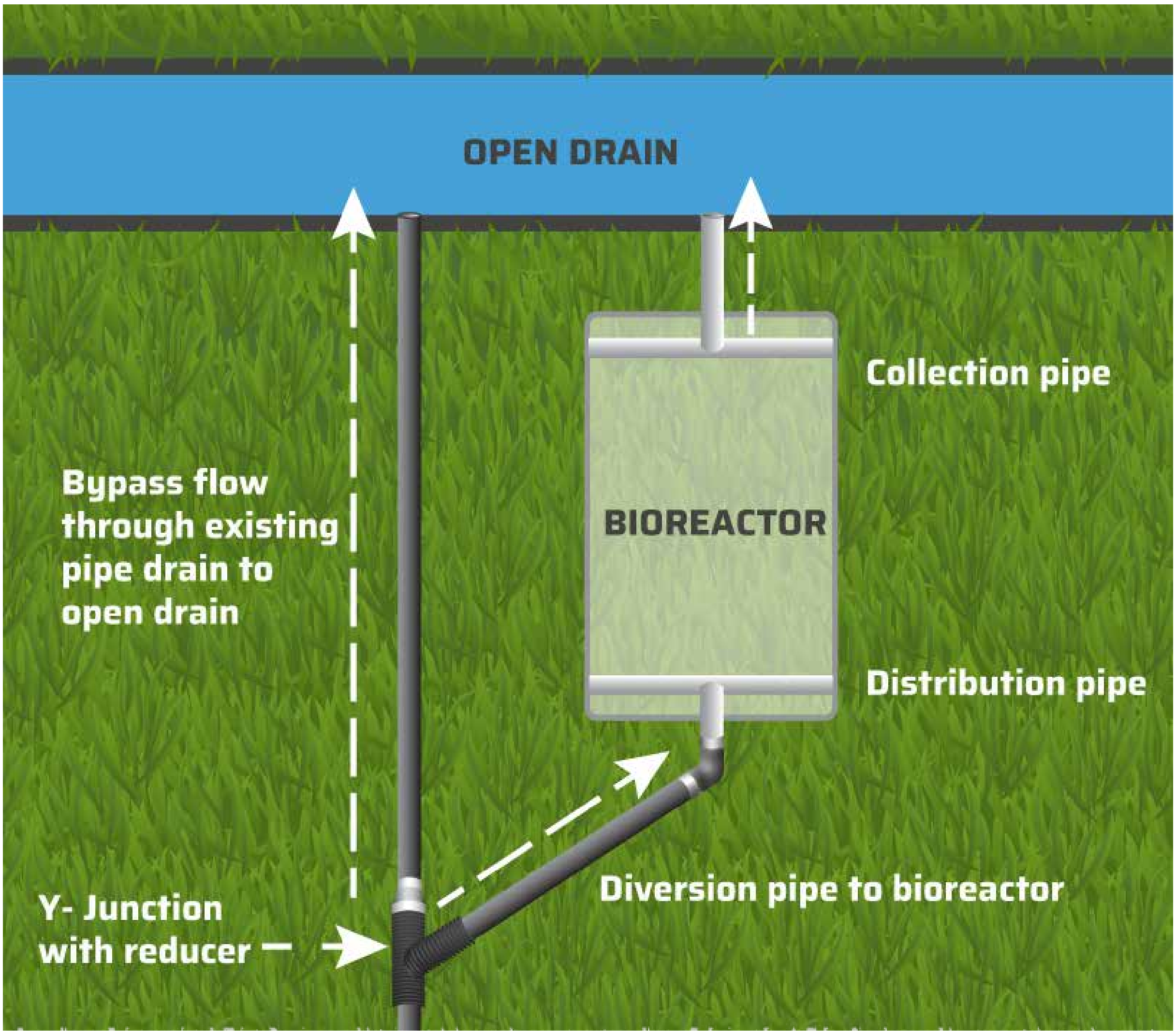

FIGURE 1
Suggested layout for a bioreactor in relation to an existing pipe drain

Excavating the cavity

Excavate a 1.5m wider cavity down to the level of the bottom of the drainage pipe than is required for the woodchip cavity itself. This will provide a convenient 0.75m wide bench to work from when installing the plastic liner and a fill level for the woodchips. This is illustrated in Figure 2.

