

Guidelines for Constructed Wetland Treatment of Farm Dairy Wastewaters in New Zealand

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ISSN 01173-0382
ISBN 0-478-08406-4

The *NIWA Science and Technology Series* is published by NIWA (the National Institute of Water and Atmospheric Research Limited.), New Zealand. It supersedes *NIWA Ecosystems Publications* (ISSN 1172-3726; published by NIWA Ecosystems, Hamilton), *New Zealand Freshwater Research Reports* (ISSN 1171-9842; published by NIWA Freshwater, Christchurch) and *Miscellaneous Publications, New Zealand Oceanographic Institute* (ISSN 0510-0054).

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Funding Agencies

Ministry for the Environment, Sustainable Management Fund
Ministry of Agriculture, Agricultural Policy Unit
Dairy Research Institute
Department of Conservation

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Constructed wetlands are a rapidly developing area of wastewater treatment technology and information on treatment of agricultural wastes is still limited. Although all reasonable care has been taken to present accurate information in these guidelines, neither NIWA nor its employees, collaborators and funding providers have any control over their application and accept no responsibility or liability for the consequences of their use.

purpose

This document provides practical guidance on the use of constructed wetlands to improve the quality of discharges from farm dairy waste stabilisation ponds. It describes methods that can be used to upgrade effluent quality from existing treatment pond systems or to develop new treatment systems capable of meeting enhanced discharge standards. It will assist dairy farmers, agricultural consultants, engineers, and regulatory authorities in New Zealand to:

- Evaluate the practicality and cost of constructed wetlands as a treatment option,
- Evaluate treatment levels achievable using constructed wetlands,
- Identify appropriate situations and sites for constructed wetlands,
- Design, construct, and operate effective constructed wetlands,
- Choose suitable wetland plants, and establish and maintain them,
- Link pond, wetland and other land-based treatment options to enhance overall treatment performance, reduce impacts on the environment, and help meet Maori cultural values regarding waste treatment.
- Enhance the aesthetic and wildlife values of waste stabilisation ponds and constructed wetlands systems.

The correct implementation of these guidelines will generally require the assistance and advice of an experienced professional consultant.

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acknowledgements

The preparation of these guidelines was made possible through funding from the Sustainable Management Fund of the Ministry for Environment, the Agricultural Policy Unit of the Ministry of Agriculture, the New Zealand Dairy Research Institute and the Department of Conservation. Valuable contributions to the guidelines were made by Bernard Brown (landscaping options) and Tony Roxburgh (wildlife enhancement). We are grateful to the following people who reviewed draft versions of the manuscript and provided written comments: James Sukias, Paul Champion, Sheila Watson and Graham McBride, NIWA; Dr John Russell, NZ Dairy Research Institute; Dr Rob McColl and Jeff Griggs, Department of Conservation; Phillip Heatley, Livestock Improvement Advisory; Steven Nightingale, Agricultural consultant, Whangarei; Colin Dall, Northland Regional Council; Robert Donald, Environment B.O.P.; N. Selvarajah, Environment Waikato; and Tony Thompson, Auckland Regional Council. We would also like to thank the many other people who have contributed to the research programme which has enabled these guidelines to be prepared, particularly James Sukias and John Clayton, NIWA; Keith Thompson, University of Waikato; Judy van Rossem, Colin Fergusson and Adrienne Moira, Environment Waikato; and Andy Bruere, Environment B.O.P. We acknowledge research funding provided by the NZ Foundation for Research Science and Technology, Environment Waikato and the New Zealand Dairy Group Ltd., and thank Environment B.O.P. for providing us with information from their farm trial in the Bay of Plenty.

glossary

Aerated pond— A pond in which the majority of aeration is supplied by mechanical aerators. In the context of this guideline it refers to partial-mix aeration, designed primarily to maintain an adequate oxygen supply, rather than to keep solids in suspension.

Aerobic— Conditions where oxygen is present.

Ammonia— Reduced form of nitrogen. Can be toxic to fish and other aquatic organisms, particularly under high pH (alkaline) conditions and at high temperatures. Its microbial conversion to nitrate results in a nitrogenous biochemical oxygen demand (NBOD).

Anaerobic—Reduced conditions occurring in the absence of oxygen.

Biofilm— A bacterial slime layer forming on the surface of soils, plants, detritus etc comprised of bacterial cells suspended in a gel-like matrix of extracellular polymers.

BOD— Biochemical oxygen demand; a measure of the oxygen consumption capacity of a wastewater. The level of oxygen required, under standard conditions, to stabilise organic wastes by microbial processes.

CBOD— Carbonaceous BOD. The oxygen consumption of the organic matter present in a wastewater, when microbial nitrification is inhibited.

NBOD— Nitrogenous BOD. The oxygen consumption due to microbial oxidation of ammonia and mineralisable organic N. Normally calculated theoretically as 4.33 times the ammonium - N concentration.

Dissolved oxygen—Oxygen available for the respiration of fish and other aerobic aquatic organisms.

Endemic— Refers to organisms that are found naturally only in a particular country or region, in this case New Zealand.

Facultative pond—A pond containing both aerobic and anaerobic zones. Algae and surface reaeration supply oxygen to the upper waters, while anaerobic conditions prevail in the deeper zones. Often wrongly referred to as aerobic ponds.

Microbes—Microscopic organisms; bacteria, algae, fungi and protozoa

Nitrate—Oxidised form of nitrogen. Generally readily converted to nitrogen gases by wetland microbes (= denitrification).

Nitrification—conversion of ammoniacal nitrogen to nitrate by microbes.

Oxidation ponds—see waste stabilisation ponds.

Plug-flow—even longitudinal flow (e.g. along a pipe or channel) with minimal longitudinal mixing and dispersion. Opposite to a fully mixed tank.

Propagules—In context of plants, refers to vegetative sections of plants, such as rhizomes or rootstocks, that can be used to propagate new plants.

Rhizome— Below-ground vegetative stem of plants, usually spreading horizontally.

SS— Suspended solids; a measure of the particulate matter present in water.

Thermal stratification— Separation into layers of different temperatures. In the context of waste stabilisation ponds, generally refers to development during the day of a warm upper layer underlain by a colder lower layer. The lower layer, in the absence of atmospheric or algal reaeration, generally becomes anaerobic.

Waste stabilisation ponds— A series of ponds used for wastewater treatment. Pond systems used for farm dairy wastewater usually comprise an anaerobic followed by facultative pond. Commonly known in New Zealand as oxidation ponds.

background

Changing environmental requirements

Agricultural land uses have major effects on the quality of New Zealand's inland and coastal waters, and their associated fisheries and wildlife. Environmental requirements for the sustainable management of natural waters under the Resource Management Act 1991 and the need to give real credence to the "clean green" image of New Zealand's dairy produce in overseas markets, have heightened the need for improved methods of wastewater treatment in the dairy industry.

The responsibility under the Resource Management Act, to take into account the principles of the Treaty of Waitangi as well as Maori preference for land-based waste treatment methods, has led to a resurgence of interest in land application of farm wastewaters. Where practically feasible and well managed, such methods are generally preferable as they promote direct recycling of much of the nutrients and organic constituents of the wastes back onto farm pastures. Many Councils are now actively encouraging such land application of farm dairy wastes by making them a Permitted Activity (subject to certain conditions) within their Regional Plans. Successful year-round land application of wastewaters is, however, difficult in many farming areas, particularly those with high rainfall, heavy clay soils or high water tables. Conversely, in sites with very free-draining or skeletal soils, treatment of wastewaters and retention of applied nutrients may be poor, contributing to nitrate and faecal bacterial contamination of groundwaters unless carefully managed. Land treatment of wastes also requires considerable capital inputs and ongoing active management to operate effectively.

Need to upgrade pond discharges

Waste stabilisation ponds, often known as oxidation ponds, have been the most common treatment option used by New Zealand dairy farmers, since the development of design guidelines in the early 1970s. Their low-cost and minimal day to day management requirements have generally proven popular with farmers. They typically consist of an anaerobic pond

followed by a facultative pond (often incorrectly called an aerobic pond). These pond systems have been instrumental in achieving substantial reductions in organic and solids loadings to waterways from the many, previously untreated, farm dairy discharges around the country. A significant proportion (20-45%) of their nutrient loading is able to be returned back to pasture when the anaerobic pond is periodically desludged.

Recent studies of farm dairy ponds have shown that despite achieving major overall reductions in BOD (biochemical oxygen demand; see Table 1 for description of major pollutants) and SS (suspended solids), their effluent quality is generally extremely variable, requiring high receiving water dilution rates to protect water quality and aquatic life. Pollutants of greatest concern now include ammonia (toxicity to aquatic life and contribution to the oxygen demand exerted in streams), SS (impacts on stream bed organisms and water clarity), faecal indicators (disease transmittance), and particularly in sensitive catchments and stream types, levels of dissolved nutrients (stimulation of undesirable algal and weed growths).

Supplementing treatment using constructed wetlands

Constructed wetlands can be used as "add-ons" to supplement the treatment of farm dairy pond systems. They are not a viable remedy for grossly overloaded or poorly functioning ponds, as their proper long-term functioning requires adequate pretreatment to at least the normal standard for dairy ponds (see Table 2). However, they offer a viable means of upgrading the performance of correctly functioning pond systems. Their low capital and operating costs (compared to most other supplementary treatment options) and lack of reliance on machinery and external energy inputs has led to a rapid expansion in their use, particularly for domestic sewage treatment. More recently they have been tested for the treatment of agricultural and industrial wastewaters. Being essentially "natural" treatment systems and offering potential additional benefits, such as

Table 1: Summary of key pollutants in farm dairy wastewaters and their significance.

