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Constructed Wetland Planting
guidelines
Chris C. Tanner
Paul D. Champion
Vivian Kloosterman

New Zealand Constructed Wetland Planting Guidelines

Chris C. Tanner, Paul D. Champion
NIWA, PO Box 11-115, Hamilton
Vivian Kloosterman
VK Consulting Environmental Engineers Ltd., PO Box 10022, Whangarei
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Introduction

During the last 10-15 years, constructed wetlands have become an increasingly popular option for upgrading waste stabilisation ponds and other wastewater treatment plants around New Zealand (Tanner et al., 2000; Tanner and Sukias, 2003). This has been encouraged by their comparatively low construction and operating costs, perceived "naturalness", and provision of ancillary benefits, such as wildlife habitat. In many situations they have also offered a practical means of addressing (at least in part) Maori cultural and spiritual values relating to waste treatment and environmental guardianship.

Constructed wetlands treat wastewaters by mimicking key features of natural wetlands. Efficiency is enhanced by optimising dispersion, flow paths, water depths, residence times, and vegetation characteristics. Recent surveys of treatment wetland users have identified plant establishment and maintenance as a key management issue for treatment wetlands in New Zealand (Tanner et al., 2000). These guidelines provide basic guidance for treatment wetland designers and operators. They focus on wetlands treating secondary and tertiary-treated domestic sewage, complementing and updating previous guidelines for wetland treatment of farm dairy wastes in New Zealand (Tanner and Kloosterman, 1997). Most wetland species will survive to deeper depths in sewage treatment systems than they will in higher strength agricultural wastewaters.

Plant establishment and management in constructed wastewater treatment wetlands

Role of plants in treatment wetlands

The proper functioning of constructed wetlands is enhanced by the establishment and maintenance of a dense cover of emergent wetland plants. Plants are crucial for the functioning of surface-flow treatment wetlands, where they provide the physical structure that promotes settling and supports the growth of biofilms. Subsurface-flow gravel-bed wetlands can still function without plants, but most controlled studies have shown that appropriate planting significantly enhances nitrogen and pathogen removal performance (Gersberg et al., 1983; 1986; Tanner, 2001b).

The diversity of roles provided by wetland plants include (Tanner 1996, 2001b):

- 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,
- shading the water surface to reduce algal growth,
- dissipating wind and wave action to reduce resuspension of solids & bank erosion,
- enhancing wildlife and aesthetic values.

Plant Selection

The key species recommended for New Zealand constructed wetlands receiving domestic sewage (at least secondary treatment assumed) are listed in Table 1. These species, which are capable of forming tall, stable growths within the wetland, may be supplemented by a range of other species that will tolerate growth around the shallow margins and on the embankments of the wetland (Table 2). Such supplementary plantings can be used to help stabilise the embankment slopes, reduce weed ingression, and enhance plant and habitat diversity.

Plant species chosen need to be able to:

- tolerate environmental conditions in the treatment wetland, including local climate, water depths and wastewater strength,
- establish and spread readily to form a dense stable vegetation cover with high pollutant removal capacity and reasonable resistance to weed invasion and normal grazing by water birds,
- not pose significant weed risks elsewhere in the surrounding catchment or region (see Tables 3 and 4, and cautions in Table 1B).

For further detailed information on the identification and geographic distribution of New Zealand wetland plants consult Johnson & Brooke (1989).

Photo 1: A well maintained surface-flow treatment wetland.
The sedge *Schoenoplectus tabernaemontani* is the dominant species visible in the foreground

Wetland species can be either obtained as small plants established from seed (e.g. 1 year-old root-trainer or PB$^{3}/_{4}$ grade) or as bare-root rhizome cuttings with shoots trimmed to 300-400 mm. Both generally establish well if in good condition and planted in the right conditions. Larger grades of plants (e.g. PB3) will give more rapid coverage and require less aftercare during establishment. In the case of bare-rooted cuttings, plants can be either sourced from nursery cultures or from natural populations. Native species can not legally be removed from natural stands on public lands or designated reserves without specific permission from the Department of Conservation or other relevant authority. Care should be taken whenever plants are removed from natural populations to safeguard the viability and sustainability of the wetlands of which they are part. Generally plants for wetland creation and restoration are best obtained from established and reputable suppliers. Where possible, they should be sourced from local populations or from regions with similar climatic conditions. All plants brought onto the site should be free of weeds especially any potentially troublesome species (see Table 3).

Plant Establishment

Wetland plant establishment can be relatively rapid and simple if it is carried out correctly right from the start. However, problems can multiply and become difficult to overcome where plant establishment is compromised by factors such as:

- planting at the wrong time of the year or too late in the season,
- provision of insufficient or excessive water levels,
- use of inappropriate soils or gravels,
- plant damage by livestock or water fowl (e.g. pukeko or Canadian geese),
- competition and suppression by weeds,
- smothering due to sludge carryover from preceding treatment stages.

Photo 2. It is important to avoid excessive sludge carry-over into constructed wetlands from preceding treatment stages. Sludge accumulations can promote weed invasion and affect the treatment performance and operational life-time of constructed wetlands.