Maintain a 1% fall down the excavation. For example the outfall for a 15m long bioreactor should be 150mm lower than the inlet at the top end[8].

Complete the excavation by digging down 1m below the bench level at the required width for the woodchips which is 5.5m in this example.

Lining and filling the cavity

The most difficult part of installation is placing the plastic liner in the cavity over the Geotech cloth, placing the outlet pipe in and filling with woodchips. If possible avoid windy days when attempting this job!

BIOREACTOR - END VIEW

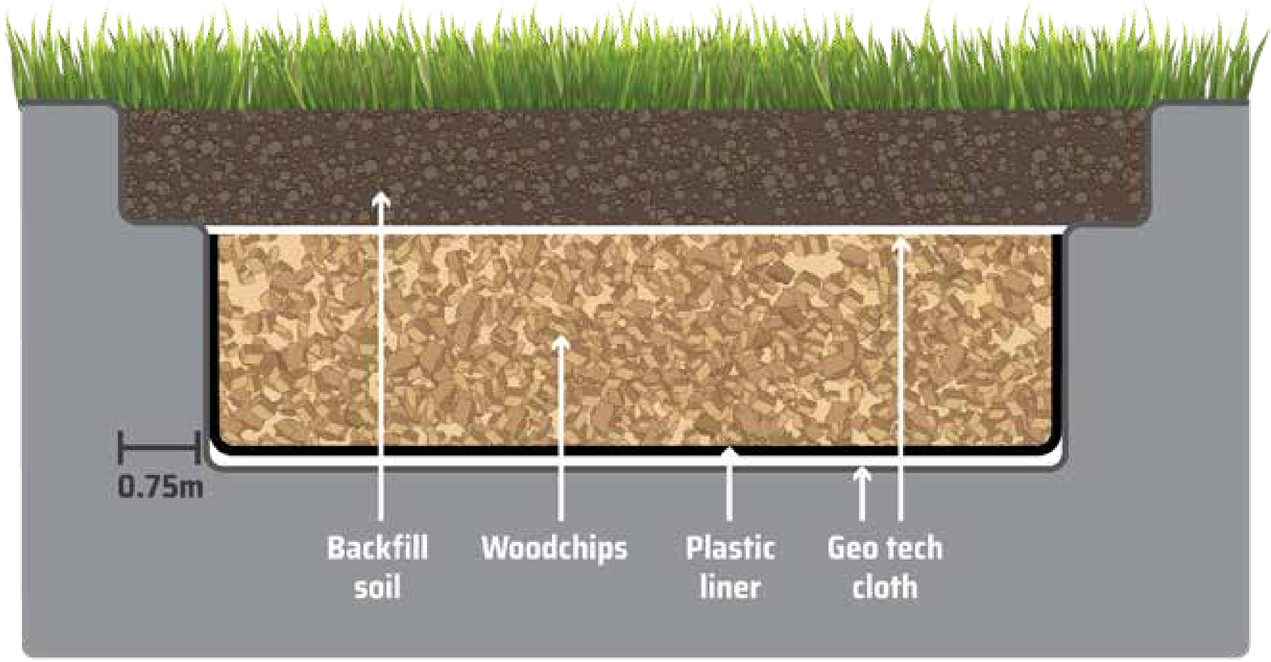

FIGURE 2
End section of Bioreactor pit

8 If you are working with less fall across your site the inlet and outlet height of the bioreactor could be level but flow will be less than where a 1% fall is maintained.

Plumbing

Piping is needed to divert drainage water from existing pipe drain to the bioreactor. A simple solution is to fit a “Y-junction” into the existing pipe drain to take drainage water to top end of the bioreactor as shown in Figure 1. Fit a 100mm-to-65mm reducer in the outlet of the Y-junction to the existing pipe drain as shown in Figure 3. At 1% fall this will divert up to 1.2 litres/sec of drainage water to the bioreactor. Excess drainage flows will bypass to existing drain. Place the reducer with the outlet upper so that flow is preferentially directed to the bioreactor.

This design will divert up to 1.2 litres per second to the bioreactor. For larger average flows, bioreactors and pipes; alternative diversion arrangements will be required.