Pollutant	Description	Significance in discharges to natural waters
Biochemical oxygen demand (BOD)	Measure of the oxygen consumption of a wastewater under standard conditions. Oxygen is consumed by bacteria decomposing organic matter present in the waste. BOD is therefore an indirect measure of the degradable organic matter remaining in the wastewater.	High levels of BOD can reduce the dissolved oxygen concentration in waterways. Minimum dissolved oxygen concentrations of around 5 g m ⁻³ are required for the survival of fish and other stream organisms. High levels of dissolved BOD can promote the growth of nuisance growths of sewage fungus.
Suspended solids (SS)	Suspended particles present in the water. Measured by passing water through a fine (0.45 micron) filter and weighing the solids retained on the filter after drying to constant weight.	Reduces water clarity, affecting visual clarity and limiting light penetration. High levels of organic SS can reduce light levels available for plant growth and smother bottom sediments, stressing bottom-dwelling organisms. Conversely, lower concentrations may provide a valuable food source for these organisms.
Ammonia	The toxic reduced form of dissolved nitrogen. Bacterial oxidation to the nitrate form consumes oxygen—this is known as nitrogenous BOD (NBOD), and exerts an oxygen demand additional to that measured by the standard BOD test.	Toxic to fish and other stream organisms. Level of toxic form increased under conditions of high pH and temperature. The NBOD, which is generally 4-6 times higher than standard BOD in standard farm dairy pond discharges, can reduce oxygen concentrations in waterways (see BOD above).
Nutrients	Dissolved forms of nitrogen and phosphorus.	Can promote undesirable growths of water weeds and algae (both slimes and filamentous forms). Particularly important in low nutrient waters where background concentrations of available N or P limit plant productivity. Under these conditions, exceedence of limiting concentrations can promote undesirable growths.
Faecal coliforms	Indicator of faecal pollution and the presence of pathogenic organisms. A range of other indicator organisms can also be used, each with a different sensitivity and relevance for different waste types and disease risks.	Increased illness and disease risks to humans, livestock and wildlife. Particularly important for areas where human bathing, aquaculture, or water abstraction occurs downstream of a discharge.

provision of wildlife habitat and parkland, constructed wetlands are generally perceived by the public as a preferred means of effluent treatment. By utilising the cleansing properties of aquatic plants and soils, constructed wetlands may also be considered by Maori as a more acceptable means of wastewater treatment, particularly when the final effluent is discharged to the ground (e.g. rapid infiltration) or dispersed via natural wetlands, riparian zones, or simple seepage and overland-flow systems.

These guidelines for the treatment of farm dairy wastewaters, are based on experimental (Tanner 1994, 1996) and pilot-scale trials (Tanner et al. 1995a, b; Tanner & Sukias 1995; Tanner et al. submitted) carried out at the Ruakura Research Centre in Hamilton over a five year period, and farm-scale trials carried out in association with the New Zealand Dairy Group and Environment Waikato (Sukias & Tanner 1996, Tanner & Sukias 1996) , and by Environment Bay of Plenty (Bruere & Donald 1997). They also incorporate information from numerous other studies of constructed wetlands treating a diverse range of wastewater types throughout the world, and from the authors' practical experiences in the design and construction of these systems in New Zealand.

Constructed wetlands are known to operate successfully over a wide range of climatic regimes, with annual mean BOD, SS, total phosphorus (TP) and faecal coliform removal generally showing little sensitivity to temperature (Kadlec & Knight 1996). Our research results for farm dairy effluents are primarily derived from seasonal milking herds in the Waikato and Bay of Plenty Regions, and are considered relevant to other areas in New Zealand with broadly similar climates. This is likely to include all the major dairying areas in the North Island, as well as coastal areas in the northern South Island. These guidelines may require adaptation for use in colder climatic regions of New Zealand where upstream pond performance and functioning is expected to be different, and operational experience of constructed wetland systems limited. Field trials are likely to be needed in these areas to define treatment performance expectations and evaluate the

performance of alternative wetland plant species suited to the local climate. Careful adaptation would also be required for effluents with different treatment characteristics, such as, those pre-treated using different methods (e.g. barrier ditches) or using alternative farm dairy management systems to those normally employed in New Zealand (e.g. low volume yard-cleaning systems, or wastewater recycling systems).

Constructed wetland treatment of agricultural wastewaters is an emerging technology. Our studies have shown that standard empirical design guidelines developed for wetland treatment or domestic sewage are inappropriate for systems treating NZ farm dairy wastewaters. These guidelines cover the application of basic constructed wetland designs for NZ dairy farming conditions. However, new developments, such as the use of intermittently loaded vertical-flow beds (see Haberl et al. 1997), have the potential to provide enhanced treatment especially ammonia removal. It is therefore important that these guidelines are adapted in the light of new information and their existence does not stifle future innovation.

What are constructed wetlands?

The filtering functions of natural wetlands and their ability to remove sediments and pollutants from water passing through them are well known. Much of New Zealand's former wetland area has now been drained or extensively modified, often as a consequence of agricultural development. Constructed wetlands are designed to harness processes that occur in natural wetlands for the treatment of wastewaters. Construction of wetlands enables treatment performance per unit area of land to be optimised and ensures less variable discharge quality. It also avoids the contamination and degradation of remaining natural wetlands, although such areas may be appropriate for final discharge of more highly treated wastewaters, e.g. after constructed wetland treatment.

There are two main types of constructed wetlands (see Fig 1). *Surface-flow* constructed wetlands consist of shallow, sealed channels planted with

tall emergent wetland plants. *Subsurface-flow* constructed wetlands are sealed channels filled with permeable gravel, in which wetland plants grow hydroponically. Wastewaters are treated as they flow along these beds, passing through the shoots and/or root-zone of wetland plants (see fig. 1). Constructed wetlands are most appropriate as a supplementary treatment system for farm dairy wastewaters, after pretreatment in two-stage waste stabilisation ponds or similar.

The two main types of constructed wetland

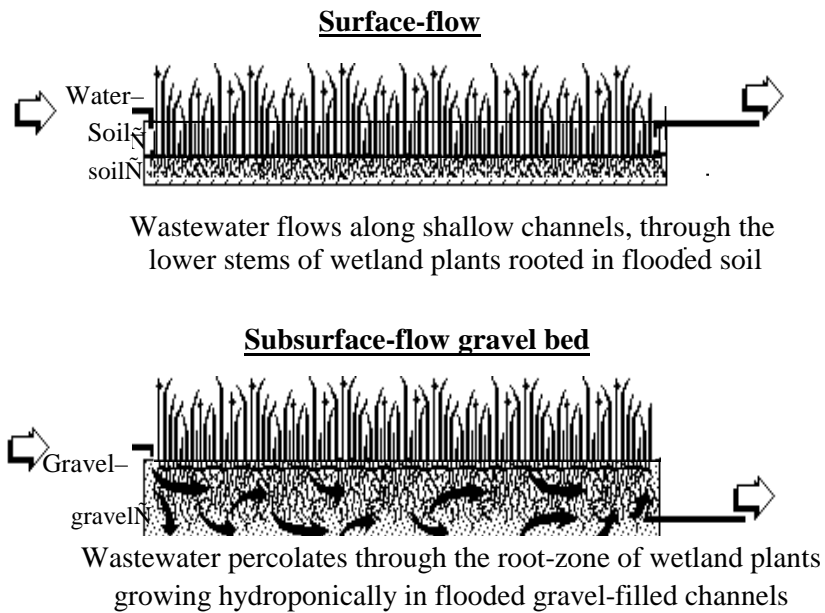


Figure 1: Basic constructed wetland designs

How do constructed wetlands work?

- *Particles settle out in shallow, slow-flowing waters.*
Settling and sedimentation of particulate material (suspended solids) occurs readily in the shallow, slow-flowing waters of wetlands. Wetland plants enhance particulate removal by dispersing water flow and stabilising sedimented material. They also shade the water surface, limiting the growth of algae which would contribute to suspended solids levels in the effluent.

- *Microbes break down the wastes.*
Microscopic organisms (bacteria, fungi, algae, and protozoa) break down organic matter, and mineralise and transform nutrients in the wastewater. In particular, microbial slimes (biofilms) which form on the extensive surface areas provided by plants, detritus, soils and, in the case of subsurface-flow wetlands, gravels, within the wetland rapidly assimilate organic substances and nutrients, enhancing removal and decomposition. The close association of oxygenated (aerobic) and oxygen-free (anaerobic) micro-environments in wetlands promote sequential microbial transformations of organic matter and nutrients (e.g. nitrogen and sulphur) to gases such as carbon dioxide, methane, dinitrogen, nitrous oxide, and hydrogen sulphide, which are released back to the atmosphere.

- *Plants take up nutrients for their growth and return them back to the wetland in organic forms when they die.*
Nutrients taken up by plants are recycled both by internal redistribution within plants and by leaching and mineralisation of litter fall, with a proportion becoming locked up within the detritus pool of the wetland. At normal wastewater application rates, nutrient uptake and storage by wetland plants, generally only accounts for a small proportion (5-10 % on an annual basis) of the observed nutrient removal of the system. Harvesting of plant biomass is therefore not advocated as an effective nutrient removal strategy, and is not generally required for effective operation or vegetation management.

Plants also produce organic exudates, leachates, litter and humic compounds which provide substrates for microbial metabolism and adsorb and complex with organic and inorganic compounds.

- *Plants act like snorkels, enhancing oxygen supply in their root-zones.*
Wetland plants have adapted to life in flooded soils by developing internal ventilation systems to oxygenate their submerged tissues. This assists treatment processes by transporting oxygen down to the plant's root-zone, forming a mosaic of aerated microzones in the sediment.