Weeds, in particular, can be difficult to selectively remove from a partially vegetated wetland once established. The aim should be to "get it right the first time", promoting the rapid development of suitable tall-growing wetland species by optimising the planting time and growth conditions, and adequately controlling weeds and pests before and during establishment.

Wetland planting in most areas of New Zealand is best carried out in spring or early summer; generally September to December inclusive and the earlier the better, to ensure a reasonable period of active growth. Longer growing seasons in northern and coastal areas of the country provide more leeway. Any weed growth should be controlled before planting (see later section). The planting surface should be level (± 20-30 mm) to allow suitable water depths to be maintained during establishment. Topsoils used in the wetland should be free of their original plant cover, and of reasonable agricultural quality without excessive clay, peat or sand content. They should be evenly spread (150-200 mm depth) and lightly compacted. The surficial layers of planted gravel-bed wetlands should be of appropriate particle size (10-20 mm) to ensure good plant root development and spread.

Plants should be ordered well in advance, with final dispatch to the site arranged to coincide as closely as possible with the time of planting (generally within a few days of receipt). The wetland plant propagules should be carefully maintained up until the time of planting, following the supplier's recommendations; generally involving keeping them well-watered in cool, semi-shaded conditions.

At planting time, water levels should be at or near the soil or gravel surface. Planting should generally be carried out at a density of 4 plants per square metre (i.e. at 0.5 m centres). It is best carried out by a team of planters working together in formation. Each planter can carry a bucket of plants which are periodically replenished or plants can be laid out in advance just ahead of the planters. Care needs to be taken to avoid desiccation damage during the planting process. A small area of the wetland (say 5 by 5 m) should initially be accurately marked out and planted to provide
a visual guide for planting the remainder of the wetland. Long-handled trowels, narrow shovels or spades and grubbers are the most common tools used for planting. Their comparative success depends on the soil or gravel type being planted into and the preferred technique of the planter, so some initial experimentation is recommended. Plants should be planted to 40-60 mm depth in the growth medium and be well firmed so they are not prone to uprooting and do not float out when water levels are raised.

Aftercare

Immediately after planting water levels in surface-flow wetlands should be raised to 50-100 mm above the soil surface to optimise conditions for the wetland plants and suppress weed growth. It is important that the water level is not raised above the height of the plant shoots, as these act much like a snorkel, providing a passage for oxygen to diffuse down to the growing plant. As the plants grow the water level can gradually be raised. In subsurface-flow wetlands, water levels should be maintained

Photo 3. Surface-flow constructed wetland treating waste stabilisation pond effluents.
Main species are *Schoenoplectus californicus* in deeper areas, with *S. tabernaemontani* and *Bolboschoenus fluvialilis* on the shallower edges.

within ± 20 mm of the gravel surface during plant establishment. If there are reliable wastewater flows of sufficiently pre-treated effluent, then low flows of this can be used, with the outlet water level appropriately adjusted. Where insufficient effluent is available at the time of planting, supplementation may be required. If water supply is a problem, periodic flooding or overhead irrigation every 5 or 10 days may be used to maintain moist conditions.
When the plants in surface-flow wetlands have established sufficiently, water levels can be raised in stages over a period of 12 to 18 months. For example, assuming good growth, water levels should be able to be raised to 200-250 mm after a full seasons growth, then to a final depth of 300-400 mm half-way through the 2nd growth season (October/November). Once fully established (generally after 2 growth seasons) plants growing in surface-flow wetlands with water retentive soils should be able to survive short periods of drought. In more severe drought conditions the above-ground parts of plants may die off, but providing conditions haven't been too severe, should regrow again from buried rhizomes (and possibly also seed banks) in the following spring.
Weed invasion is likely to be enhanced during such episodes requiring additional control and possibly also replanting of badly affected areas.

Plants growing in gravel-bed wetlands are much more dependant on careful maintenance of water levels because of the low water retention capacity of the gravel. Once well established (generally after 2 seasons growth) plants in gravel-bed wetlands should be able to survive periods of several weeks of low water levels (up to 150 mm below the gravel surface), but operational water levels should normally be maintained at around 10-30 mm below the gravel surface over as much of the bed as possible. Levels can be fluctuated to up to 300 mm above the gravel-surface for short periods (1-2 weeks) if required, to facilitate control of susceptible weed species. Treatment performance may be reduced somewhat during such periods, due to short-circuiting of the effluent across the surface-waters.

Weed and Pest Management

Weeds

Uncontrolled weeds can compete with and suppress establishment of the desirable plants in treatment wetlands. Plants are most vulnerable during initial establishment. Maintenance of proper water levels combined with occasional deeper flooding of the wetlands can control many non-aquatic weed species, which may colonise wetland sediments. Exclusion of creeping and sprawling weeds such as Mercer grass (Paspalum distichum) and kikuyu (Pennisetum clandestinum) that can form floating mats across the water, and control of embankment weeds more generally, is best achieved by maintaining relatively steep (2:1) and well defined edges rather than shallow shelving banks. Weed growth can then be controlled by mowing or herbicide application along this edge, or by dense planting around the wetland margins with hardy species such as NZ flax (harakehe, Phormium tenax) and native varieties of toetoe (Cortaderia spp.). This latter option also has the advantage of stabilising the wetland embankments, providing cover for wildlife and, where the wetland is open to the public, acting as a barrier to direct human access.

