

Guideline for the use of horizontal subsurface-flow constructed wetlands in on-site treatment of household wastewaters

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Contents

- Executive summary.....5**
- 1 Introduction7**
 - 1.1 Key treatment processes.....8
 - 1.2 Scope of guideline.....9
- 2 Constructed wetland specifications11**
 - 2.1 Configuration.....11
 - 2.2 Size and dimensions12
 - 2.3 Liner and edges16
 - 2.4 Gravel media.....18
 - 2.5 Inlet, outlet and water level control19
 - 2.6 General construction steps.....20
- 3 Vegetation.....22**
 - 3.1 Species22
 - 3.2 Planting.....23
- 4 Operation and maintenance25**
 - 4.1 Primary treatment system25
 - 4.2 Inlets, outlets and water levels25
 - 4.3 Plant care.....25
 - 4.4 Final effluent management.....26
 - 4.5 Operation and maintenance checklist.....26
- 5 Acknowledgements.....28**
- 6 References.....29**
- Appendix A Examples of septic tank effluent filters.....31**
- Appendix B Options for entry and exit of pipes through plastic liners.....32**
- Appendix C Plastic arch trench for influent zone33**
- Appendix D List of suppliers.....34**
 - Liners34
 - Plants.....34

Appendix E Herbicides for weed control in constructed wetlands35

Tables

Table 1: Recommended wetland areas and dimensions for household wastewaters. 12
Table 2: Basic wetland gravel media specifications. 18
Table 3: Key wetland plant species and planting densities for on-site house-hold constructed wetlands. 23

Figures

Figure 1: Conceptual cross-section of an on-site household wastewater treatment system incorporating a constructed wetland. 10
Figure 2: Example plan layout for a constructed wetland sized for a standard three bedroom household. 14
Figure 3: Longitudinal cross-section through a constructed wetland sized for a standard three bedroom household. 15
Figure 4: Detail showing anchorage of plastic liner and protective geotextile cover around the wetland edge. 16
Figure 5: Example of installed constructed wetland liner before filling with gravel media. 17
Figure 6: Transverse cross-section through the wetland inlet zone. 19

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Executive summary

Gisborne District Council are interested in offering a broader suite of options for the management of domestic wastewater for homes that are reliant on on-site wastewater treatment. Constructed wetlands have the potential to supplement conventional on-site wastewater treatment systems to reduce pollutant discharges, but there has been no readily available information to guide appropriate usage under New Zealand conditions. This guideline aims to assist designers, plumbers and drain-layers to construct reliable wetland treatment systems that can provide dependable performance and treatment of effluent to secondary standards. Rather than provide a myriad of different design options, it attempts to distil the first-hand practical experiences gained by the authors in New Zealand and Australia, with those developed elsewhere around the world where on-site wetland treatment has been widely practiced.

The guideline focuses on horizontal subsurface-flow constructed wetlands in which wastewater flows horizontally through a shallow gravel bed vegetated with emergent plants adapted to wetland conditions. These systems have been used widely around the world in this role for a number of decades. If correctly designed, installed and serviced, they are capable under New Zealand conditions of providing reliable long-term, secondary treatment of septic tank pre-treated domestic wastewaters with average effluent Total Suspended Solids (TSS) levels < 30 and Biochemical Oxygen Demand (BOD₅) levels <20 g m⁻³. Median levels of faecal bacteria (*E. coli*) will also be reduced by ~99% (2 log reduction). Treated effluents from the wetland should be discharged to an appropriate land application system.

Wetland surface areas, dimensions, lining, media, inlet and outlet structures, and planting requirements are given, based on expected wastewater flows specified in New Zealand and Australian standards for on-site domestic wastewater management (AS/NZ1547; 2000). Conceptual design drawings show the recommended wetland layout and provide detail of key components of the wetland. Operation and management requirements, including plant care and weed management, are outlined, and potential sources of lining materials and wetland plants are listed in the appendices.

The horizontal subsurface-flow wetlands described in this guideline have the advantage that they are simple to construct and can operate passively without need for mechanical apparatus or external energy sources if there is sufficient fall to provide for gravity flow. They are able to cope well with fluctuating wastewater loads, and to function with minimal, but not zero, maintenance and management. Other more complex constructed wetland systems that operate with pulsed loading, vertical- or tidal-flows and/or recirculation have potential to provide higher levels of tertiary treatment, including advanced levels of nitrogen removal. These alternative systems, not addressed in the current guideline, should be considered where higher treatment levels are desired.

1 Introduction

Constructed wetlands are engineered treatment systems that utilise physical, chemical and biological water-purifying processes similar to those that occur in natural wetland ecosystems. They have been widely used around the world to treat a diversity of different wastewaters and stormwaters. After more than 5 decades of accumulating research and practical experience, the performance characteristics of the main constructed wetland types are now well-established [1-4].

Gisborne District Council are interested in offering a broader suite of options for the management of domestic wastewater for homes that are not serviced by a community or Council sewerage system and therefore require their own on-site wastewater management systems. Constructed wetlands have the potential to provide effective secondary treatment of household wastewaters when incorporated within an appropriate on-site wastewater management system.

The 3 technology components that are required to ensure their successful operation are:

1. Suitable source technologies (e.g., toilets, showers, baths, washing machine and household sinks) that provide for efficient use of water and do not leak.
2. Preceding primary treatment (such as septic tanks fitted with effluent filters) to trap raw wastewater solids and scums, and digest putrescent matter.
3. Subsequent land treatment systems (such as soakage trenches or beds, mounds or subsurface drip irrigation fields) with appropriate dosing devices (such as pumps, flouts or siphons) to promote even application and sustain the soils infiltration capacity.

The 3 services required for their successful application and operation are:

1. Competent soil and site assessment.
2. Proper system design, installation and commissioning.
3. Regular operational management and servicing.

If any one or more of these key components are neglected then the whole system is at risk of failure.

A wide range of different constructed wetland designs have been developed and tested around the world, each with their own advantages and disadvantages. The present guideline focuses on horizontal subsurface-flow constructed wetlands, which have been the type most widely used for on-site treatment of household wastewaters [3-11]. In such a system wastewater flows horizontally through a shallow gravel bed vegetated with emergent plants adapted to wetland conditions. If correctly designed, installed and serviced, horizontal subsurface-flow constructed wetlands, as described in this guideline, have the capability to provide long-term, reliable secondary treatment of septic tank pre-treated domestic wastewaters.

Horizontal subsurface-flow constructed wetlands have the advantage that they can operate passively with no requirement for mechanical equipment or dependence on external energy sources if there is enough slope on the site for wastewater to flow by gravity. On flatter or more congested sites, pumps may be needed to move wastewaters into or out of the wetland. Once established these systems have low maintenance requirements and operational costs, although they still require occasional checking and preventive management to ensure sustainable operation. As wastewaters are retained below the gravel surface, there is minimal potential for human exposure or mosquito proliferation. In practice properly designed, constructed and maintained horizontal sub-surface flow systems have proven to provide reliable TSS and BOD removal. They have also been shown to operate without odour or insect problems, and to cope well with fluctuating waste loads. The gravel media is, however, susceptible to clogging if suspended solid and organic loading rates are excessive, or soil materials erode from the wetland embankments or flow-in from surrounding areas. With appropriate upstream treatment, and appropriate wetland design and management these risks can be managed [12, 13] to ensure sustainable operation over periods in excess of 20 years.

Rather than provide a myriad of different design options, this guideline attempts to distil the first-hand practical experiences gained by the authors in New Zealand and Australia, with those developed elsewhere where on-site wetland treatment has been widely practiced. Our aim is to provide a standardised approach which is able to provide reliable and predictable performance. In particular, this guideline draws from practical experience gained in north-eastern New South Wales, Australia, where this technology has been widely adopted for on-site treatment of household wastewaters [5, 14]. The performance characteristics of these systems have been verified under New Zealand conditions in pilot-scale trials over two years at the Pukete Sewage Treatment Plant in Hamilton [15]. Further monitoring under field conditions is recommended to verify their performance in practice.