Requirements for effective constructed wetland treatment

1. Adequate pretreatment– the minimum for dairy farm wastewaters is a properly sized, designed and maintained waste stabilisation pond system, operating within the normal range of treatment performance for farm dairy pond systems (see Table 2, p.21).
2. Sufficient wetland area to treat the waste load to the required discharge quality. Generally the larger the wetland area the better the level of treatment that will be achieved.
3. Simple and robust design able to cope with variations in wastewater loadings and adapted to the specific site conditions, and careful construction using appropriate techniques.
4. Sealing of wetland base to limit infiltration losses and groundwater additions, and exclusion of stormwater. Sufficient effluent flow to ensure year-round survival of wetland plants.
5. Appropriate shape and depth to promote plug flow, minimise short-circuiting and maintain required flow velocities, and allow the establishment and long-term survival of wetland plants.
6. Appropriate timing and initial care of plantings (including pukeko management) to ensure rapid establishment. Planting with species

that are hardy and easy to grow, and largely self-maintaining once established, providing a dense sward of vegetation through the year.

7. Fencing to exclude grazing and trampling of the wetland by livestock.
8. Regular checking and maintenance to ensure correct operation of all stages of the treatment system.
9. Appropriate siting to meet dairy hygiene requirements (>45 m away from farm dairy), ensure site stability, avoid contamination of potable water sources, and co-ordinate with other land uses.

evaluation of constructed wetland treatment options

This section overviews the issues that need to be considered in evaluating constructed wetland treatment for a particular farm situation. The flow-chart included, summarises the key issues that need to be taken into account.

What level of treatment do you need?

Constructed wetlands can be sized and designed in different ways to fulfil a range of different treatment requirements. Within practical constraints, generally the larger the wetland area employed the greater the level of treatment that can be achieved. Figure 2 overviews the three treatment options presented in these guidelines. These have been chosen to cover the likely range of practical treatment levels achievable using constructed wetlands, and the requirements of the Resource Management Act 1991. The preparation of Regional Plans (and Rules), in many regions of New Zealand, during the next few years will define regional treatment requirements further.

Expected effluent qualities for each treatment option are summarised in Table 2. Treatment level 1, utilises simple and relatively low-cost surface-flow wetlands to provide a basic level of treatment and effluent quality buffering. Higher levels of treatment (level 2) are provided using larger wetlands which include final subsurface-flow, gravel-bed sections. Here the permanent matrix provided by the gravel provides enhanced, more consistent treatment performance.

Treatment option 3 provides the highest level of treatment, combining mechanical aeration with constructed wetlands. Mechanical aeration, although widely practised in sewage and industrial treatment, is a relatively new concept for New Zealand dairy farms. Recent studies carried out by NIWA for the Dairy Research Institute have shown that mechanical aeration of the second (facultative) pond of standard farm dairy systems can markedly improve treatment performance. In addition to providing improved removal of BOD, these systems can substantially reduce toxic ammonia levels in pond discharges, converting them to the nitrate form. Constructed wetlands offer a valuable means of

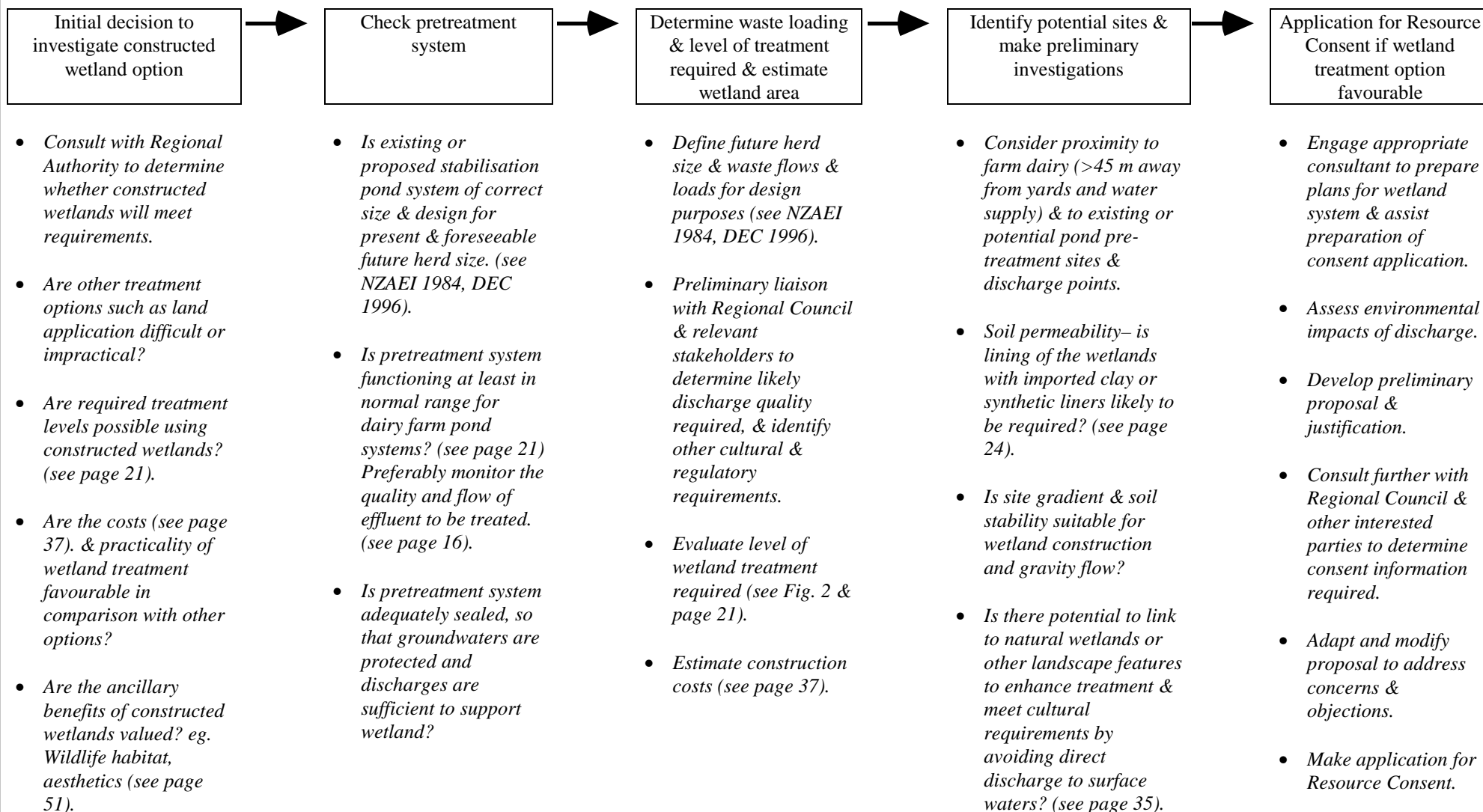
supplementing such systems, by further reducing suspended solids, nitrate and faecal bacterial levels and buffering final water quality. Used together, these systems offer the capability of achieving very high levels of treatment.

At the time these guidelines were being prepared standard guidelines for mechanical aeration of farm dairy ponds were not yet available. The expected performance of mechanically aerated ponds has therefore been conservatively estimated based on data from field studies of continuously aerated farm dairy ponds (Sukias et al., 1995, 1997).

Is pretreatment adequate?

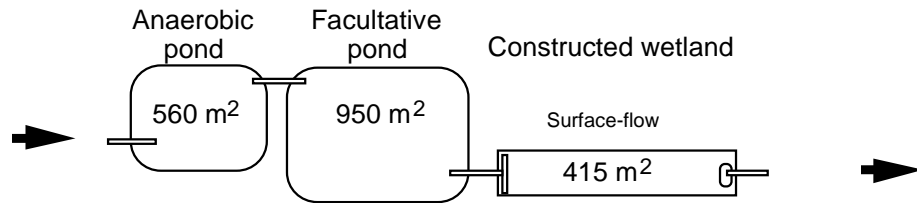
The wetland design guidelines given in this document presume “normal” farm dairy effluent quality and flows from a standard 2-pond waste stabilisation system. Effluent quality and flow from the actual farm system should at least be checked to determine whether it fits within the range suitable for constructed wetland treatment (see Table 2). Preferably appropriate monitoring of existing discharges should be carried out to aid design. This would require sampling on 4-6 occasions at one to two-monthly intervals during the main milking season. Samples need to be taken in clean containers, refrigerated (4°C), and analysed within 24 hours (preferably < 8 hrs) for BOD (biochemical oxygen demand), SS (suspended solids) and ammonium nitrogen or TKN. Regional Councils can generally assist with information on analytical services and costs. Additional variables may be required where specific discharge conditions need to be met. Where monitoring data shows values outside the suggested range given in Table 2, wetland sizing should be adjusted to achieve the specified mean areal mass loadings. Effluent flows also need to be checked to ensure that they are sufficient to support the establishment and survival of the wetlands.

Overview for preliminary investigation and planning of constructed wetland treatment system for dairy farm wastewaters.



Key Design Options - Based on hypothetical 200 cow dairy herd

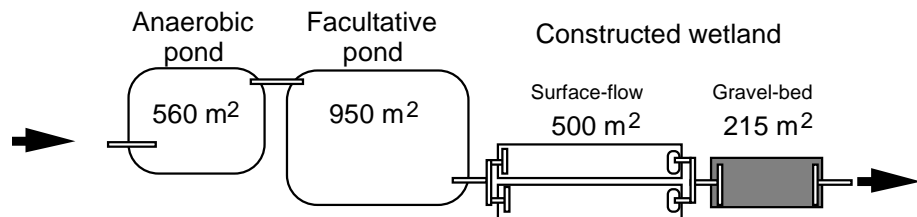
Treatment Level 1: Standard pond system plus small constructed wetland



Addition of a small surface-flow constructed wetland will provide basic buffering of flow and water quality

- 30-70% additional removal of BOD and suspended solids over ponds alone
- 70-85% additional removal of faecal coliforms
- Potentially suitable for discharge to rivers and large streams with high assimilation capacity (providing 100-110 fold dilution*) or indirect discharge via farm drainage systems, natural wetlands (see p35) etc.