During initial plant establishment it is important that seeds or vegetative fragments of pest plants are not brought to the site inadvertently attached to plant propagules. It is always best to keep weeds at low levels, rather than let them get to the stage where they have become a serious problem. Monthly inspections are advised during the first 4-6 months of plant establishment, with appropriate weed control undertaken as required. Three-monthly inspections and weed control should then be made for a further 12 months after the initial plant establishment period, reducing to 2-3 times per year weed control thereafter. Table 3 lists potential problem species in constructed wetlands. Useful guides for weed identification include Johnson and Brooke (1989) and Roy et al. (1998). If pest species controlled under the Biosecurity Act are noted, then you should contact your local Regional Council for advice.

Guidance on control of common weed species is given in Table 4. Pre-planting applications of a non-residual systematic herbicide such as glyphosate (e.g. Roundup G2™ or similar, at recommended label rates) are advised to ensure weed-free conditions at the time of planting. Thereafter, regular checks followed up, where necessary, by spot applications and/or hand weeding should be used to control weeds around and within the wetlands. Water levels should be dropped before herbicide applications are made in the wetlands and left down for at least 48 hrs before being re-flooded. Care should be taken where large areas of weed growth are being sprayed to avoid deoxygenation problems associated with the decay of large masses of plant material in the wetland waters.

Waterfowl and Livestock management

Pukeko and Canadian geese, in particular, can cause serious damage to new plantings if large populations are present or attracted to the area. They tend to pull out new plants before their root systems can gain good anchorage, either grazing on young shoots and underground rhizomes, or on "bugs" associated with their roots. They can almost completely "un-plant" a wetland in a few days if bird numbers are high and left unchecked. As well as suppressing plant establishment, grazing and nesting activities can sometimes damage established growths, creating and maintaining gaps in the plant cover. Although there is no guaranteed way of excluding them completely, they can usually be adequately controlled for sufficient time to enable plant establishment, after which plantings are generally less susceptible. If there is a large resident population of waterfowl it may be wise to temporarily reduce numbers during the preceding game-bird shooting season. Outside of the shooting season, the local Fish and Game Council may be able to provide additional assistance and advice.

During initial plant establishment the wetland needs to be visited frequently to identify and deal with problems due to pukeko or other pests. Pukeko are generally reluctant fliers, preferring to walk into areas from the margins. Combined electric fences and electric trip wires have proved successful in a number of situations in overcoming pukeko problems for sufficient time (3-4 months) to allow plant establishment. A series of electric trip wires (3 or 4) set ~200-300 mm apart, and ~100 mm off the ground are required in

association with a 3 or 4 wire vertical electric fence (Bob Corker, pers. comm.). These should be set up around the wetland margins and along any internal embankments. Weed growth needs to be controlled under the trip wires to avoid shorting of the lines. As pukeko tend not to land in areas of standing water, maintenance of water depths ≥ 100 mm can provide an additional impediment to their entry into the centre of wetland. Other options that may be considered include:

1. provision of bird-proof fencing
2. temporarily tethering guard dogs on a long lead or within a sturdy fence around the wetland. Provision of adequate housing, exercise, and supplies of food and water are required to ensure the health and welfare of the dog
3. employing a gas banger device as used for horticultural bird control

These generally involve the randomly activated ignition of propane gas in a specially designed chamber producing a shotgun like volley of fire. The noise from such devices can be a nuisance if the wetland is sited near to residences or sensitive livestock.

Other bird scaring devices and repellents presently available on the market generally have shown only limited success.

Livestock need to be excluded from all planted wetland areas using suitable permanent fences. Cattle and other heavy livestock can cause serious structural damage to wetland and associated waste stabilisation pond embankments, and are capable of wading into shallow wetland areas, fouling the water and grazing on the wetland vegetation. Sheep may however be used to graze grassed outer embankment areas, using temporary fences to protect planted wetland and inner embankment area.

Operation and Maintenance Requirements

Prevention is better than cure in the management of constructed wetlands. Regular maintenance helps to ensure that they operate correctly and potential problems are identified at an early stage. This keeps maintenance requirements to a minimum. A recent evaluation of treatment wetlands in New Zealand (Tanner et al., 2000) found that many systems were poorly maintained, and that this was reducing their performance and, in some cases, their potential operational lifetime.

The main areas of maintenance relate to care for the pre-treatment system, plants, inlet and outlet structures, embankments and fencing. It makes good sense to keep records of all operation and maintenance activities, and to actively monitor the effectiveness of the waste management system.

Constructed wetlands, although well proven, are still an emerging technology. Wetlands systems generally have an expected operational lifetime of ~20 -30 years, providing appropriate pre-treatment is used and maintenance is carried out regularly. After this time additional maintenance such as de-sludging of influent zones may be required to extend their operational life.