1.1 Key treatment processes

Wastewaters are treated in constructed wetlands by a combination of natural physical, chemical and biological processes. Suspended solids (measured as Total Suspended Solids, TSS) are removed by settling and entrapment within the gravel media. Organic matter (measured as Biochemical Oxygen Demand, BOD) and other degradable compounds (e.g., constituents of detergents and personal care products) are broken down by microbes growing in biofilms attached to the media and plant roots. Concentrations of faecal bacteria (indicated by *E. coli*), protozoa (e.g., *Cryptosporidium* and *Giardia*), helminths (intestinal worms) and viruses that can cause human illness are substantially reduced as wastewaters pass through the wetland media. The key disinfection mechanisms in this type of wetland are extended retention in the media, exposure to unfavourable environmental conditions, and grazing by free-living protozoa [16, 17]. However, it should be noted that although a horizontal subsurface-flow wetland can reduce levels of faecal micro-organisms by over 99%, it will not produce a fully disinfected effluent. The outflow from the wetland still represents a potential health hazard and must be properly managed.

Beneficial microbes that occur naturally in these wetlands can transform nitrogenous compounds in the wastewater into nitrogen gases that are released back into the atmosphere. This is assisted by transport of small quantities of oxygen into the root-zone via the internal air spaces of the specially-adapted wetland plants, which provide aerobic micro-zones within the predominantly anaerobic bed media [18]. The plants also take up a proportion of the nutrients and recycle them in the system, along with a supply of degradable organic matter (plant litter and root exudates) that stimulates microbial activity [19].

1.2 Scope of guideline

This guideline describes horizontal subsurface-flow gravel-bed wetlands as a supplementary treatment component following primary treatment of household wastewaters in a septic tank. The guideline aims to assist designers, plumbers and drainlayers to build reliable horizontal-flow wetland treatment systems that can provide dependable performance and treatment of effluent to secondary standards. Other approaches to wetland treatment, or other technologies, that may be equally or more appropriate for the given situation should also be properly considered. The information given in this guideline assumes flat or gently sloping sites without flooding, land stability or erosion issues. Expert design assistance should be sought for such difficult conditions and sites.

The guideline is primarily targeted for use in the Gisborne region, but would also apply to most other low altitude (less than ~350 m ASL) areas of North Island and the northern South Island. The guideline assumes that:

1. A septic tank designed and sized appropriately as specified in AS/NZ1547 (2000) [20], provides primary treatment prior to the wetland.
2. The septic tank is fitted with an effective effluent filter to reduce solids carryover into the wetland, and is maintained appropriately, including regular removal of sludge.
3. Household occupancy and average water usage is similar to that proposed for design purposes in AS/NZ1547 (2000) [20]; i.e., 180 L/person/day for reticulated community or bore water supplies and 140L/person/day for rain water tanks.
4. Household wastewaters discharged to the system do not contain chemicals that adversely affect the operation of the septic tank or are unduly toxic to plants or microbes in the wetland.

The guideline focuses on horizontal subsurface-flow constructed wetlands in which wastewater flows horizontally through a shallow gravel bed vegetated with emergent plants adapted to wetland conditions. These systems have been used widely around the world in this role for a number of decades. If correctly designed, installed and serviced, they are capable under New Zealand conditions of providing reliable long-term, secondary treatment of septic tank pre-treated domestic wastewaters with average effluent Total Suspended Solids (TSS) levels < 30 and Biochemical Oxygen Demand (BOD₅) levels <20 g m⁻³. Median levels of faecal bacteria (*E. coli*) will also

be reduced by ~99% (2 log reduction). Treated effluents from the wetland should be discharged to an appropriate land application system. Higher TN removals are achievable with various hybrid constructed wetland systems employing recirculating and/or intermittently dosed vertical-flow stages [7, 15]. These generally require dosing or recirculation pumps and more sophisticated plumbing. Design guidance for these types of wetland are not covered in the present guideline.

Effluents from constructed wetlands such as those described in the current report are not suitable for direct discharge to surface waters and will require further land treatment before disposal to ground. It is not within the scope of this guideline to provide details on the various land application options for the management of the effluent from the wetland, as there are a number of different systems that may be chosen. Possible options include; soakage trenches and beds, mound systems and sub-surface drip irrigation fields, all of which must be appropriately designed and installed to suit the local site conditions. To ensure reliability of performance, most land application systems will require a dosing mechanism (such as a pump, float or siphon). The design and selection of both the dosing technology and the land application system will depend on such factors as site conditions (e.g., soil types, land area available, slope, land use and cover, ground and surface water setbacks), compliance requirements and property owner preferences. Gisborne District Council (or other relevant regulatory body) should be consulted regarding compliance requirements for design and installation of septic tanks and land application systems for final effluent disposal/reuse.

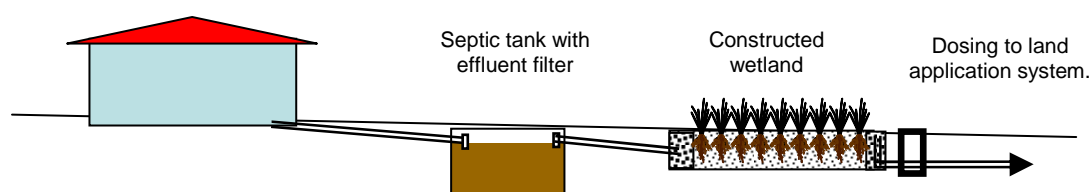


Figure 1: Conceptual cross-section of an on-site household wastewater treatment system incorporating a constructed wetland. Note that some slope is required if relying on gravity flow through the system.

2 Constructed wetland specifications

2.1 Configuration

The general layout of a constructed wetland as a secondary treatment stage within an on-site treatment system is shown in Figure 1. Please refer to your local regional and district council rules, plans and codes regarding set-back distances from dwellings, boundaries and natural features such as waterways, and required reserve areas and exclusion zones. For the Gisborne District Council area these restrictions are set out in the On-site Wastewater Treatment Guidelines.

Some slope is required to enable gravity flow through the treatment system. Alternatively pumps can be used, either before or after the constructed wetland. Where pumps are required for loading the wetland, the option of using an intermittently-dosed vertical-flow wetland, sand-filter or other alternative should also be considered, as these are likely to provide superior treatment in a smaller area.

This guideline is for wetlands receiving household wastewater after primary treatment in a septic tank that at least conforms to the requirements specified in AS/NZ1547 (2000) [20] and has an appropriate septic tank filter fitted (e.g., Orenco™ Biotube, Ecogent™ Ecotube, Zabel™ A1800, Zoeller™ WW or similar (See Appendix A, Ref [21]). The wetland gravel media is susceptible to clogging if it receives excessive solids carry-over from the septic tank, which can lead to surface-flow of poorly-treated wastewater and consequent exposure risks. The septic tank therefore needs to be de-sludged regularly (every 3-5 years depending on usage) to maintain the operational life-time of the system. If a pump or dosing siphon is used to transfer effluent from the septic tank to the wetland it should be done from a separate sump (not direct from the septic tank) and dose no more than 25% of the daily design volume (as specified in Table 1) to the wetland at one time.

The wetland itself consists of the following structural components:

- excavated basin
- impermeable lining material to prevent leakage of wastewater or infiltration of groundwater
- gravel media
- wetland plants
- inlet and outlet structures to ensure uniform flow distribution
- adjustable water level control device at the outlet

After passage through the wetland the effluent needs to flow to an on-site land application system suitable for secondary-treated wastewaters, such as pressure-compensating subsurface drip irrigation, soakage trenches or sand mounds (depending on specific site conditions). Further details of appropriate land application options are available in the AS/NZS 1547 standards and ARC TP58 [20, 22].

2.2 Size and dimensions

The recommended wetland surface areas and dimensions are shown in Table 1, based on the number of bedrooms in the house, standard design population and water usage (180 L/person/day for standard water fixtures including automatic washing machines) assumptions as set out in AS/NZ1547 (2000) [20]. This recognises the inherent variability in household occupancy, water usage and practices, and how this may vary during the lifetime of a treatment system.

Table 1: Recommended wetland areas and dimensions for household wastewaters.
All wetland areas have been rounded to the nearest metre, and distances to the nearest 0.1 m.

Number of bedrooms	Population equivalents for design	Daily wastewater volume (m ³ /d)	Wetland area at mid-depth (m ²)	Wetland area at top (m ²)*	Suggested wetland top width (m)*	Suggested wetland top length (m)*	Length to width ratio
1-2	4	0.72	24	26	4.0	6.5	1.6
3	5	0.9	30	33	4.5	7.2	1.6
4	6 (-7 [#])	1.08 (1.26)	36 (42)	39 (45)	5.0	7.7 (8.9)	1.5 (1.8)
5	8	1.44	48	51	6.0	8.5	1.4
6	9 (-10 [#])	1.62 (1.80)	54 (60)	57 (63)	6.0	9.5 (10.5)	1.6 (1.8)

* assumes side walls of wetland slope 0.2 m from base to top. Basal dimensions can be calculated by taking 0.4 m off the top of wetland dimensions

Area of wetland should be proportionally increased for higher levels of occupancy.