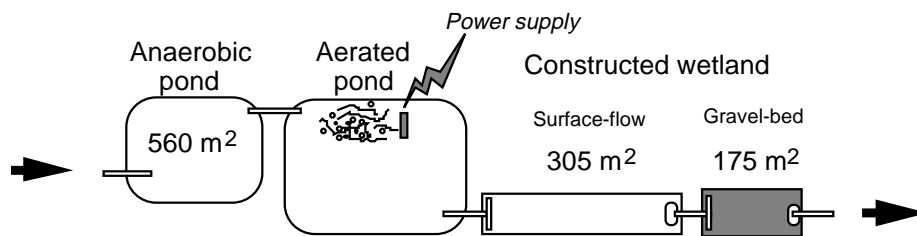
Treatment Level 2: Standard ponds plus surface-flow and gravel-bed constructed wetlands



Addition of a combined surface-flow and gravel-bed constructed wetland will provide a moderate level of treatment and buffering of flow and water quality

- 60-75% additional removal of BOD and suspended solids over ponds alone
- 35-50% additional removal of total ammonia and total nitrogen
- 85-95% additional removal of faecal coliforms
- Potentially suitable for discharge to moderate to large streams (providing 65-85 fold dilution*) or indirect discharge (as above).

Treatment Level 3: Mechanical aeration plus constructed wetlands



Addition of a constructed wetland in association with aerated second pond will provide a high level of treatment. The constructed wetland will, in particular, enhance suspended solids, total nitrogen, and faecal coliform removal from aerated pond systems

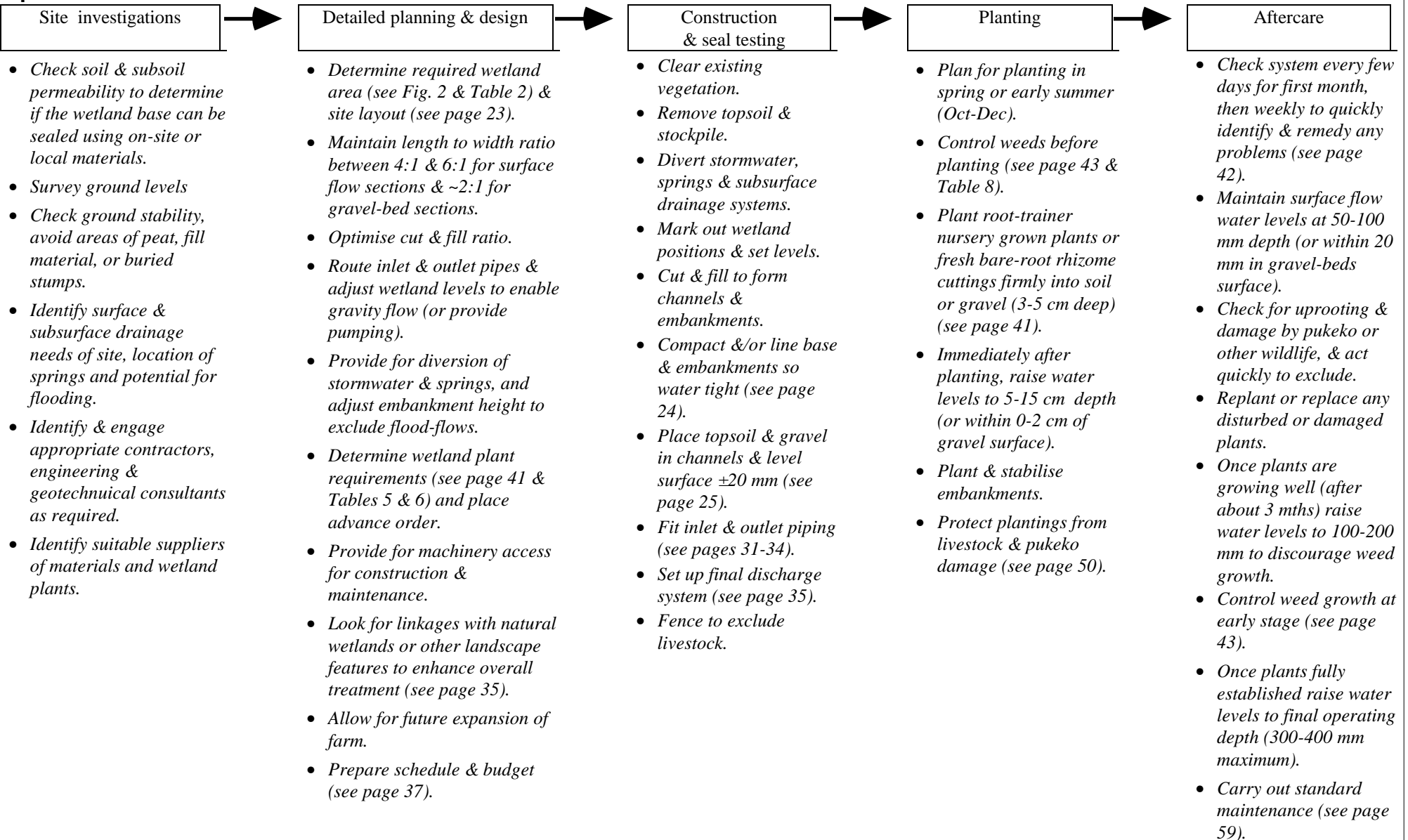
- A combined aerated pond and constructed wetland would be expected to remove:
- 70-80% more BOD and suspended solids than a standard two-pond system
 - 65-80% more total ammonia and total nitrogen
 - 85-90% more faecal coliforms
 - Potentially suitable for discharge to small to moderate sized streams (providing over 20-fold dilution*) or other sensitive receiving waters.

Fig 2: Three treatment options for farm dairy pond upgrading using constructed wetlands. See Tables 2 and 3 in following section for details of treatment levels and basis of wetland sizing). Pond sizing is based on DEC (1996) guidelines for the upper half of the North Island.

* Suggested receiving water dilution requirements are based on guidelines for BOD, SS, NH₄-N, and maximum faecal coliform levels recommended for stock drinking water as outlined in Sukias et al. (1996). Higher dilutions may be necessary to meet guidelines for nutrient limitation in sensitive catchments or faecal contamination guidelines for human contact recreation. Regional councils may require different dilution levels (higher or lower) to meet their specific objectives.

design and construction specifications

Overview of constructed wetland planning, construction, planting and aftercare



Levels of constructed wetland treatment

Table 2: Treatment expectations for the three constructed wetland design options (Treatment levels 1-3). See Fig. 2 for summary of treatment level options, and Table 3 for details of wetland sizes and design.

All concentrations are g m^{-3} (= mg l^{-1} or ppm), except FC, number of colony forming units (100 mls) $^{-1}$.

Pretreatment in standard two-stage waste stabilisation ponds

Pollutant*	Pond discharge	Treatment level 1			Treatment level 2		
	Mean annual concentration†	Mean areal mass loading ($\text{g m}^{-2}\text{d}^{-1}$)	Mean annual effluent concentration	Mean annual percentage removal in wetland	Mean areal mass loading ($\text{g m}^{-2}\text{d}^{-1}$)	Mean annual effluent concentration	Mean annual percentage removal in wetland
BOD	80-120	1.9-3.0	30-70	35-50	1.1-1.7	25-50	60-75
SS	150-250	3.6-6.0	60-140	40-65	2.0-3.5	35-65	70-75
TN	80-120	1.9-3.0	55-85	15-35	1.1-1.7	40-70	40-50
NH ₄ -N	60-100	1.4-2.4	45-75	10-30	0.8-1.4	30-65	35-50
CNBOD	425-640	10-15	270-450	30-40	6-9	180-350	45-65
TP	20-35	0.5-0.85	17-33	5-15	0.3-0.5	16-30	10-25
FC	30,000-100,000	-	5,000-30,000	70-85	-	2,000-15,000	85-95

Pretreatment in mechanically aerated waste stabilisation ponds

Pollutant*	Pond discharge	Treatment level 3		
	Mean annual concentration††	Mean areal mass loading ($\text{g m}^{-2}\text{d}^{-1}$)	Mean annual effluent concentration	Mean annual % removal in wetland
BOD	30-40	0.6-0.9	20-30	20-30
SS	100-150	2.1-3.2	40-60	50-70
TN	50-100	1-2.1	25-40	40-60
NH ₄ -N	10-30	0.2-0.65	6-20	40-60
NO ₃ -N	30-60	0.6-1.3	6-18	70-80
DIN	40-90	0.8-1.9	12-30	60-70
CNBOD	120-220	2.5-4.6	95-140	20-40
TP	20-35	0.4-0.73	17-30	10-20
FC	30,000-100,000	-	3,000-15,000	85-90

*Pollutant abbreviations

BOD	=	Standard (carbonaceous) biochemical oxygen demand based on 5 day test with nitrification inhibited.
SS	=	Suspended solids.
TN	=	Total nitrogen (Total Kjeldahl N + NO ₃ -N + NO ₂ -N).
NH ₄ -N	=	Total ammoniacal nitrogen.
NO ₃ -N	=	Dissolved oxidised N (NO ₃ -N + NO ₂ -N).
DIN	=	Dissolved inorganic nitrogen (NH ₄ + NO ₃ -N + NO ₂ -N).
CNBOD	=	Total carbonaceous and nitrogenous biochemical oxygen demand. NBOD can be calculated as 4.33 times (NH ₄ -N + mineralisable organic N).
TP	=	Total phosphorus. Approx. 70-80% of TP in constructed wetland effluents likely to be in dissolved reactive forms.
FC	=	Faecal coliforms, an indicator of faecal pathogen levels.