Pre-treatment

Adequate preceding treatment of wastewaters is necessary to ensure effective and sustainable treatment in constructed wetlands. The upstream treatment system used should be routinely checked to ensure it is functioning properly. It is particularly important to guard against excessive sludge carry-over from ponds or package treatment plants. Sludge entering the wetland will clog the influent zone and gravel-bed sections, reducing treatment performance, the vigour of wetland plants and the lifetime of the wetlands. Where substantial sludge accumulations occur in the wetlands affected areas may need to be mechanically cleared and the wetland replanted.

Pipe blockages or leakages in pre-treatment systems can reduce or halt flows into the wetland, affecting treatment performance and wetland health and survival.

Plants

Plant establishment and care immediately after planting has been covered above. Once the plants are established, a key element of routine maintenance involves quick fortnightly visual inspections. The main purpose

of these inspections is to identify any problems at an early stage, before major problems develop.

When undertaking inspections, look for weeds and undertake control while they are relatively sparse and it still remains easy. Hand-weeding, application of appropriate herbicides (see Table 4) and short periods of elevated water level are potential control options. Also keep an eye out for plants which appear to be dead or showing signs of stress. Some plants become dormant or die-off over cold winter periods (see Tables 1 & 2), but if plants look stressed or unhealthy (wilting, yellowing or blackened) at other times, then the cause needs to be established and rectified. Insufficient water is a likely cause during dry periods. Supplementary water may need to be supplied, for example by siphoning or pumping from pre-treatment ponds or alternative water sources.

In addition to routine inspections and maintenance, an annual gardening session in early spring is highly recommended. As well as regular weed control, this should include replanting of bare patches with new plants or transplants from healthy areas of the wetland. To make replanting easier, the water level can be temporarily lowered using the outlet control.

Inlet

Fortnightly maintenance of the inlet distribution pipe consists mainly of checking that the flow is the same from each outlet, and carefully adjusting these until the flow from each is visually uniform. This helps to spread the flow evenly across the wetland channel so that the entire wetland area is used for treatment. While this is being done check for any blockages, leaks, cracks or damage to the inlet pipes or timber support structure. Blockages should be removed and any damage or wear repaired.

An annual clean out of the inlet system is required to complement routine inspections. This is done by unscrewing the end caps on the inlet pipes and flushing and cleaning them thoroughly to remove slimes and blockages. Pressurised water or mechanical cleaning is best, chemicals such as chlorine which could wash into the wetland and affect plants and treatment processes should not be used.

Outlets

Routine inspections for blockages or damage of the outlet structure should also be carried out. Water levels should be adjusted at the outlet to maintain normal operating depths of 300-400 mm for surface flow wetlands and just below the gravel surface for sub-surface flow wetlands. When the wetland is established and in steady state operation, water level adjustment will generally only be required to accommodate gradual sludge accumulations in the wetlands.

Each year, flush out and thoroughly clean the outlet pipe to remove any slime build-up and blockages, as for inlets.

Embankments

Routine visual inspections should also include the embankments. Look for weeds, erosion and damage by animals such as rabbits or roaming livestock. Weeds on inner embankments should be controlled to reduce their potential spread into the wetland. To ensure weeds do not become established in the first place and protect against erosion it is advisable to plant the inner embankments with hardy plants as listed in Table 2.

If the outer embankments are grassed, this should be mown or grazed with sheep regularly to control growth. The frequency will depend on the time of year, but would average about once per month. Heavy livestock such as cattle and horses should not be allowed to graze these areas as they can damage the embankments and wetland plants.

Fencing

Fencing must be maintained so that livestock cannot gain access to the wetland area. Movable electric fences may be used to control sheep grazing around the wetland, but permanent fencing is recommended around the wetland site. Fences should be checked during routine inspections and any repairs carried out promptly.