The wetland dimensions recommended should apply irrespective of the type of water supply (e.g., piped supply or rainwater tanks), as the constituent waste loads produced by the household should remain similar.

The recommended gravel depth is 40 cm, with the water level maintained ~5 cm below the upper surface of the gravel at the outlet end. This bed depth is recommended, as it promotes flow through the root-zone of the plants, and shallow beds receiving equivalent areal hydraulic loadings have been generally shown to outperform deeper (60 cm or more) beds [23, 24], despite having lower retention times.

The wetland sizing proposed to achieve secondary treatment standards (BOD <20 g/m³, SS <30 g/m³) is based on a mid-depth areal loading rate of 30 mm per day (i.e., 30 L of wastewater applied per m² bed area per day), which equates to 6 m² of wetland area per person equivalent per day. At the recommended gravel depth of 40 cm (water depth 5 cm below surface), with a gravel porosity of 40%, this equates to a nominal hydraulic retention time of 4.7 days at the full design loading.

The wetland surface dimensions provided assume the side walls of the wetland slope outwards 0.2 m from base to top. A shallower slope may be required when

excavating in sandy sites, and the wetland top dimensions should be adjusted accordingly to ensure the required mid-depth area is achieved. The sizing for a standard 3 bedroom house are illustrated in Figure 2. A longitudinal section through the wetland is shown conceptually in Figure 3

To ensure the influent BOD and TSS load to the inlet zone does not cause undue clogging, and that the cross-sectional area of the bed is sufficient to maintain subsurface-flow, the wetland length to width ratio¹ should be maintained between 1 and 2, with a minimum length of 6 m. This will ensure that (providing suitable gravel media is used) the hydraulic conductivity² of the gravel is not exceeded and thus surface flows of effluent avoided, whilst sufficient flow path length is maintained to promote the required level of treatment.

The base of the wetland and surface of the gravel media should be flat level for the size range and dimensions recommended in the present guideline. Water level should be maintained just below (5 cm) the gravel surface, by adjustment of the outlet pipe level. The gravel surface can be accurately levelled using a rake, by filling the wetland with water and using the water surface as a guide.

¹ This can be calculated by dividing the wetlands length by its width (both in metres).

² Hydraulic conductivity is the maximum rate at which wastewater will move through the saturated gravel media.

Household on-site constructed wetland

Plan view

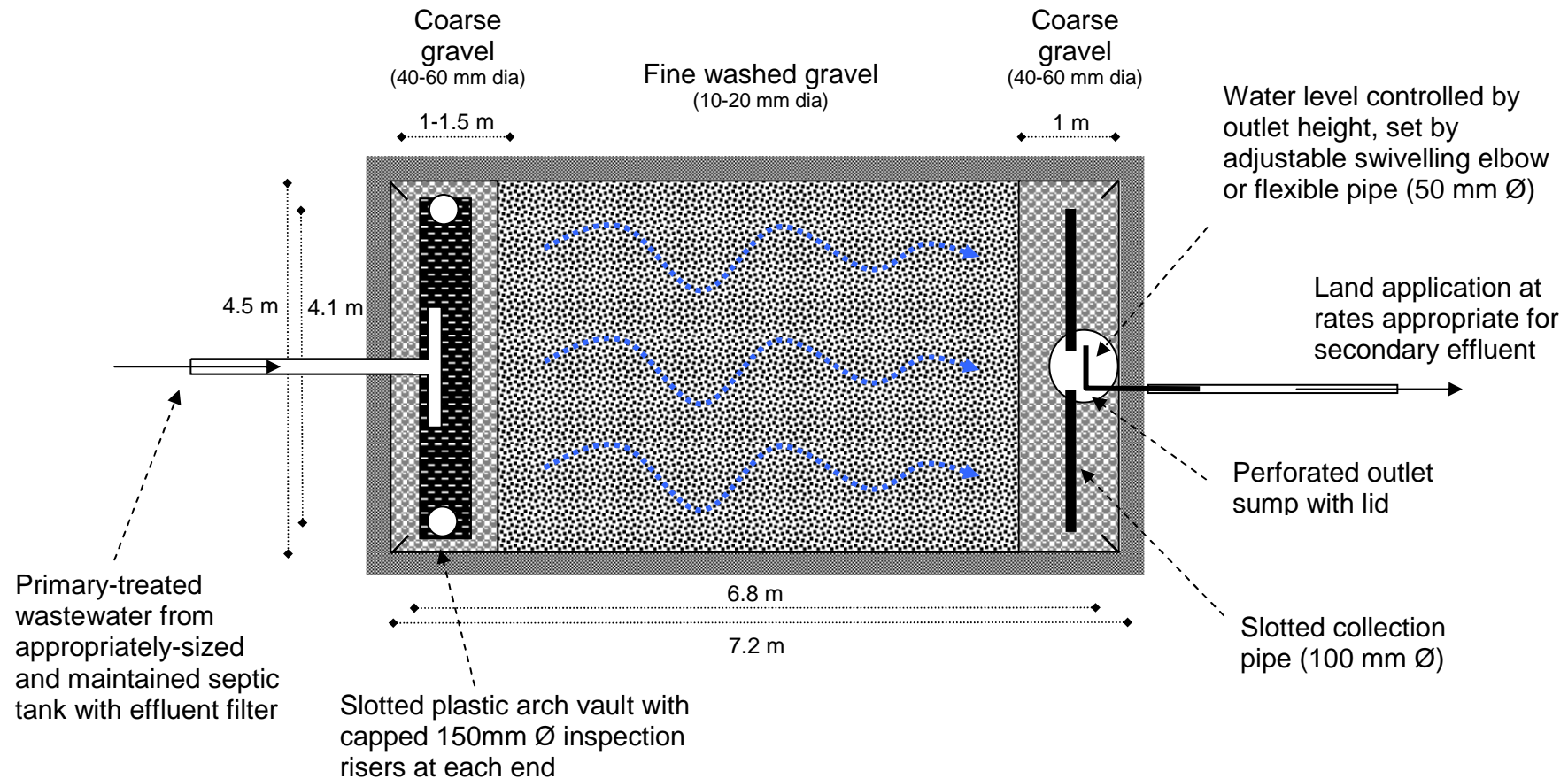


Figure 2: Example plan layout for a constructed wetland sized for a standard three bedroom household.