† Based on data of Hickey et al. (1989).

†† Presumed discharge quality from aerated pond system.

Wetland size recommended

Table 3: Recommended sizing of constructed wetlands to achieve three different levels of waste water treatment. See Table 2 for information on presumed influent quality and predicted treatment performance.

Recommended wetland treatment areas ^a (m ²)								
Herd size*	Daily wastewater volume** (m ³ d ⁻¹)	Treatment level 1 ^b (2.1 m ² cow ⁻¹)	Treatment level 2 ^c (3.6 m ² cow ⁻¹)			Treatment level 3 ^d (preceeded by mechanically aerated pond) (2.4 m ² cow ⁻¹)		
		Surface-flow	Surface-flow	Gravel-bed	Total area	Surface-flow	Gravel-bed	Total area
100	5	210	250	105	355	150	90	240
120	6	250	300	130	430	185	105	290
140	7	290	350	150	500	215	125	340
160	8	335	400	170	570	245	140	385
180	9	375	450	195	645	275	160	435
200	10	415	500	215	715	305	175	480
250	12.5	520	625	270	895	380	220	600
300	15	625	750 [†]	320	1070	455	265	720
350	17.5	730	875 [†]	375	1250	535	305	840
400	20	835 [†]	1000 [†]	430 [†]	1430	610	350	960
450	22.5	940 [†]	1125 [†]	480 [†]	1605	685	395	1080
500	25	1045 [†]	1250 [†]	535 [†]	1785	760 [†]	440 [†]	1200

* These wetland sizings based only on normal waste loads from twice daily milking (i.e. approx. 5-10% of total waste production).

** Influent to constructed wetlands estimated as 0.05 m³ cow⁻¹ d⁻¹. Where possible constructed wetlands should be designed on the basis of actual farm effluent flows and quality.

^a Areas apply to actual wetland area at mid-depth. Treatment volume assumed to be 80% of constructed volume for surface-flow wetlands (i.e. 20% occupied by plant shoots, sludge and litter accumulations), and 35% of constructed volume for gravel-bed wetlands (i.e. 35% effective porosity).

^b Based on a retention time of 10 days in the surface-flow wetland (ave. depth 0.3 m), giving a nominal areal hydraulic loading of 24 mm d⁻¹.

^c Based on a retention time of 12 days in a surface-flow wetland (ave. depth 0.3 m) followed by 3 days in gravel-bed wetland (ave. depth 0.4 m), giving nominal areal hydraulic loading of 14 mm d⁻¹.

^d Based on a retention time of 8 days in a surface-flow wetland (ave. depth 0.3 m) followed by 2 days in gravel-bed wetland (ave. depth 0.4 m), giving a nominal areal hydraulic loading of 21 mm d⁻¹.

[†] Division into two parallel cells is recommended.

Design

Constructed wetland design objectives include the following:

- Flexibility and versatility, to enable operation in a number of different modes, at a range of water levels and flows.
- Simplicity of construction and operation. Control structures should be easy to operate, and require minimal day to day maintenance.
- Provision for maintenance works to be carried out easily and quickly.

It is important to seek appropriate professional advice regarding site suitability, stability, the need for detailed geotechnical assessment on steep or unstable sites, and the preparation of specific design plans.

The following drawings illustrate design and construction details for constructed wetlands. The recommended construction sequence is shown in Drawing 1 and a simplified basic site layout in Drawing 2. Drawings 3 and 4 give long and cross section plans for surface-flow wetland channels, while Drawing 5 shows details specific to gravel-bed wetlands. The standard and alternative inlet and outlet structures and piping arrangements considered most suitable for farm constructed wetland application are detailed in Drawings 6-10. Key design principles include:

Channel shape and length to width ratios

It is important to strike a balance between achieving plug flow hydraulics and even flow distribution, and ensuring that the cross sectional area is hydraulically capable of passing the required flows (particularly relevant for gravel wetlands). A length to width ratio in the range of 4:1 to 6:1 will generally provide an appropriate balance for the surface-flow systems proposed in these guidelines, at minimal construction cost. A length to width ratio of around 2:1 is suggested for gravel-bed wetlands. Provision of two or more parallel wetland cells is advisable in larger systems, offering the potential for cells to be isolated and water levels altered individually to facilitate maintenance, without affecting overall system operation. Such multi-cell systems may allow more efficient use of space

on confined or sloping sites. Gravel-bed wetlands used in combination with surface-flow wetlands (Treatment levels 2 and 3) are generally best constructed as separate beds to enable individual adjustment of water levels. This allows conditions for plant establishment to be optimised and gives greater operational flexibility. Where there is insufficient head to provide for gravity flow between separate beds, they can be combined. However, plant establishment will generally have to be done in two stages (surface-flow first, then gravel-bed) to provide suitable water depths for growth in each of the systems.

The shape of wetland channels can be altered within reasonable limits to provide a more natural shape that fits better into the surrounding landscape and enhances wildlife habitat (see landscaping section). To ensure efficiency of treatment only gentle curves should be used, taking care not to create stagnant backwaters. Widths along the channels should not vary more than $\pm 20\%$ for surface-flow sections and $\pm 10\%$ for gravel-bed sections from those specified. Additional treatment area should be allowed for any shape modifications beyond these limits.

Inlet distribution system

The inlet system is designed to achieve even distribution of the flow across the entire wetland channel. This provides the most effective use of the wetland area, and minimises overloading and excessive sludge accumulation in the inlet zone. It is important that the inlet pipe is laid level so that inflows are dispersed evenly across the channel using the adjustable tee pipes for final balancing of flows. Drawing 6 illustrates the simplest option, where the inlet pipe is laid directly on the coarse gravel inlet zone. Alternatively (Drawing 7), the pipe can be strapped to a sturdy timber support, reducing the chance of blockages by wetland plant and weed growth, and facilitating easier visual checks of inflow system performance. This option, however, requires greater available head to enable gravity flow to and from the wetland.

Outlet Structures

Outlet structures allow the depth of the water in the wetland to be controlled. This is required to:

- * Assist plant establishment by allowing water levels to be raised gradually as the young plants mature. This ensures that developing plant shoots do not dry out or drown.
- * Allow water levels to be lowered to facilitate weed control, maintenance, and any structural or pipework repairs.
- * Allow water levels to be gradually increased to maintain optimum detention times and treatment efficiencies as sludge and plant detritus levels build up in mature wetland systems.

A swivelling outlet pipe system has been specified which allows simple water level adjustment and low clogging potential. The swivel pipe should be contained within a perforated concrete sump unit or alternatively an H5 treated timber box unit (see Drawings 8 and 9) both set in a coarse gravel zone. A close-fitting lid will reduce potential blockages from plant litter accumulations or algal growth within the sump and pipe-work. For gravel-beds greater than 10 m in width an alternative slotted pipe outflow collector (see Drawing 10) is required to maintain even hydraulic flow across the width of the bed.

Wetland channel construction

The equipment recommended for on-farm construction of the embankments is an hydraulic excavator for earth moving and placement, and a rubber-tyred tractor towing a sheepsfoot roller for compaction. Embankment materials should be spread and compacted in layers of no more than 200 mm thickness.

Other alternatives include the use of a tractor and a scoop for the earth moving, and forming and trimming batters, however, in this case it is necessary to operate a second tractor towing a sheepsfoot roller, to

ensure that the compactive effort keeps pace with the rates of earth moving. A rubber-tyred farm tractor on its own is not sufficient to provide suitable compaction for the embankments.

Where there are porous areas of soil, or the wetland is to be built above ground, then key trenches are required under the embankments. These key the embankment into the soil layer below, providing structural integrity and preventing seepage. As for the embankments, key trenches should be filled with thoroughly compacted clay spread in layers of no more than 200 mm depth.

Clay liner

The base and sides of the wetland channel must be sealed with a suitable material to ensure that the wetland is water tight. This is important to minimise pollution of groundwater and ensure sufficient water is retained in the wetland for the survival of the wetland plants.

Suitable clay obtained from on-site is typically used for this purpose, and spread and compacted to form a final compacted thickness of 150 mm. It is important to keep this clay liner moist so that it does not dry and crack before the wetland is filled with water. The water tightness of the wetland channels can then be tested by filling with water and monitoring the drop in water level. This should be done prior to planting (see design Drawing 3)

If suitable clay is not available on-site, then clay for sealing can be imported to site or alternative liners with acceptable watertightness, durability, strength, and resistance to ultra-violet light can be selected. Generally, alternative lining options are considerably more expensive than the use of a clay liner. Examples of suitable alternative liners include high density polyethylene (thickness greater than 1 mm), polypropylene (thickness greater than 0.75 mm) or products containing bentonite clays (see appendix for suppliers).

Any alternative liner used must be able to cope with the loads applied during installation of the liner itself and also with the loads applied during placement of gravel, topsoil and planting. Manufacturers and suppliers specifications must be followed closely to ensure joints are watertight, preparation of the subgrade is carried out properly and the installed liner is protected as required.