Table 1A: Key native constructed wetland plants

Hardy native species suitable for main constructed wetland plantings

Plant species	Common names	Geographicrange in NZ	General growth characteristics[1]	Depth range[2] (m)	Comments
Baumea articulata	jointed twig-rush	From Northland south to Levin.	1.8-2 m tall. Green year-round. Darkgreen, "leafless", cylindrical shoots with "joints". Red-brown pendulous seed heads borne on separate fertile shoots.	0-0.4	Suitable for surface and subsurface-flow wetlands, but relatively slow to establish. Can be planted in association with *S. tabernaemontani* as nurse-crop at ratio of 3:2 Baumea. Generally takes two growth seasons for plants to develop fully. See Adcock & Ganf (1994) and Tanner (1996) for further information.
Carex secta	purei, makura, niggerhead	Throughout .	1-1.5 m tall. Drooping harsh tussocks forming trunk-like base when mature. Green year-round.	0+-0.2	Suitable for gravel-bed constructed wetlands, and margins, shallow zones and embankments of surface-flow wetlands. Establish initially in moist conditions or shallow water (<100mm). Can grow in deeper water if gradually acclimatised, tending to form a trunk-like shoot base. Classic plant of NZ wetland and stream margins.
Eleocharis sphacelata	kuta, tall spike-rush, spike-sedge	Throughout; common in North Island; uncommon in Canterbury.	0.8-1.3 m tall above water level. Stout, bright green," leafless", hollow shoots with transverse septa, arising from thick rhizome. Seed heads forming at tip of shoots. Thick rhizome.	0-0.6	Moderately quick to establish. Commonly the deepest growing native emergent species in natural wetlands and on lake margins. Excellent for surface-flow wetlands. Not suitable for use in gravel-beds because of thick rhizome and requirement for standing water for proper development of shoots. Traditionally used by Maori for weaving. See Sorrell and Tanner (1999) for further information.
†Schoenoplectus tabernaemontani	kapungawha, soft-stem bulrush or lake clubrush	Northland south to Westland and Canterbury.	0.6-1.8 m tall. Shoots die back over winter, except in northern coastal areas. Erect green to blue-green, "leafless", cylindrical shoots with white central pith, arising from horizontal rhizome. Brown seed heads form a tuft just below the shoot tip.	0-0.4	Suitable for surface and subsurface-flow wetlands. Quick to establish and spread in spring and early summer. Grows well from rhizome cuttings. Has been the most common species planted in NZ constructed wetlands, but is relatively susceptible to pukeko grazing and has a tendency in some situations to decline in vigour after a few years in constant deep water conditions. Best used in warmer coastal zones or in combination with other species that do not die back strongly in winter. See Tanner (1994, 1996, 2001a) for further information.

Plant species	Common names	Geographicrange in NZ	General growth characteristics[1]	Depth range[2] (m)	Comments
Typha orientalis	raupo, bulrush equivalent to: cumungi (Aust.), reed mace (UK) & cattail (US)	Throughout.	1.5-3 m tall. Tall, dull green to blue-green, erect leaves arising in clumps from green stout spongy rhizomes. Thick, cylindrical brown seed heads borne on tall shoots. Shoots die back strongly in winter. Generally the dominant emergent wetland plant in fertile lowland NZ swamps.	0-0.4	Although closely related species are used widely in constructed wetlands overseas, this plant is often regarded as inferior to other species in New Zealand. It tends to produce large accumulations of standing and decomposing litter, and can be invasive in nutrient-rich situations, excluding other more desirable species. However, it is common in many areas of the country and will readily establish and flourish in surface-flow constructed wetlands. It is not recommended for growth in gravel-bed wetlands because of its thick soft-pithed rhizome. Its leaves have been traditionally used by Maori for thatching etc. and its pollen and rhizome eaten.

1. Consult Johnson & Brooke (1989) for detailed species descriptions and illustrations.
2. Suggested sustainable final operational depth range for constructed wetlands receiving secondary treated sewage wastewaters. Shallower depths will be necessary during establishment (generally <100 mm depth) and will generally promote denser plant growths. Greater depths can generally be tolerated for short periods.

† Revised name for species formerly referred to in New Zealand (in order of precedence) as *Schoenoplectus validus, Scirpus validus*, and *S. lacustris*. See de Lange et al., 1988 for revised key to NZ species

Baumea articulata

Carex secta

Eleocharis sphacelata

Schoenoplectus tabernaemontani

Typha orientalis

Table 1B: Introduced constructed wetland plants only suitable for restricted use.

Tall-growing, hardy introduced species only suitable for constructed wetland plantings in restricted areas of the country. To guard against spread into new areas, use should be restricted to localities and catchments where these species are already well established in the wild. Regional Plant Pest Strategies should be checked and advice sought from Regional Council Biosecurity Staff before use of these plants. Restrictions may apply to propagation, sale, spread and/or planting of these species. Where natural wetlands, particularly those with reserve status, occur nearby or downstream, the Department of Conservation and NZ Fish and Game Council should be consulted.

Plant species	Common names	Geographic range in NZ	General growth characteristics[1]	Depth range[2] (m)	Comments
**Schoenoplectus californicus*	giant bulrush or giant clubrush	Waikato Heads, Kaipara, and scattered constructed wetlands in the upper North Island.	1-2.2 m tall. Shoots remain green year-round. Very similar growth form to *S. tabernaemontani*, but shoots are generally triangular in cross-section and taller.	0-0.5	Only relatively recently identified in NZ, growing mainly in tidal estuarine situations. Forms taller, deeper-growing, more robust growths than *S. tabernaemontani*, with much reduced winter die-back. Less susceptible to pukeko grazing once established. Avoid spread into any new catchments. See de Lange et al. (1998) for further information.
**Glyceria maxima*	reed sweet grass (formally widely known in NZ as *Poa aquatica*)	Common in North Island, except eastern areas. Scattered in the South Island; locally common in Otago and Southland.	0.5-1.5 m tall. Generally remains green year-round apart from superficial frost damage. Bright green, broad-bladed grass with hollow lower stems/rhizomes, bearing erect feathery seed-heads during summer and autumn. Often forms floating inter-twinned mats over shallow open water.	0-0.3 (will tend to form floating mats at deeper depths)	Quick to establish. Common weed of drainage channels and wet ground in many areas. Do not introduce into new catchments. Often grazed by cattle, but high cyanide levels can cause poisoning of unaccustomed livestock (see Sharman 1967, 1968 and Barton, 1983). Tends to overgrow and dominate other species and have lower wildlife habitat values. Establishment problems have occasionally been experienced due to grazing by Canada geese. See Tanner (1996), for further information.