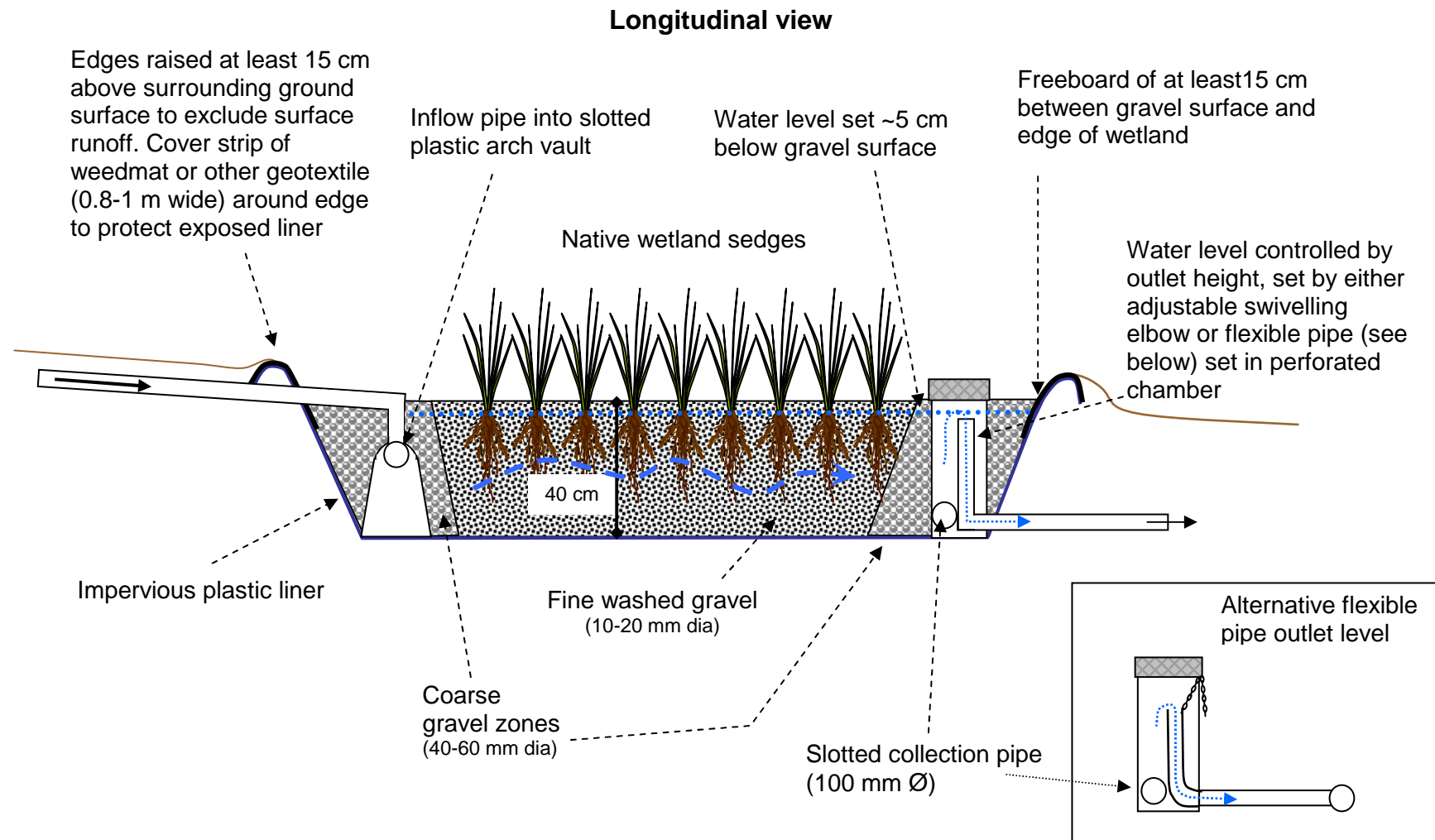


Figure 3: Longitudinal cross-section through a constructed wetland sized for a standard three bedroom household.

2.3 Liner and edges

2.3.1 Plastic liners

To protect groundwater and maintain sufficient water to sustain plant growth, the wetland should be lined. A flexible, but puncture resistant and durable impermeable plastic liner will generally be required, unless suitable clay occurs on site that can be compacted to provide a near impermeable barrier. The latter will need to be specifically approved by council. Polypropylene or Linear Low Density Polyethylene (LLDPE) of 0.75–1 mm thickness are the lining materials of choice, and should be a single continuous piece. Any joins should be factory welded (not merely taped). Contact details for a range of liner suppliers across the country are given in Appendix D. Before laying the liner, the excavated basin needs to be carefully prepared to remove all sharp objects such as rocks and tree roots. The liner should be underlain by a 5 cm layer of bedding sand and protected from above by a layer of geotextile. A high level of care is also required during laying and media addition (e.g., no contact with work boots or machinery). After laying and fitting of penetrating inflow and outflow pipes (see Appendix B), all lining materials, should be tested for a minimum of 24 hours before and after filling with media to ensure they are water tight. If leakages are observed, then the source of the leakage must be sought out and repaired. In the worst case, where the liner is punctured beyond repair, the liner will need replacement. The liner must be carefully anchored 20 cm into the soil around the wetland (Figure 4) or attached to a heavy-duty treated wooden frame (Figure 5). Anchorage should be done after filling with media and water to avoid stretching and stress on the liner. The liner material must be UV resistant, with additional coverage provided around the exposed edges using a UV-resistant geotextile (see Figure 4). This edging also provides a barrier against weed ingress into the wetland.

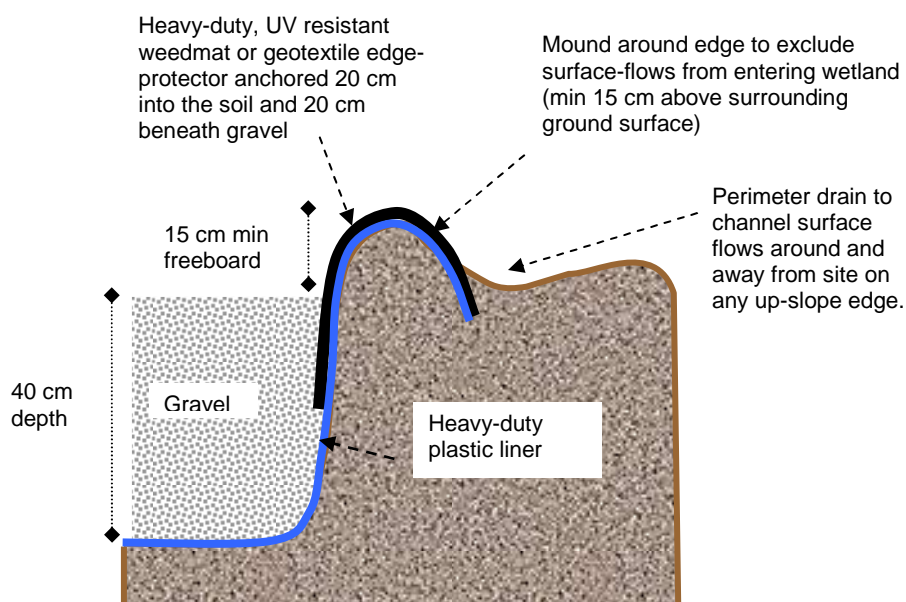


Figure 4: Detail showing anchorage of plastic liner and protective geotextile cover around the wetland edge.

Surface-water flows need to be diverted from entering the wetland. Such external inflows will overwhelm the capacity of the wetland and subsequent disposal system, and wash fine soil materials into the wetland that will clog the gravel and reduce the operational life-time of the wetland. The edge of the wetland should be mounded at least 15 cm above the surrounding ground surface (Figure 4). If desired a 20 cm x 10 cm H5 -treated timber frame can be used to create a definite edge around the wetland. Higher edges may be required if the wetland is built in a depression that acts as a ponding area during high rainfall events or on a sloping site where runoff may pose a problem. Perimeter drains are advisable on the upslope side of the wetland to redirect any surface flows around and away from the wetland.



Figure 5: Example of installed constructed wetland liner before filling with gravel media. In this case the liner has been attached to a treated timber frame around the wetland margin. Alternatively it may be anchored to 20 cm depth into the ground via a shallow trench. A water tightness test needs to be carried out when the inlet and outlet pipe connections through the liner have been fitted. (Photo credit: Rob Van Deun, Geel, Belgium)

2.3.2 Clay lining

For sites where suitable clay are available on-site or nearby, there is potential to use this to line the wetland rather than use plastic liners as described above. If a clay liner is to be contemplated then it is recommended that the following factors are taken into consideration:

- Check with local Regional Council's rules in terms of acceptable leakage rates.
- Assess the following risks:
 - Contamination of groundwater.
 - Slope instability.
 - Wetland plants suffering water stress in the dry season and/or during periods of low wastewater input. (This can be assessed by carrying out a detailed water balance).

Achieving a water-tight clay liner requires:

- Advice from a geotechnical engineer on suitability of the clay as a liner and the required depth of the clay liner.
- A non-dispersive soil with at least 20% clay content.
- Careful compaction with appropriate machinery at the optimum soil compaction moisture content, in layers of 100mm on the floor and sides of the wetland (it will be necessary to flatten the batter of sides the wetland to at least 3:1 to enable adequate compaction).

The water tightness of any clay liner should be tested over at least 24 hours using clean water before any media is added³. When properly constructed such liners have the advantage that they are more permanent than plastic liners and not susceptible to long-term UV damage or accidental puncture. A layer of geotextile should be laid on top of the clay liner material to separate it from the overlying gravel media. To protect the edges of a clay-lined wetland from erosion (and potential clogging of the gravel media), a heavy-duty UV resistant weedmat or geotextile cover should be used on the embankments, similar to that recommended for protection of plastic liners (Figure 4).

2.4 Gravel media

Basic specifications for the wetland gravel media are summarised in Table 2. A good quality, structurally sound gravel (such as greywacke) that will not crush, crumble or degrade into fine particles (i.e., not “rotten rock”) is recommended. Crushed angular gravel is preferred as it tends to pack down less densely, providing a greater pore-space volume and hydraulic conductivity. Scoria, limestone chip, crushed shells and melter slag are alternative media options which have also been used successfully in subsurface-flow constructed wetlands, but would need to be specifically assessed and approved on a case by case basis. The media should be screened and washed to remove fine particles which can reduce interstitial porosity. Particular care is also required to ensure the media used in the wetland does not get contaminated with soil materials during stockpiling and construction, or subsequently from erosion of embankments or surface runoff.