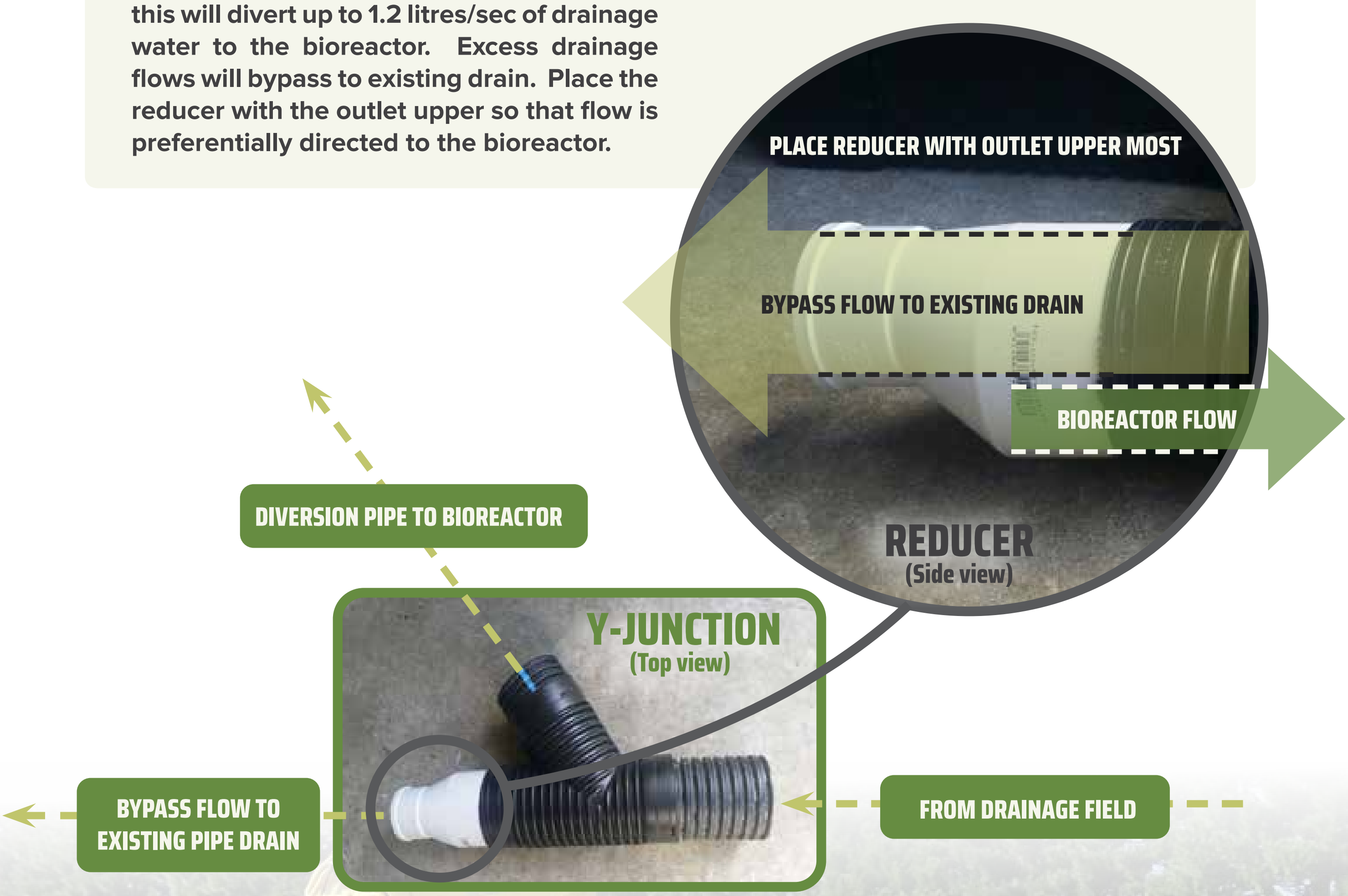

FIGURE 3
Arrangement of “Y” junction with 100 to 65mm reducer

A collection pipe and vertical riser (Figures 1 and 4) at the bottom end must be installed in the base before the cavity is filled with woodchips. A punched drainage pipe is required with a smooth internal wall (eg iPlex nexus flo, Maixpipe Maxitwin, Marley Drainflo or similar). Ideally choose a pipe system with “tee” junction and end cap fittings available. Lay the pipe on the plastic liner at the outlet end of the cavity with a tee join in the centre facing up with a riser pipe fitted to take water up and out of the bioreactor.
Make sure you have fitted end caps or blocked the open ends of the collection pipe in some way to avoid the pipe filling with woodchips. Figure 4 shows a side view of the bioreactor and arrangement of inlet and outlet pipes.