1. Consult Johnson & Brooke (1989) for detailed species descriptions and illustrations.
2. Suggested sustainable final operational depth range for constructed wetlands receiving secondary treated sewage wastewaters. Shallower depths will be necessary during establishment (generally <100 mm depth) and will generally promote denser plant growths. Greater depths can generally be tolerated for short periods.

* Introduced species

Table 2: Supplementary wetland species

Plants suitable for marginal shallow-water, embankment and areas surrounding constructed wetlands. Plants that are reasonably easy to grow and able to tolerate wet soils and periodic flooding.

Plant species	Common names	Geographic range in NZ	General growth characteristics[1]	Depth range[2] (m)	Comments
Bolboschoenus fluviatilis & *B. medianus*	purua grass, kukuraho, riri-waka, river bulrush, marsh clubrush	Northland south to Westland and Canterbury.	1-1.8 m tall. Leafy sedges with stems, triangularin cross-section, emerging from woody bulbous tubers. Seed heads borne in leafy terminal umbel.	0+-0.3	Particularly common in coastal areas. Fast-growing in spring and early summer, but dies back strongly during winter. Useful species to provide seasonal diversity.
Carex spp.; especially *C.geminata complex* & *C. lessoniana*	rautahi, carex	Generally throughout.	0.5-1.5 m tall. Harsh leafy sedges. Green year-round.	0+-0.05	Valuable for wildlife. Suitable for wetland margins and embankments.
Cortadera richardii, C. fulvida, C. toetoe	toetoe (NZ native species only)	Different species common in different regions.	1.5-3m tall. Coarse green tussocks, with tall feathery flower heads borne on cylindrical stems.	0++	Useful, hardy plants suitable for bank stabilisation and screening. Ensure invasive introduced pampas species (also *Cortaderia* spp.) are avoided.
Cordyline australis	ti kouka , cabbage tree	Throughout .	Tall-growing soft-stemmed tree bearing tufts of fibrous leaves.	0++	Classic NZ tree common in wet soils. Suitable for areas surrounding constructed wetlands. Ensure plantings do not weaken embankments.
**Cyperusinvo lucratus*	umbrella sedge	Common garden plant through-out NZ; occasionally reported in wild.	1-1.8 m tall. Stems, rounded triangular in cross-section, with seed heads formed in terminal leafy umbells. Thick densely branched rhizomes. Green year-round.	0++-0.3	Introduced garden plant. Not common in wild. Tolerates both dry and moderately wet soils. Suitable for wetland margins and embankments, and grows well in gravel-bed wetlands. (seeTanner, 1996 for further information).
Cyperus ustulatus	toetoe upoko-tangata,giant umbrella sedge	Northland south to Canterbury and Fiordland; mainly coastal and lowland.	0.5-1 m tall. Harsh pale-green leaves in clumps, with emergent seed-bearing leafy umbells.	0+-0.1	Tolerates dry periods. Suitable for wetland margins and embankments, and shallow water. Uncommon in constantly inundated conditions in the wild.

Plant species	Common names	Geographic range in NZ	General growth characteristics[1]	Depth range[2] (m)	Comments
Eleocharis acuta	sharp spike-rush or -sedge	Throughout.	0.1- 0.5 m tall. Small short-growing leafless shoots similar to *E. sphacelata*.	0-0.2	Suitable for localised plantings in shallow wetland margins, in association with *E. sphacelata*. Likely to be shaded out by taller, denser-growing species. Often colonises wet areas naturally.
Juncus spp.; especially *J. pallidus, J. edgariae, *J. effusus*	leafless rushes	Throughout .	Generally range in height from around 0.4 to 1.5 m, but *J. pallidus* & *J. procerus* will grow to 2 m or more. Form clumps of green cylindrical stems with seed heads emerging from just below the tip.	0+-0.25	Rush species commonly found in wet pastures and swampy areas. Suitable for stabilising wetland margins and embankments. Tend to grow in periodically wet conditions, and once established, will tolerate periods of dryness.
Lemna & **Spirodela* spp.	karearea, duckweed	Generally throughout.	Minute floating platelets (leaves) with fine rootlets extending down into the water.	Free-floating	Provides a surface cover in surface-flow wetlands. Reduces algal growth by shading the water surface. Can be a problem where it forms a dense cover over sheltered open-water zones and ponds, promoting deoxygenation of the bottom waters. Least problematic in exposed open water areas >500 m_2 where wind and waves maintain lower densities. Valuable wildlife food plant, which generally colonises naturally, transported by waterfowl.
Phormium tenax	harekeke, NZ flax	Throughout, many local forms and varieties.	Robust clumps, 1-3 m tall, of tough fibrous leaves. Tall dark brown to black flower heads.	0++-0.15	Suitable for wetland embankments. Does not generally grow well in continuously flooded conditions in wastewater. A very important plant for Maori, traditionally providing fibre for weaving& rope making, as well as nectar and buoyant flower stalks. Also an important nectar source and cover plant for wildlife.