Table 2: Basic wetland gravel media specifications.

Zone	Gravel media	Size range (mm)	Porosity
Inlet and outlet zones	Coarse gravel	40-60	45%
Main wetland	fine angular gravel	10-20	40%*

*Rounded alluvial river gravel is likely to have a porosity closer to 35%

³ Secure the site to minimise drowning hazards during leak testing.

2.5 Inlet, outlet and water level control

To reduce the chance of odours or the incidence of clogging in the inlet zone, wastewater is dispersed below the water level into a perforated plastic vaulted chamber (see Appendix C for example) set in coarse gravel across the width of the wetland (see Figure 6). The chamber increases the influent dispersion area and allows for even distribution across the wetland width perpendicular to the flow direction. It also allows for the higher flow rates that may occur with dose pumping of primary-treated wastewater into the wetland. Capped ports are fitted at each end of the inlet chamber to allow for inspection and, if necessary, removal of accumulated solids. If a pump is used to pump from the septic tank, make sure it is set to pump small doses frequently; i.e., no more than 25% of the daily design volume (as specified in Table 1) pumped to the wetland at one time.

The pipeline from the septic tank filter outlet should be on a grade of at least 1:80 and should preferably enter the vault vertically or at a steep angle to minimize the risk of suspended solids settling in the submerged section of the inlet pipe.

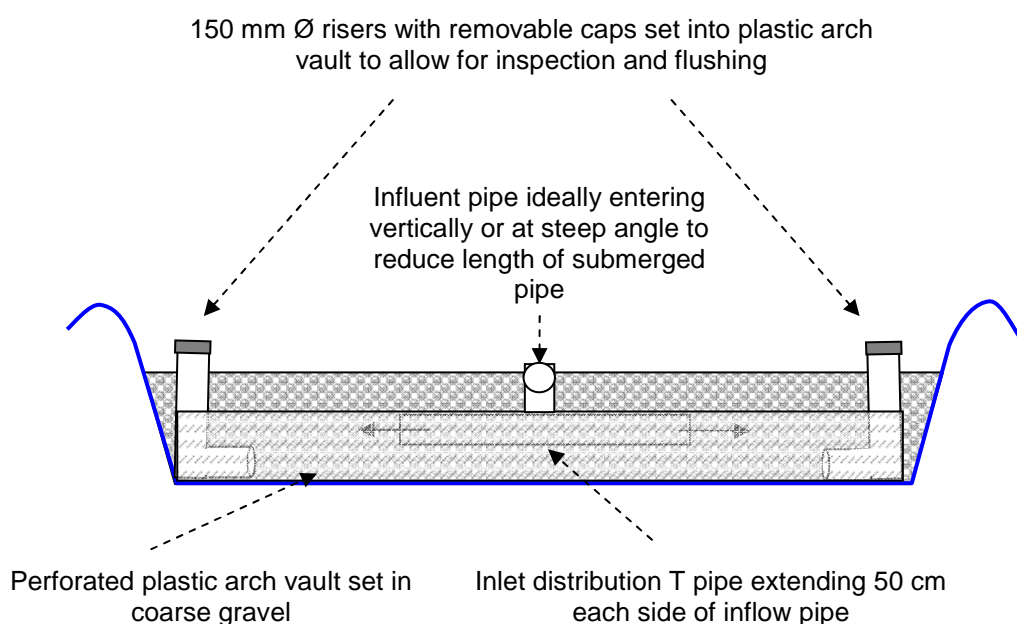


Figure 6: Transverse cross-section through the wetland inlet zone.

The outlet from the wetland is via a 100 mm perforated pipe (15 mm holes at 50 mm centres) set in coarse gravel (Figure 2). The water level in the wetland should be controlled by the height of the outlet riser pipe, set in a capped chamber. This should allow for adjustment and, if necessary, draining of the wetland (e.g., to facilitate maintenance). Two recommended options are shown in Figure 3; either a swivelling standpipe that can be assembled using a close-fitting un-glued PVC pipe elbow with a removable section of pipe attached as a riser, or a flexible section of hose that can be secured using a stainless steel chain or wire, or durable rope. To accommodate the swivelling pipe option and enable reasonable movement, careful placement of pipework in a rectangular or circular sump of at least 500-600mm width or

diameter is required, whilst a smaller sump of 400mm width or diameter may be sufficient for the flexible pipe option.

2.6 General construction steps

1. **Layout:** Mark out the area of the required wetland surface area and embankment levels relative to ground level using pegs and string lines. If relying on gravity flow, be aware of the wetland levels relative to upstream and downstream stages.
2. **Excavation and forming:** Taking note of the final level of the wetland surface and embankment edges, excavate to the required depth. Dig from the inside outwards to avoid broken edge walls. Remove all excavated soil well away from the edges so it does not fall back in. Carefully cut the sloping walls at required angle and level base using laser level, spirit level laid on plank edge, or clear plastic hose filled with water to check and adjust levels.
3. **External pipework:** Put pipework in place so points of entry and exit through the liner are set.
4. **Lining:**
 - 4.1 Plastic liner
 - 4.1.1 Take special care to remove all roots, loose rocks, sharp stones etc. Gently sprinkle surface with water to settle any loose dirt or sand. Lay a protective layer of soft sand or protective geotextile across base to protect liner.
 - 4.1.2 Dig the anchoring trench for the liner around the wetland margin or, if using a timber frame, lay and secure this.
 - 4.1.3 Unfold and lay-out the plastic liner on flat ground and allow 30-40 minutes for liner to “relax”.
 - 4.1.4 Drape the wetland liner into the formed basin. Temporarily lay smooth stones or sand bags around the periphery to lightly hold the liner in place and stop it from flapping in the wind. Press the pond liner gently into the contours of the basin, folding tidily into the corners.
 - 4.1.5 Find pipe entry/exit points, carefully cut liner and make durable watertight connections (see Appendix B). **This is a critical step and represents one of the greatest risks of failure during construction.**
 - 4.1.6 Trim back the liner edges and tuck loosely into the anchoring trench (or over a timber surround if being used instead). Avoid anchoring until the media and water have been added.

- 4.1.7 Water-test the liner and inlet/outlet pipe connections with removable plugs fitted in the pipes for 24hrs. Secure the site to minimise drowning hazard. The weight of the water will allow the liner to fit securely into the contours. If watertight then anchor the edges by burying in the trench (or attaching to the timber frame).
 - 4.1.8 It is recommended that a layer of geotextile fabric be placed over the liner to protect it from penetration during installation of the gravel.
- 4.2 Clay liner
- 4.2.1 If using a clay liner, spread in 10 cm layers and compact as outlined in 2.3.2.
 - 4.2.2 Carefully compact around pipework penetrating the liner, using seep collars to minimise water flowing along the outside of the pipe.
 - 4.2.3 Recheck and adjust all levels and slopes, then plug outlet pipes, fill and water test for 24 hrs. Secure the site to minimise drowning hazard.
5. **Inlet and outlet zones:** Lay inlet vault and pipes, and outlet pipes and sump. Exercise care when walking on the liner. This should preferably be done without work-boots on. The exposed liner also represents a “no-smoking” zone.
6. **Media addition:** Add coarse gravel over pipework to form inlet and outlet zones and then carefully add fine gravel media in between and level. Care must be taken when loading the gravel to prevent puncturing the liner with sharp aggregate, tools or the impact of dropping gravel from height out of earthmoving machinery. Ensure that the weight of the gravel does not stretch or place excessive stress on the liner around fixed points, such as where the inlet and outlet pipes penetrate the liner. **Puncturing the liner during gravel insertion poses one of the greatest risks of failure during construction.**
7. **Final water test:** Retest water tightness with media in place over 24 hours.
8. **Planting and commissioning:** Plant selected species at the recommended rates (see Table 3). Remove the potting media from the plant roots and plant to ~10 cm depth into the gravel. After planting raise water level to ensure plant roots are kept moist. Adjust water level to 2-3 cm below gravel surface initially, lowering the water level to 5 cm below the gravel surface once plants are actively growing and root systems have had time to develop.