Topsoil

Topsoil should be initially removed from the construction site and stockpiled, taking care to exclude lumps of turf, tree roots etc. This can then be respread in the base of the surface-flow section of the wetland after the embankments and clay liner have been completed. Lime should be incorporated into the soil at a rate of 0.2-0.3 kg m⁻² (2-3 tonnes ha⁻¹) to reduce potential toxicity to plants after flooding. Where possible it is also advisable to allow the flooded soil to stabilise for a period of 2-4 weeks before planting is undertaken. The soil should be carefully levelled (± 20 mm) across the base of the wetland channel and lightly compacted. Poor attention to levelling often results in patchy plant establishment, as some plants become drowned while others are left high and dry.

Gravel

It is important that good quality gravel is used, so that it does not crush, crumble and degrade into fine particles. It is also important that the size range is as specified to provide sufficient hydraulic conductivity and enable the proper growth and spread of wetland plant rhizomes and roots.

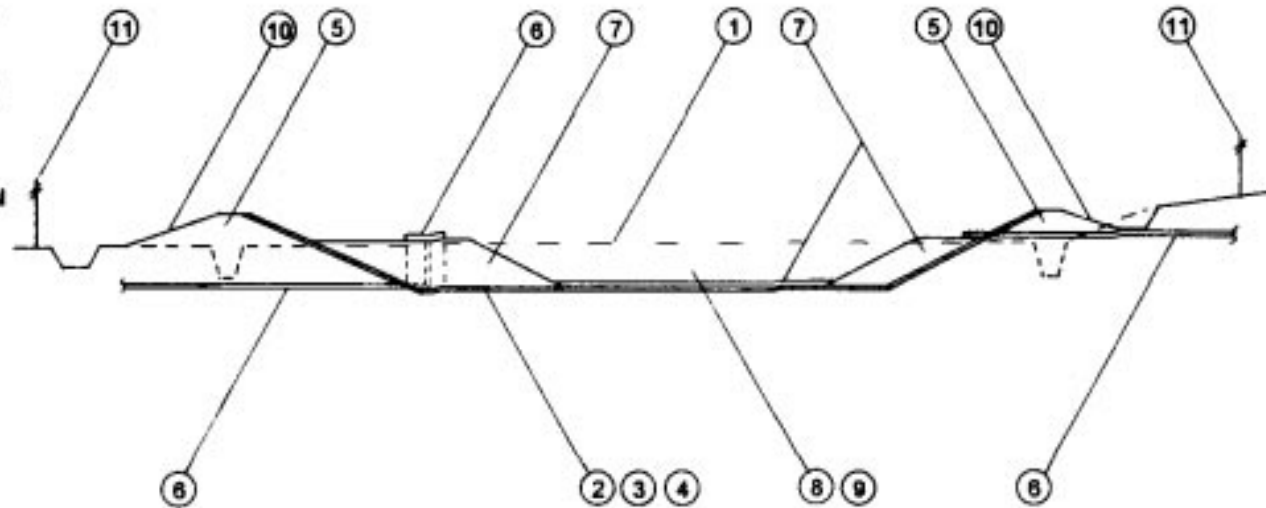
The gravel zones around the inlet and outlet structures and the main bed of gravel wetlands require coarse 65/40 mm clean hard gravel with no fines. A 150 mm layer of finer 20/12 mm gravel is used on the surface of gravel-bed wetlands to provide a suitable medium for plant growth. The surface of the gravel should be carefully levelled (± 20 mm) to ensure suitable water levels can be maintained for even plant growth. The water itself can be used as an accurate levelling device, by temporarily

flooding the bed to just above the gravel surface. Any low or high spots can then be readily identified and relevelled.

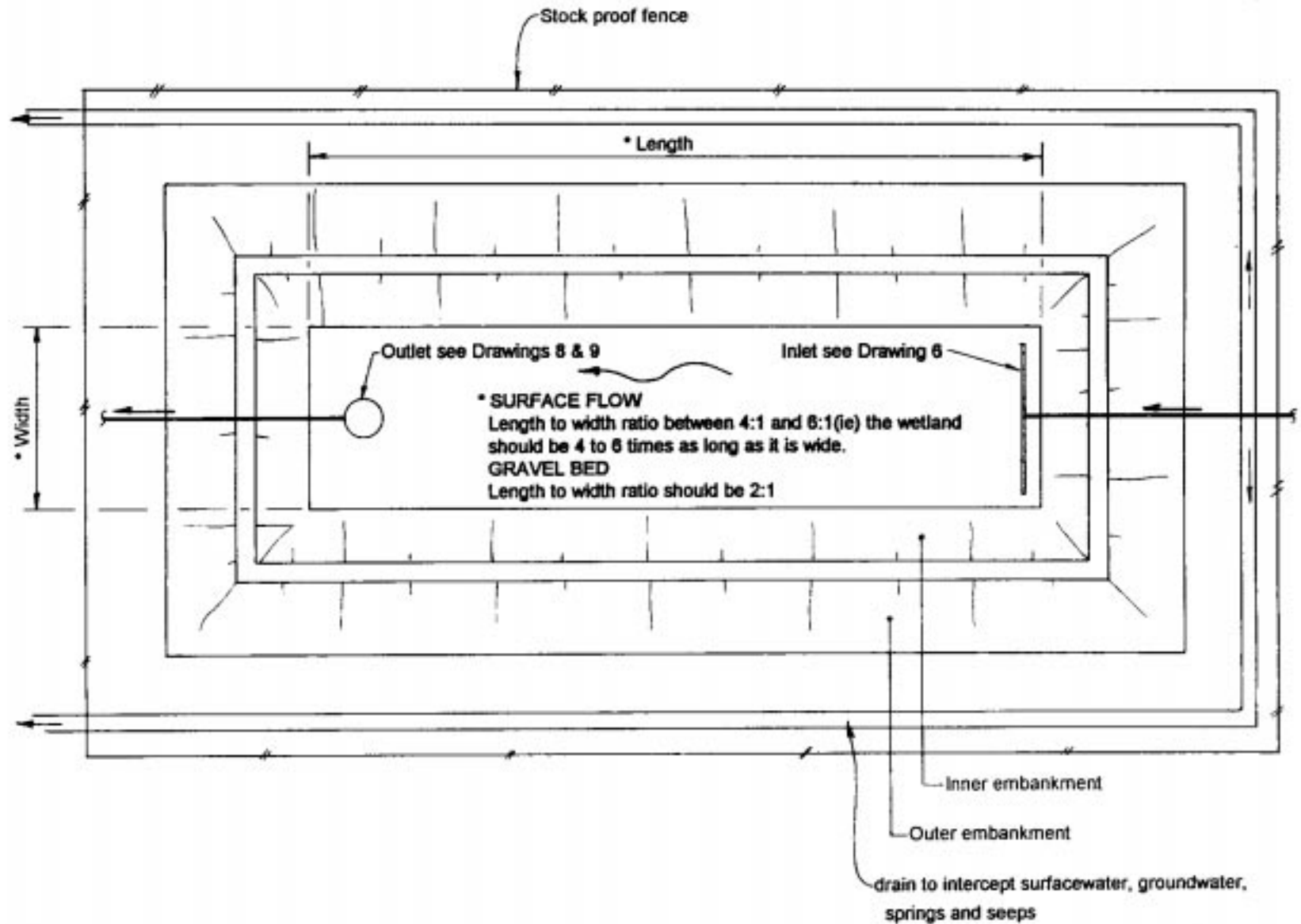
Particular care needs to be taken to ensure the gravel does not become contaminated or clogged by soil either during or after construction (e.g. due to embankment erosion). This will reduce its hydraulic conductivity, causing surface flooding and poor treatment performance.