1. Consult Johnson & Brooke (1989) for detailed species descriptions and illustrations.
2. Suggested sustainable final operational depth range for constructed wetlands receiving secondary treated sewage wastewaters. Shallower depths will be necessary during establishment (generally <100 mm depth) and will generally promote denser plant growths. Greater depths can generally be tolerated for short periods. Depths shown as "0" refer to water table at or within 50-100 mm of the soil surface; "0+" refers to tolerance of periodically wet soils and conditions where the water table generally remains within 200 mm of the soil surface; "0++" refers to tolerance of relatively dry conditions, approaching those of normal temperate terrestrial plants. Embankment species are likely to require supplementary water supply during establishment under dry conditions.
* Introduced species

Table 3: Important introduced wetland weed species to avoid

Ensure plants brought onto the site are not contaminated with propagules of these species. These weeds pose unacceptable weed risks in New Zealand and should not be planted or allowed to spread beyond their existing range. Classified as Pest Plants under Regional or National Pest Plant Management Strategies (Biosecurity Act 1993). These are high-risk pest plants banned from sale, propagation and distribution. For control information contact your regional council.

Plant species	Common name	Geographic range in NZ	Growth form[1]	Comments
Alternanthera philoxeroides	alligator weed	Common Northland south to northern Waikato, rare further south to Canterbury and Westland.	Sprawling emergent	Small clover-like white flowers. Very invasive and difficult to control. Capable of excluding other species and spreading into pastures and cropping areas.
Myriophyllum aquaticum	parrot's feather	North Island and northern South Island.	Sprawling emergent	Perennial herb with whorls of feather-like leaves emerging from the water. Can completely choke waterways, excluding other species.
Eichhornia crassipes	water hyacinth	Northern half of North Island, generally very limited distribution in wild.	Free-floating	Distinctive mauve flower spikes and spongy leaf bases. Known as the world's worst aquatic weed. A notifiable organism under the Biosecurity Act 1993. Often used in tropical areas of the world where it is a widespread weed.
Gymnocoronis spilanthoides	Senegal tea	North Island and northern South Island, very limited distribution in wild.	Sprawling emergent	Highly scented white flowers. Has shown major invasive tendencies in the few reported field sites.
Iris pseudacorus	yellow flag iris	Locally common in central and southern North Island, and Canterbury to Southland.	Emergent	Tall yellow-flowered iris. Can displace other tall emergent vegetation.
Ludwigia peploides subspp. *montevidensis*	water primrose	Northland to Waikato & Manawatu.	Sprawling emergent	Glossy elliptic-leaved herb with long floating stems rooting at nodes. Distinctive yellow primrose-like flowers.
Lythrum salicaria	purple loosestrife	Horowhenua and Canterbury to Southland.	Tall emergent	Perennial herb with distinctive purple flowers. Capable of invading pasture and drainage channels. Presently of limited distribution in NZ, but has shown high weed potential in other areas of the world, especially North America.

Plant species	Common name	Geographic range in NZ	Growth form[1]	Comments
Phragmites australis	common reed	Hawkes Bay and Murchison.	Tall emergent	Tall bamboo-like reed with feathery flowers. Widely used in constructed wetlands in many other parts of the world where it occurs naturally, but a major potential weed in New Zealand.
Sagittaria spp	arrowhead, sagittaria	Few naturalised sites in Auckland and Waikato.	Tall emergent	Three species, two with arrow-shaped leaves, the other with lance-shaped leaves, superficially similar to water plantain (*Alisma* spp).Very invasive.
Salvinia molesta	salvinia	Northern half of North Island. Very limited distribution in wild.	Free-floating	A water fern capable of forming thick floating mats that can choke waterways. A notifiable organism under the Biosecurity Act 1993.
Zizania latifolia	Manchurian wild rice	North Island. Abundant in localised areas, particularly around the Kaipara Harbour.	Tall emergent	Forms very tall growths (> 3m) capable of invading pasture, drainage channels, and natural wetlands and lake margins.

* Consult Roy et al (2004) for detailed descriptions and photographs. For illustrations of these species see the NIWA website: http://www.niwa.co.nz/rc/prog/aquaticplants/species/

Table 4: Common wetland weeds and their control

Common weeds of wet soils that often require control, particularly before and during plant establishment, to avoid suppression of main wetland species. Significant expansion of any weed species should be controlled. Many common pasture weeds and grasses (not listed) can cause weed problems if pre-planting weed control is not properly carried out and/or flooding frequency and depth is insufficient. Where specific wetland vegetation types are desired (e.g. diverse native species associations) then invasive species, such as raupo or reed sweet grass, which have the potential to dominate the vegetation may also require control. Strategic hand-weeding or spot-spraying before invading species become well established is the most effective means of control.