3 Vegetation

The proper functioning of constructed wetlands is enhanced by the establishment and maintenance of a dense cover of emergent wetland plants. Subsurface-flow wetlands can still function without plants for a while, but comparative studies show that appropriate planting significantly enhances nitrogen and pathogen removal performance [19] and long-term system sustainability of the treatment system. The diversity of roles provided by wetland plants include:

- promoting the settling and retention of suspended solids
- dispersing flow to minimise short-circuiting
- providing surfaces for the development of microbial biofilms
- transporting oxygen into their root-zone to enhance nitrification and other aerobic microbial processes
- assimilating nutrients and returning them in slowly-available organic forms, a portion of which are retained in accreted sediments
- producing litter as a source of organic carbon for denitrification and other microbial processes
- enhancing wildlife and aesthetic values.

3.1 Species

Planting of 2-3 different plant species provides visual and functional diversity in the wetland. If one species is temporarily affected by disease or pests then there is a back-up to fill the gaps. It is recommended that the species to be used are chosen from one or other of the two different vegetation options presented in Table 3. The first option (Group 1) is to plant low stature sedges (*Carex* sp.) or rushes (*Juncus* sp.), which will remain relatively unobtrusive in a backyard garden setting. The second option (Group 2) is to plant taller-growing species.

Plants from both categories will grow to form a dense sward or canopy and be reasonably resistant to weeds once established. However, because of their different statures they do not grow so well together, so it is generally best to only combine species from one group. All of the species recommended should retain green shoots year-round, except for *Schoenoplectus tabernaemontani* whose shoots will die back over winter in colder inland sites that experience significant frosts [26]. This will not greatly affect treatment performance, but may make the wetland look “untidy” in a backyard setting. If establishing tall erect vegetation (Group 2), it is recommended that *Baumea articulata* be used as the predominant species (at least 60% cover), with one or more of the other tall-growing species used in a secondary role.

A number of ornamental flowering plants like canna (*Canna* sp.) and some varieties of bird of paradise (*Heliconia* sp.) have also been successfully used in constructed wetlands overseas, especially in the tropics [25]. Because they tend to grow prolifically during spring and summer and then die back strongly over winter in New Zealand, they require a lot more work (e.g., harvesting of dead litter) to keep them tidy in a back-yard setting.

Table 3: Key wetland plant species and planting densities for on-site house-hold constructed wetlands. Species are native unless otherwise stated.

Plant species	Common names	Plants per m ²
Group 1: low stature (~1m) growth-forms		
<i>Carex virgata</i>	purei, carex	6
<i>Carex secta</i>	purei, makura*, niggerhead	4
<i>Cyperus ustulatus</i>	toetoe upokotangata, giant umbrella sedge	6
<i>Juncus edgariae</i>	wiwi, rush	6
<i>Juncus effusus</i> (widespread introduced species)	soft rush	6
Group 2: tall stature (1.5-2m+) erect growth forms		
<i>Baumea articulata</i>	jointed twig rush	4
<i>Cyperus involucratus</i> (introduced garden species)	umbrella sedge	4
<i>Cyperus papyrus</i> (introduced, frost sensitive)	papyrus	4
<i>Juncus pallidus</i> (minor component <20% of area)	wiwi, rush	6
<i>Schoenoplectus tabernaemontani</i>	kapungawha*, lake clubrush, soft-stem bulrush	4

* A range of other regional Maori names also exist.

3.2 Planting

The gravel media used in the wetland has little water-holding capacity, so care needs to be taken during plant establishment to ensure there is adequate water available in the wetland that is accessible to the roots of the new plants. Make sure the planting surface is carefully levelled (± 2 cm) so water levels can be maintained close to the gravel surface across the whole wetland without ponding. Any weeds present in the wetland should be removed before planting as they will compete with the establishing wetland species. Suitable plants should be ordered well in advance and kept well watered until planting. A list of wetland plant suppliers is given in Appendix D.

The wetland should be filled with clean water up to the gravel surface either before or immediately after planting. This is also important to avoid health risks associated with wastewater contact during planting. Plant vigorous young plants established in 1–1.5 L containers (e.g., PB3 grade or equivalent) at 4-6 plants per square metre (see individual species recommendations,

Table 3) to promote rapid growth and coverage of the wetland. Ideally, the plants should have been grown up from seed sourced from local populations or from regions with similar

climatic conditions. Plants from Group 1 should generally be at least 0.4 m tall and those from Group 2 at least 0.6⁴ m tall at the time of planting.

It is also possible to use smaller grades of potted plants (e.g., PB 3/4 or “root-trainer” grades) or, for Group 2 species, carefully cleaned, bare-rooted rhizome cuttings of the tall-stature erect plants. However, these more vulnerable plant propagules should only be used if planting is carried out in spring or early summer (September to December inclusive) when plant growth and spread is most rapid and there is a full growth season available for establishment. Irrespective of source, all plants planted into the wetland should be free of weeds, particularly potentially invasive species [26].

Group 1 plants are best planted either as solid bands of 1-2 m width stretching across the width of the wetland or with one (shorter-growing) species around the edges and another species in the centre of the bed. Group 2 plants can be planted in the same ways, or interspersed in small clumps amongst each other. Hardy screening plants such as the mountain flax or wharariki (*Phormium cookanum*) or native tussock grasses (*Carex* and *Chionochloa* sp.) can be planted outside the wetland to form a vegetative barrier, help protect the liner edges, and naturalise the site.

The potting soil media should be carefully removed from the plant roots before planting in the gravel. This is to avoid unnecessary clogging of the gravel media with organic material, and leaching of slow-release fertilisers present in the potting media into the wetland. There will be ample nutrient available for growth in the primary-treated wastewaters applied to the wetland. The plants should be planted well down into the fine gravel media, leaving the coarse-gravel inflow and outflow areas unplanted. Long-handled trowels, narrow-bladed shovels, spades or grubbers are the most useful tools for planting. Once planting is completed primary-treated wastewater can start to be introduced to the wetland.

Further general information on constructed wetland planting and aftercare can be found at: http://www.waternz.org.nz/documents/publications/books_guides/constructed_wetland_planting_guide.pdf [27]

⁴ Note, that plant suppliers will sometimes trim the upper parts of the plants back.

4 Operation and maintenance

Particular care needs to be taken to avoid contact with partially treated wastewaters when working in the wetland. Surface biosolids and plant litter and the surfaces of plants that have grown up through the contaminated water may be contaminated. Therefore it is advisable to wear impervious gloves, protective clothing and footwear, and wash your hands thoroughly after working in the wetland. If any remedial maintenance is done that involves digging down into the wetland media, then the water level should normally be lowered and special precautions taken to protect against direct human contact and to decontaminate any tools used etc.

4.1 Primary treatment system

Desludge septic tank regularly (generally every 3-5 years), and maintain functioning outlet filter as recommended by the manufacturer. Maintain household water fixtures and toilet cisterns in good condition to avoid excess flows due to leaks.

4.2 Inlets, outlets and water levels

Check and adjust water levels in the wetland media to 5 cm below the gravel surface once plants have gained a foothold. If surface-flows or clogging are observed, lower outlet water level. If water levels in the bed do not respond, this suggests clogging of the media. Check the primary treatment system (septic tank and effluent filter) to ensure it is functioning properly (see 4.1) and is not allowing carry-over of suspended solids into the bed. If a pump is used between the septic tank and wetland, check that it is not pumping excessive quantities of effluent (>25% of the daily design load) at one time.

If biosolids do accumulate in the inlet zone and clogging is occurring, clean out accumulated biosolids from the inlet vault chamber and lower water levels for a few weeks. This will help to aerate the bed and promote aerobic breakdown of accumulated biosolids in the media.

4.3 Plant care

4.3.1 Plant care during establishment

Problems during plant establishment are most likely to be due to water levels being too low (desiccation). Water levels can be controlled by adjusting the vertical height of the outlet pipe. To ensure good establishment of plants, water levels should normally be maintained close to the gravel surface particularly during the initial 3-6 months after planting. The health of the plants should be watched carefully initially, as plants grown in normal nursery conditions may take a while to acclimatise to growing in saturated conditions. If the plants start to look unhealthy soon after inundation then it would be wise to lower and raise water levels by 10-15 cm every 2-3 days for a few weeks.

Weeds and any pests should be controlled as the plants establish. Hand weeding should normally be sufficient, but needs to be done before weeds become well-established and deeply rooted into the media. Pests such as pukeko (purple swamp hen), which can pull out young plants, should also be kept out of the wetland during establishment.

4.3.2 Plant care once established

Remove weeds by hand when they are young. If you leave them to grow large, they can develop extensive root systems that can be hard to pull out. Spot spraying, wiping or painting with herbicides may also be useful where weeds are particularly troublesome or have become well established. For further guidance on suitable herbicides and their appropriate use see Appendix E.