Drawing 1: Construction sequence

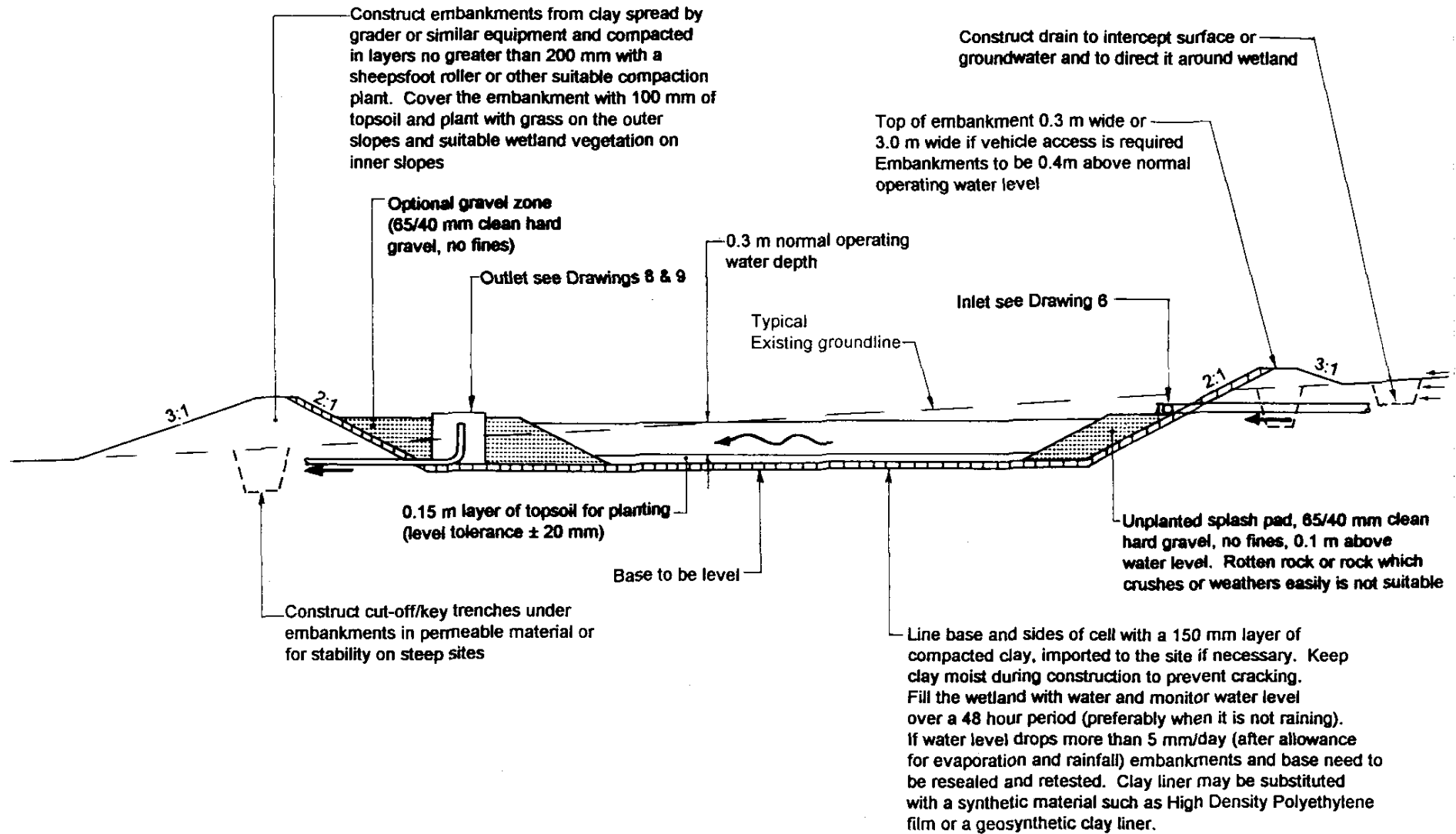
- 1 Strip vegetation and topsoil from wetland site and stockpile for later use.
- 2 Excavate any unsuitable base material.
- 3 Excavate wetland using any suitable material for embankment construction - see Long Section.
- 4 Construct clay liner using excavated material, if suitable or imported material. Clay liner may be substituted with a synthetic material - see Long Section.
- 5 Construct embankments using excavated material if suitable or imported material.
- 6 Lay all inlet and outlet pipes and water test pond.
- 7 Place and level topsoil and gravel zones in base of wetland.
- 8 Plant wetland plants in topsoil and fill with water to top of topsoil layer.
- 9 Maintain water level as plants grow to ensure that plant roots stay saturated but the cut stems are never submerged.
- 10 Topsoil outer slopes of embankments and regrass. Plant inner slopes - see Table P2
- 11 Fences should be erected around entire wetland including embankments to exclude stock.



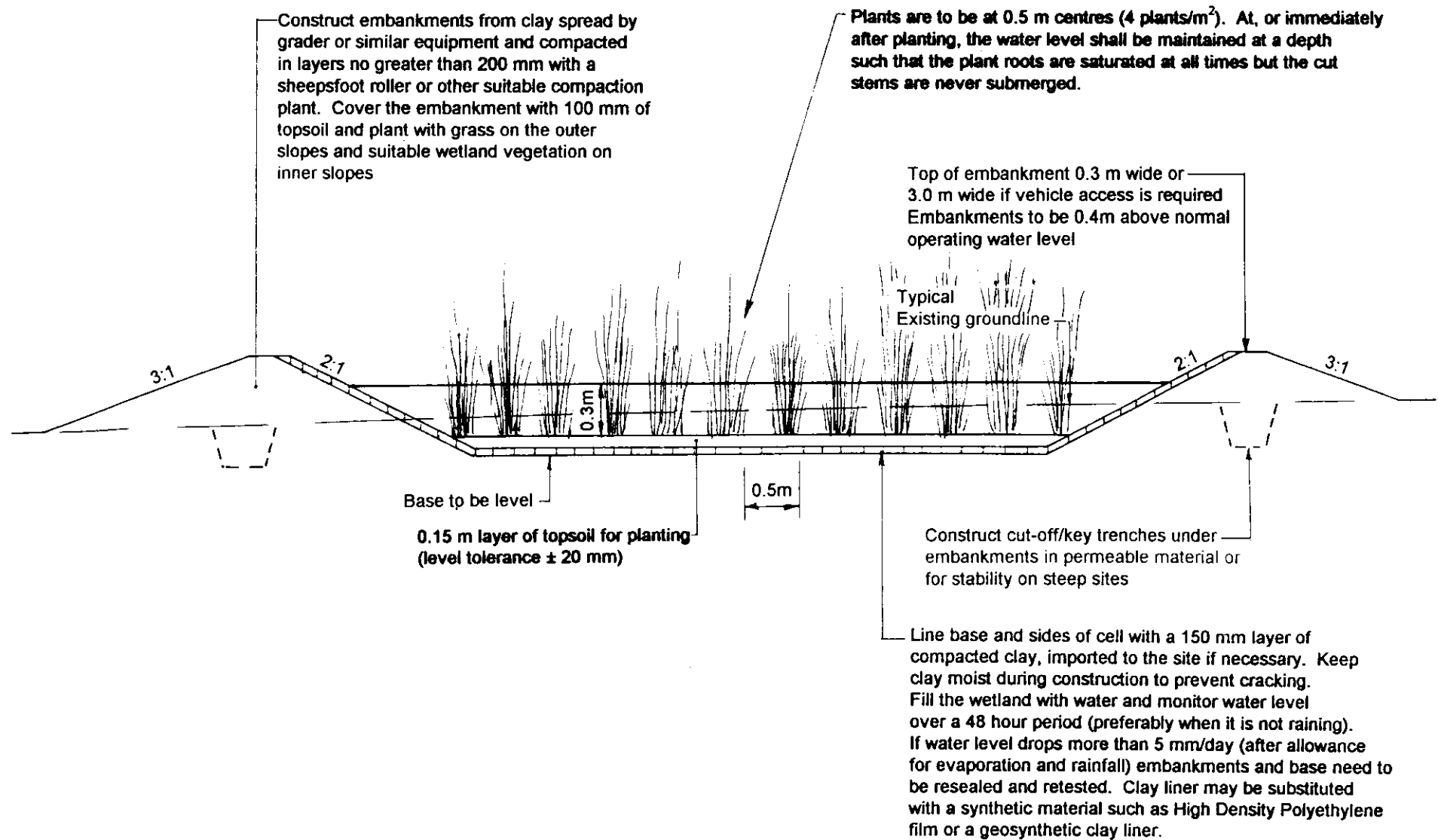
Drawing 2: Basic site design and layout



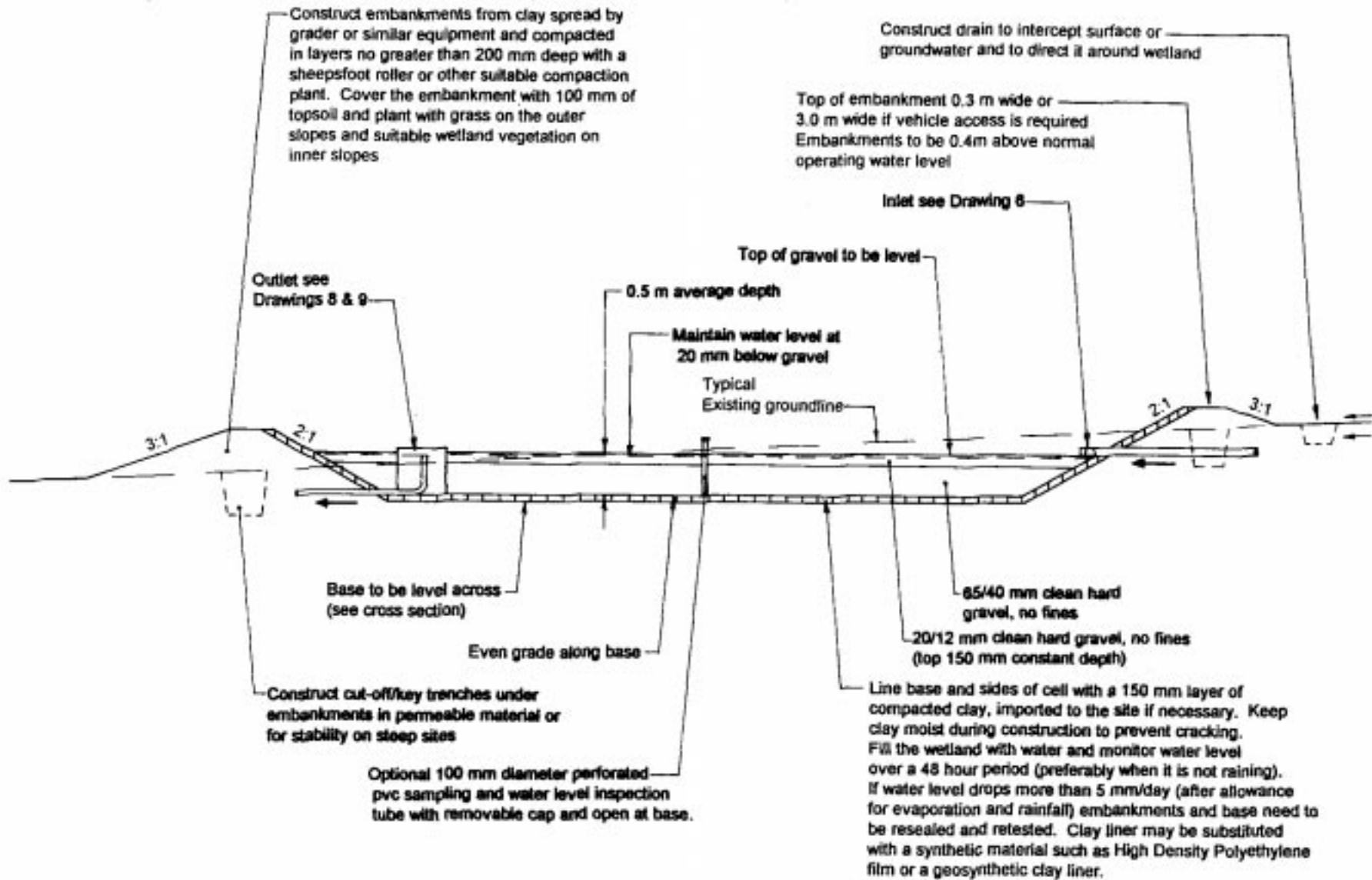
Drawing 3: Surface-flow wetland channel—long section