Species[1]	Common Name	Areas commonly found.	Suggested chemical control[2,3]
Apium nodiflorum	water celery	North Island.	glyphosate, amitrole†
Glyceria fluitans / *G.declinata*	floating sweet grass	Throughout.	glyphosate, or selective grass herbicides e.g. fluazifop†& haloxyfop†
Glyceria maxima	reed sweet grass	Scattered (see Table 1)	
Holcus lanatus	Yorkshire fog	Throughout.	glyphosate, or selective grass herbicides e.g. fluazifop†& haloxyfop†
Phalaris arundinacea	reed canary grass	Widely scattered and only locally common.	glyphosate, or selective grass herbicides e.g. fluazifop†& haloxyfop†
Juncus spp. e.g. *J. articulatus*	leafy rushes	Throughout.	glyphosate
Ludwigia palustris	water purslane	Throughout.	glyphosate
Lycopus europaeus	gypsywort	Waikato and Bay Of Plenty.	glyphosate
Paspalum distichum	Mercer grass	North Island and scattered in Nelson and Canterbury.	glyphosate, or selective grass herbicides e.g. fluazifop† & haloxyfop†
Persicaria spp.	willow weeds and water pepper	Throughout.	glyphosate
Rubus fruticosus	blackberry	Throughout.	glyphosate, metsulfuron†, amitrole†
Rumex spp.,particularly *R. conglomeratus*	docks, clustered dock	Throughout.	glyphosate

Species[1]	Common Name	Areas commonly found.	Suggested chemical control[2,3]
Salix spp., particularly *S. cinerea* (this species is in the Pest Plant Accord)	willows, grey willow	Throughout.	glyphosate, metsulfuron†
Zantedeschia aethiopica	arum lily	Throughout.	glyphosate, metsulfuron†

1. Consult Johnson & Brooke (1989) and Roy et al. (2004) for detailed descriptions and illustrations.
2. Care should always be taken to reduce spray drift, contamination of waterways, and effects on non-target plants. Herbicidal control of large areas of weed growth under flooded conditions can result in deoxgenation and release of toxic substances into the water as weeds rot, detrimentally effecting desirable wetland plants. Herbicides should therefore only be spot-applied over <10% of the wetland area at a time, before weed growth becomes serious and preferably in the absence of standing water. Label recommendations should be followed for all herbicides.
3. Specific trade names of herbicides, rather than the generic herbicide names used here can be found online on: http://www.spraybible.com/.

† Herbicides not specifically registered for use in waterways. Should only be sprayed under drained conditions, with overflows to waterways avoided for suitable withholding periods.

Table 5: Summary of maintenance requirements.

During wetland establishment

WEEKLY ACTION LIST

Plants	• visual inspection of plant health and damage by pukeko or other pests. Replant any uprooted plants and control pests • check water levels and adjust as appropriate (particularly during dry periods and when effluent flows are low)
Inlet	• visual inspection for adequate inflow and identification of blockages and damage • check inlet distribution system for uniform flow and adjust as required
Outlet	• visual inspection for blockages and damage • clear any plants or blockages around the outlet • adjust water level as required
Embankments	• visual inspection for weeds, erosion and damage by rabbits or other pests

MONTHLY ACTION LIST

Pre-treatment	• visual inspection of upstream treatment system for structural integrity, and quantity and quality of effluent
Plants	• control weeds in wetland by hand-weeding, herbicide application, and/or temporary water level increases • replace any significant areas of unsuccessful plantings
Embankments	• control weeds on inner embankments by hand-weeding or herbicide application • where appropriate, mow or graze (sheep only) grass on outer embankments and wetland surrounds

Once wetland established

FORTNIGHTLY ACTION LIST

Plants	• visual inspection for any weed, plant health or pest problems. Take remedial action as necessary
Inlet	• visual inspection for adequate and uniform inflow and identification of blockages and damage • maintain and adjust as required
Outlet	• visual inspection for blockages and damage, and visual check of water level and outflow quality and quantity
Embankments	• visual inspection for weeds, erosion and damage
Fencing	• check that fence and gate is stock-proof

TWO-MONTHLY ACTION LIST

Pre-treatment	• visual inspection of upstream treatment system for structural integrity, and quantity and quality of effluent
Plants	• control weeds in wetland by hand-weeding, herbicide application, and/or temporary water level increase
Outlet	• check functioning of discharge system and apparent health of receiving
Embankments	• where required control weeds on inner by embankments hand-weeding or herbicide application where appropriate, mow or graze (sheep only) grass on embankments and water wetland surrounds

YEARLY ACTION LIST

Pre-treatment	• check sludge levels in upstream treatment stages and de-sludge as necessary to maintain treatment performance and avoid sludge carry-over into wetland
Plants	• remove dead plants and replant if necessary (some plants may be dormant or die-back over the winter months)
Inlet	• remove end caps from inlet pipe and flush out and clean thoroughly to remove slimes and blockages
Outlet	• clean and remove plants around outlet pipe to provide access and guard against blockages

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