Maintain a dense canopy of wetland plants across the wetland to resist weed growth. Replant any bare or dead areas with a plant species that seems to be growing well in the wetland. Harvesting is normally not required, as direct plant uptake of nutrients generally only accounts for a small proportion of nutrient removal (10-20%). If harvesting is practiced, it should ideally be done in midsummer, allowing sufficient growth season for the regrowth of a canopy before winter. If not managed appropriately, harvesting of the plant canopy can enable weed invasion.

If plants look to be suffering from lack of water, check water levels are correct and water is inflowing from the septic tank. This may indicate a problem with leakage in the system, or may be due to low wastewater flows and high plant evapotranspiration rates in dry summer conditions.

4.4 Final effluent management

Ensure final effluent disposal system is working correctly, the outflow from the wetland is not backing up, and effluents are not creating health hazards or contaminating surface- or ground-waters in the land application system.

4.5 Operation and maintenance checklist

One of the advantages of using a constructed wetland as a wastewater treatment facility is that it requires relatively low levels of operation and maintenance input. However there are some simple measures recommended below to ensure the sustainable and effective operation of the wetland.

4.5.1 Fortnightly action list for first three months

▪ Plants
– Visual inspection of plant health, weed and pest problems, take remedial action as necessary.
– Control weeds in wetlands and surrounds by hand-weeding and careful herbicide application. Be very careful of liner when using garden tools and trimmers around the wetland.
▪ Wetland
– Check for adequate inflow and outflow, and identify any blockages or damage to pipework or liner.
– Check water level and adjust outlet height so plants are not desiccated or drowned.

4.5.2 Normal seasonal action list (October, January, April, July)

<ul style="list-style-type: none"> ▪ Plants
<ul style="list-style-type: none"> – Visual inspection of plant health, weed and pest problems. Take remedial action as necessary.
<ul style="list-style-type: none"> – Control weeds in wetlands and surrounds by hand-weeding and careful herbicide application. Be very careful of liner when using garden tools and trimmers around the wetland.
<ul style="list-style-type: none"> – Avoid shading of wetland vegetation by overhanging trees, or accumulation of leaves from around the site. Trim surrounding vegetation to maintain open air-space above the wetland.
<ul style="list-style-type: none"> ▪ Wetland
<ul style="list-style-type: none"> – Check for adequate inflow and outflow, and identify any blockages or damage to pipework. Annually check inspection ports in inlet arch vault chamber to determine whether excessive sludge has accumulated. Pump out vault if necessary.
<ul style="list-style-type: none"> – Check liner and protective edging materials are intact and well anchored. Repair if required.
<ul style="list-style-type: none"> – Adjust water level in bed so flow remains below the gravel surface. Any evidence of wastewater flows across the gravel surface or localised accumulation of sludge should be remedied, as these are likely to indicate malfunctioning, media blockage or incorrect water-level adjustment.
<ul style="list-style-type: none"> – Check for evidence of surface-waters flowing into the wetland, or sediments eroding in from around the wetland. Remedy quickly if evident.
<ul style="list-style-type: none"> – Visually check the outflow quality and flow. Sample for analysis if required to corroborate treatment performance.
<ul style="list-style-type: none"> ▪ Upstream and downstream treatment components
<ul style="list-style-type: none"> – Check no overflows or damage to septic tank and clean down septic tank effluent filter according to manufacturers recommendations. Have excess sludge accumulation (septage) pumped out of the septic tanks every 3-5 years, to maintain sludge level below half the depth of the septic tank.
<ul style="list-style-type: none"> – Check the land application system is operating properly without any evidence of leakage or surface-ponding.

5 Acknowledgements

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Appendix A Examples of septic tank effluent filters

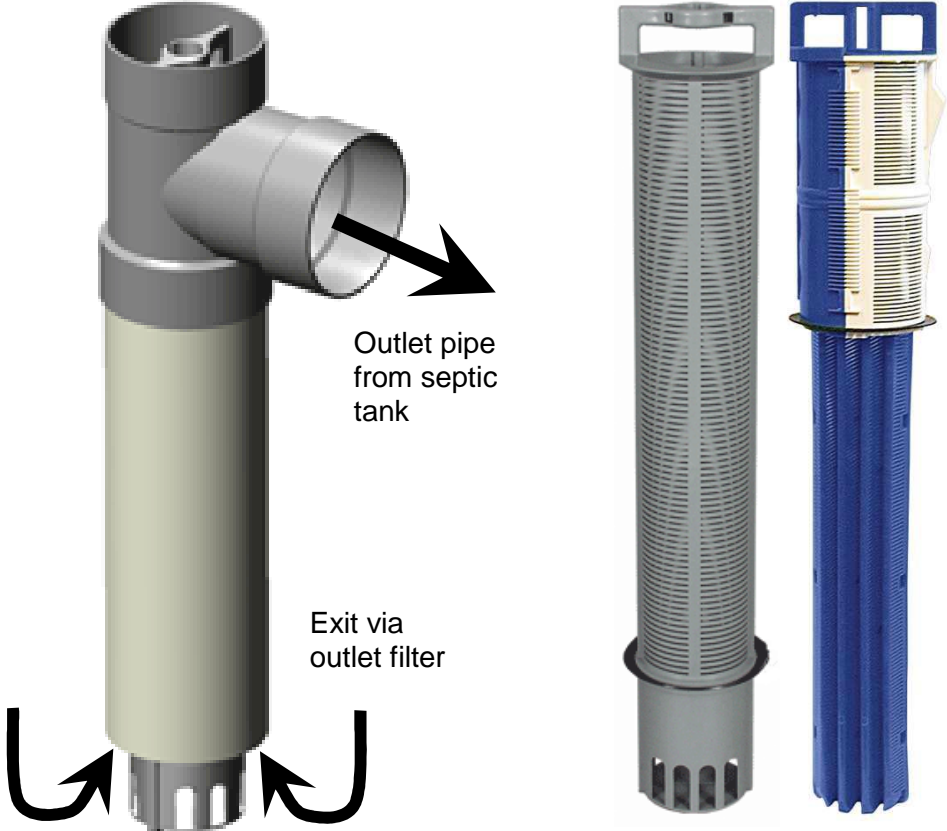


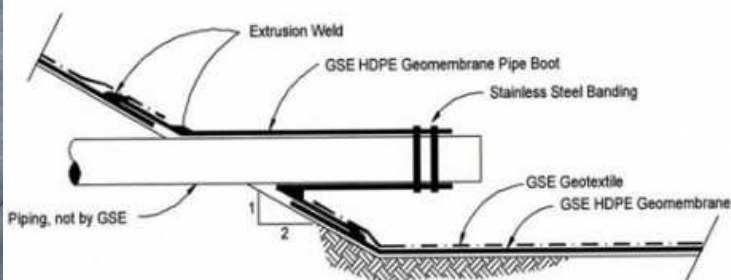
Figure 1: Examples of septic tank effluent filters. The most common systems are columnar filter units which are slotted into the septic tank outlet "T" pipe. Generally an additional piece of pipe is attached to the lower side of the "T" connector to control the depth from which effluent is drawn. The pictures on the right shows two different filter units before insertion, while the picture on the left shows a filter inserted into the outlet "T" pipe. The filter can be withdrawn vertically out of the pipe for periodic cleaning (hosing down). Frequent clogging of the filter is often symptomatic of a septic tank requiring desludging.

Appendix B Options for entry and exit of pipes through plastic liners

(i)



(ii)



(iii)



(iv)



(v)

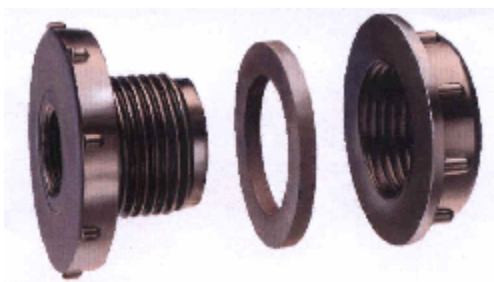


Figure 2: Options to ensure water-tight seals where pipes penetrate the liner sidewalls.