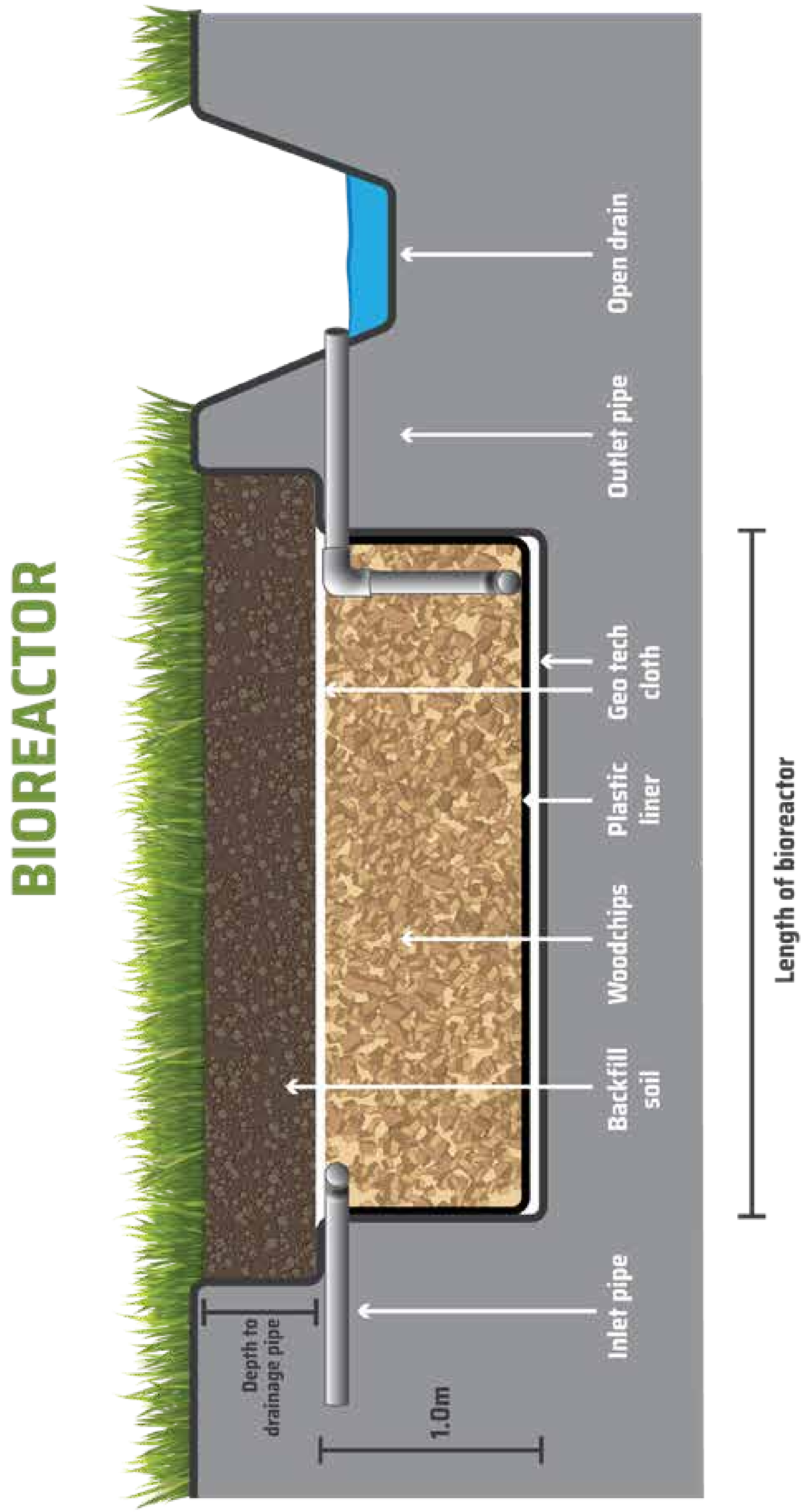

FIGURE 4
Lateral distribution and collection pipes.

FIGURE 4
Shows the outlet pipe rising up from the base of the bioreactor and exiting to open drain.

FIGURE 5
Size of woodchips

Woodchips

Woodchips may be the most expensive part of a bioreactor and are critical to success as they provide the carbon and energy source for the denitrifying bacteria. They should be free of bark and leaves. Avoid fine woodchips as they are less likely to allow water to flow through as compared with larger woodchips. The woodchips used in Wairarapa are shown above. They are flat untreated radiata pine chip which ranged from 20 to 90mm long, 5 to 40mm wide and 3 to 20m thick. A flow of 2.4 litres per second was achieved through these woodchips with 1% fall. Ultimately the size of woodchips you use will depend on what is available locally. Sawdust is not recomended.

Once the woodchips have been loaded into the cavity up to the required level, the distribution pipe at the top or inlet end of the bioreactor can be laid on top of the woodchips as shown in Figure 6. Check the distribution pipe is level to maximise the spread of drainage water across the bioreactor. Fit end caps to the distribution pipe. Cover the woodchips and pipe with Geotech cloth and back fill with soil. Figure 7 shows a cross section of the bioreactor during backfilling.

FIGURE 6
Arrangement of the Distribution Pipe at the inlet end of the bioreactor.

FIGURE 7
End view of bioreactor showing, Geotech cloth, woodchips and backfill.

Indicative cost and performance

Cost

The biggest cost for installation may be the woodchips. In the Wairarapa these were $20/m^3 delivered to the site. The table below shows the costs for installing a bioreactor of the size calculated earlier in the Wairarapa.

ITEM	QUANTITY & COST/UNIT	$
Excavation and backfilling	12 hrs @$150	$1,800
Woodchips	110*m^3 @$20/m^3	$2,200
Pipe (110mm) and fittings	$200 fittings + 30m pipe @ $6/m	$380
Pipe Install	12 hrs @$110	$1,320
Plastic liner	Silage cover 15m x 30m	$400
Geotech cloth	210m @$1.5/m^2	$315
		$6,415

**Bioreactor volume of 98m^3 but at least 10% more woodchips will be needed to allow for waste and shrinkage*

Nitrogen removal performance

For the example calculation of this guide (18m long x 5.5m wide x 1m deep) we are expecting that 2.5 gm^3 of N will be removed and average flow will be 0.9 litres/second for about 120 days. This equates to a removal of 26 kg N/year and a capital cost of $6,415, this equates to around **$246/kg N removed** and compares favourably with other mitigation techniques.

Bioreactors are relatively new in NZ but in the USA there are reports of bioreactors removing Nitrate for more than 15 years without further maintenance or carbon supplementation because wood chips degrade very slowly without oxygen. The key to the longevity of the bioreactor is that it remains waterlogged during the dry season. Therefore take care during installation to protect the liner from puncture. If the bioreactor dries out life expentancy will be reduced.

Further reading

Rivas, A., Barkle, G., Moorhead, B., Clague, J., and Stenger, R., 2019. *Nitrate removal efficiency and secondary effects of a woodchip bioreactor for the treatment of agricultural drainage.* In: Nutrient loss mitigations for compliance in agriculture. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 32. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 10 pages.

Rivas, A., Barkle, G., Moorhead, B., Clague, J., and Stenger, R., 2019: *Nitrate removal and secondary effects of a woodchip bioreactor for the treatment of subsurface drainage with dynamic flows under pastoral agriculture.* Published in Ecological Engineering 148 (2020) 105786.

Schipper, L.A., Robertson, W.D., Gold, A.J., Jaynes, D.B., Cameron, S.C.; 2010: *Denitrifying bioreactors—An approach for reducing nitrate loads to receiving waters.* In: Ecological Engineering 36 (2010) 1532–1543

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