Photo (i) and cross-section drawing (ii) of a welded pipe boot (Aspect Lining Ltd. NZ); (iii) A Firestone™ Quick-seam pipe flashing that can be bonded to the liner to create a secure boot that is able to be clamped around a pipe; (iv & v) Two different versions of plastic screw-thread bulkhead fittings with internal screw threads to enable attachment of pipes; the example on the left (iv) is a Hanson™ “female pipe fitting”, widely available in New Zealand. Additional bonded layers of liner material should be used to strengthen the area around the pipe penetration area, and rubber washers or gaskets can be used to ensure a water-proof seal. Note that it is not advisable to add a silicone sealant when using screw-thread bulkhead fittings with rubber gaskets, as this will frequently cause the gasket to slip and squeeze out when tightening the fitting.

Appendix C Plastic arch trench for influent zone

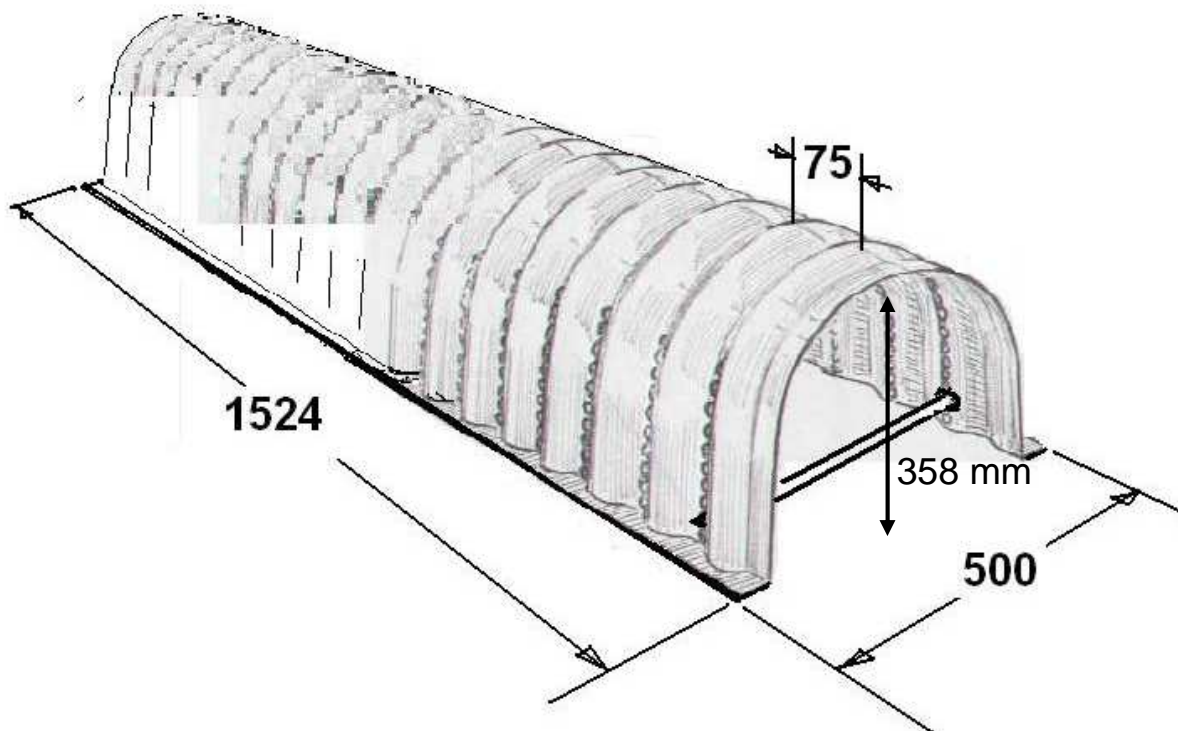


Figure 3: An example of plastic arch vault and end caps. The type shown, is Evertrench Sullage Trench produced by Everhard Industries Pty Ltd, Australia, which should be available through Mitre10 stores in New Zealand. A trench height of 30-36 cm is recommended so the vault remains below the gravel surface. It is also important that there are multiple perforations in the side-walls to promote good dispersal into the gravel. Other similar options are available from Alphaline Industries (PO Box 441, Dargaville 0340, Northland; Ph: 09 439 6912 sales@alphalineindustries.co.nz).

Appendix D List of suppliers

These lists only cover suppliers we are aware of who specialise in large-scale and/or nation-wide supply. They have been listed from north to south of the country. Other local suppliers may also be able to provide equivalent supplies. No endorsement or discrimination of specific vendors is intended or implied.

Liners

- Permathene Ltd., 404 Rosebank Rd., Avondale. PO Box 71015, Auckland 1348. Phone: 0 800-888333 or 09-9688888 www.permathene.com
- Cosio Industries Ltd., 27-33 Lansford Cres. Avondale, PO Box 15014, New Lynn, Auckland 0602. Phone 0800-109093 or 09-8200272 <http://www.cosio.co.nz/>
- Maccaferri New Zealand, 14 Goodman Pl., PO Box 12536, Penrose, Auckland 1642. Phone 0800-606020 or 09-6346495. Also located in Christchurch. www.maccaferri.co.nz
- Aspect Environmental Lining Ltd., 94 Duke St, Frankton. PO Box 15623, Hamilton. Also located in Christchurch. Phone 0800-464234 or 0272-145816 www.aspectlining.co.nz
- Viking Containment, 2 Nazareth Ave, Middleton, PO Box 9117, Tower Junction, Christchurch 8024. Phone 0800-454646 Also located in Auckland and Hamilton. www.containment.co.nz

Plants

- Kauri Park Nurseries Ltd, State Highway 1, PO Box 63, Maungaturoto 0547, Kaiwaka. Phone: 09-4312125 www.kauriparklimited.co.nz
- The Native Plant Centre, 35 Sunnyside Rd, Coatesville, RD3, Albany, Auckland 0793. Phone 0800-696284 www.nznativeplants.co.nz
- Oratia Native Plant Nursery, 625 West Coast Road, Oratia, Auckland 0604. Phone: 09-8186467. www.oratianatives.co.nz
- Naturally Native New Zealand Plants Ltd, 30 Gamman Mill Road, RD3, Tauranga. Phone: 07-5431494. Also located in Auckland and Whakatane. www.naturallynative.co.nz
- Native Garden Nursery, 56 Main Rd, Makara, Gisborne, 06-8684483. www.nativegarden.co.nz
- Taupo Native Plant Nursery, 155 Centennial Drive, Tauhara, Taupo 3378. Phone: 07 378 5450. www.tauponativeplant.co.nz
- Titoki Nursery, 26 Palmer Road, Waimea West, Nelson. Phone/Fax: 03 542 3421. www.titokinursery.co.nz

Appendix E Herbicides for weed control in constructed wetlands

Generally regular hand weeding before weeds get well established is the method of choice. Herbicides, such as those noted below that can kill plant root systems, may be useful if the situation has got out of hand and weeds that are difficult to remove have become well established. In this case herbicides, either spot sprayed on foliage or painted onto cut stumps, can avoid the need to excavate root systems that have become deeply embedded in the gravel media.

Use all herbicides carefully according to label recommendations. Wear appropriate protective gear (e.g., gloves, overalls, masks) to minimise contact with concentrates and sprays. Avoid spraying in windy conditions and avoid overspray of non-target plants growing nearby. The herbicides recommended below generally break down rapidly with minimal residual effects, but be aware of potential effects on sensitive plants that may be irrigated with the treated effluent or come into contact with it soon after herbicide application.

Mention of specific herbicides does not constitute endorsement, nor mean that other products with equivalent active ingredients will not provide similar results.

Target plants to be controlled	Recommended herbicide*	Notes on use
General weed control	Glyphosate (e.g., Roundup®)	Non-selective, it will kill most plants. Careful spot application required to avoid impacts on wetland plantings. Generally low toxicity and non-residual, broken down rapidly. Use formulations recommended for use over and around waterways e.g., Roundup Renew, Agpro Green Glyphosate. Also useful for cut stem/stump treatment of woody weeds (e.g., grey willow).
Selective control of grasses	Haloxfop (e.g., Gallant®)	Generally kills grasses only. Minimal damage to other monocots (cabbage trees, flax, rushes, etc.), but minimise overspray. Does not kill broadleaf plants, ferns, etc. Foliar active with minimal soil activity, moderately low toxicity, short soil residue. Not registered for use in waterways.
Selective control of woody broadleaf plants (e.g., blackberry and willow)	Triclopyr amine (e.g., Garlon® 360)	Kills many broadleaf species including shrubs, vines and trees. Does not kill grasses, but may cause limited damage to sedges, flax or other monocots or ferns. Moderately low toxicity, short soil residue. Also useful for cut stem/stump treatment. Registered for use over water and close to waterways.