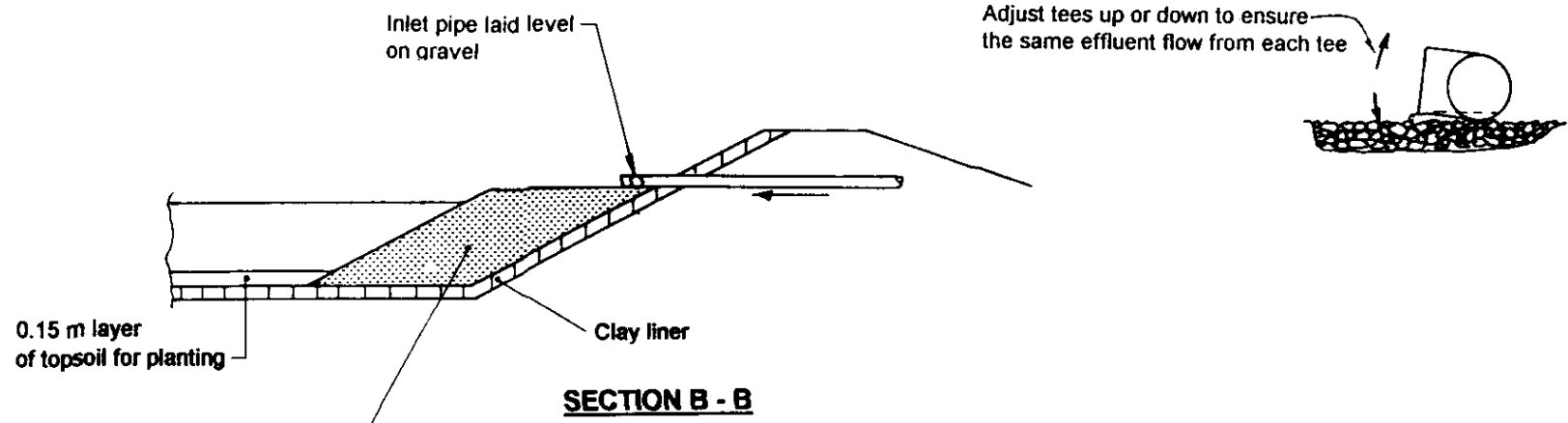
Drawing 4: Surface-flow wetland channel—cross section



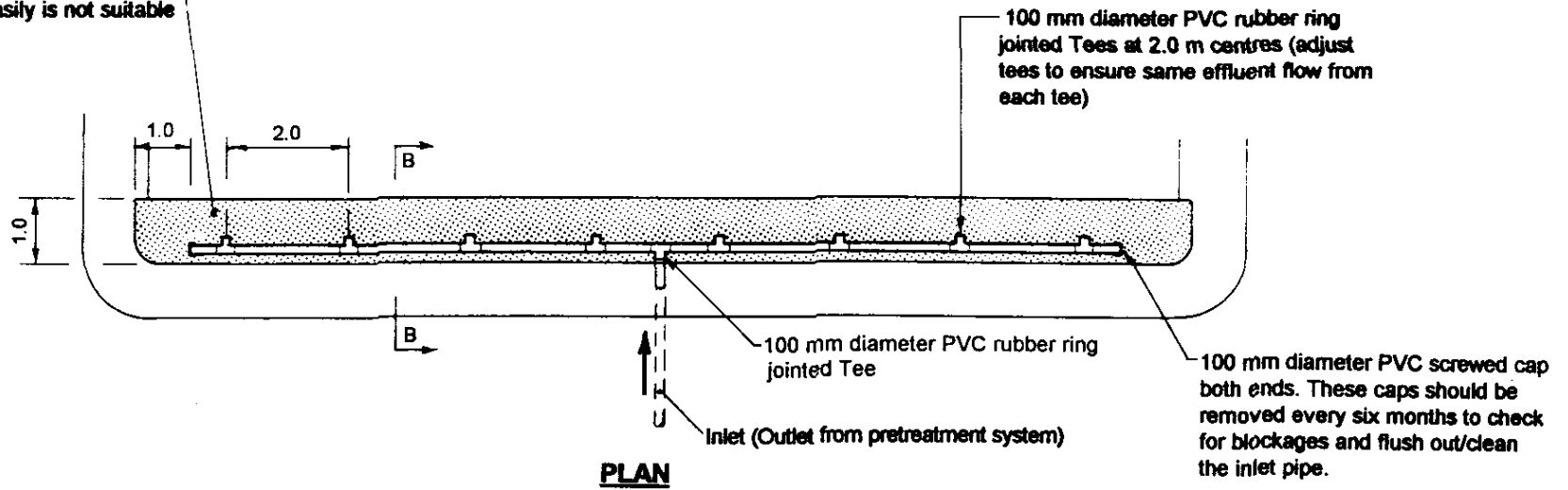
Drawing 5: Gravel-bed wetland channel—long section



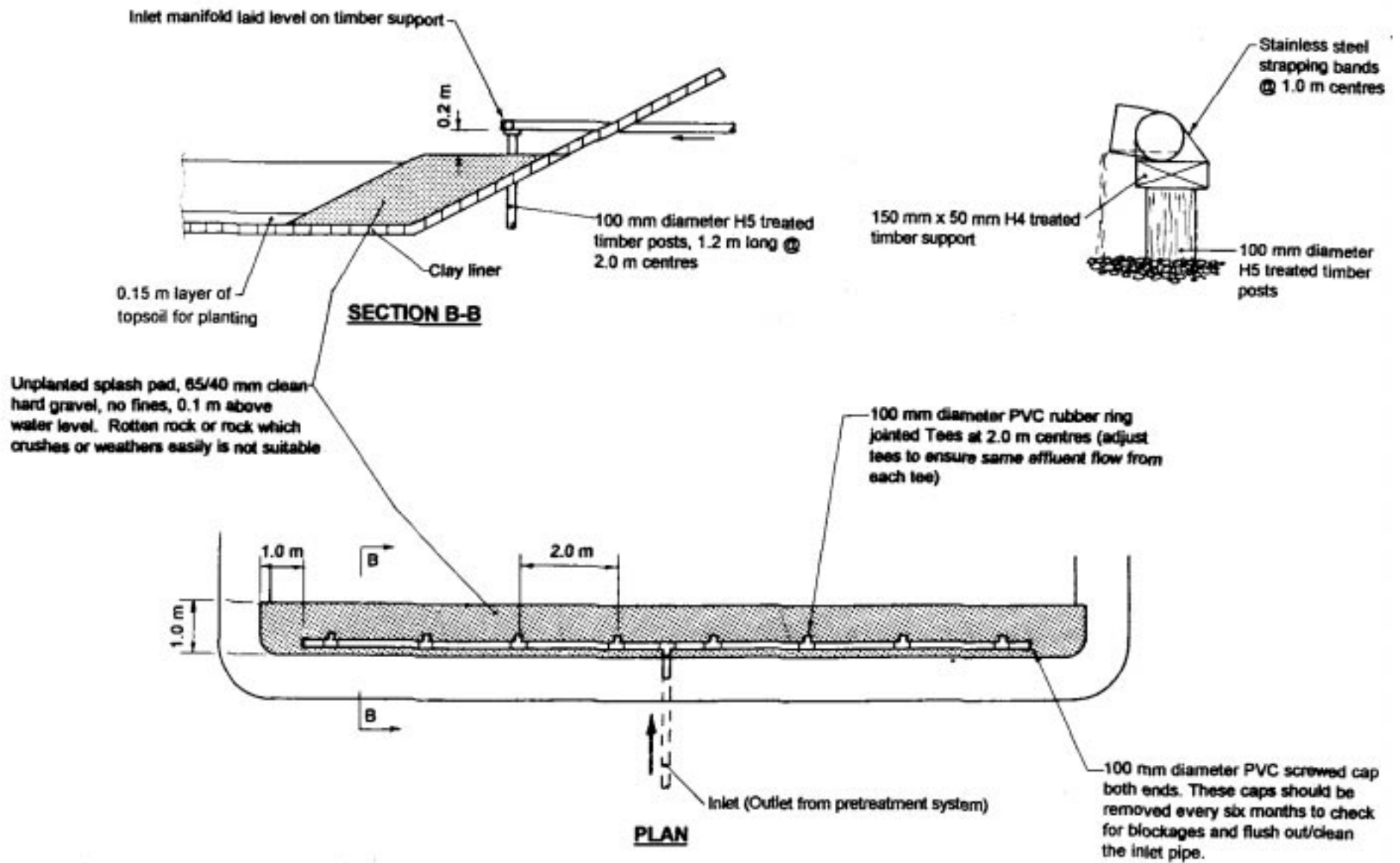
Drawing 6: Standard Inlet structure



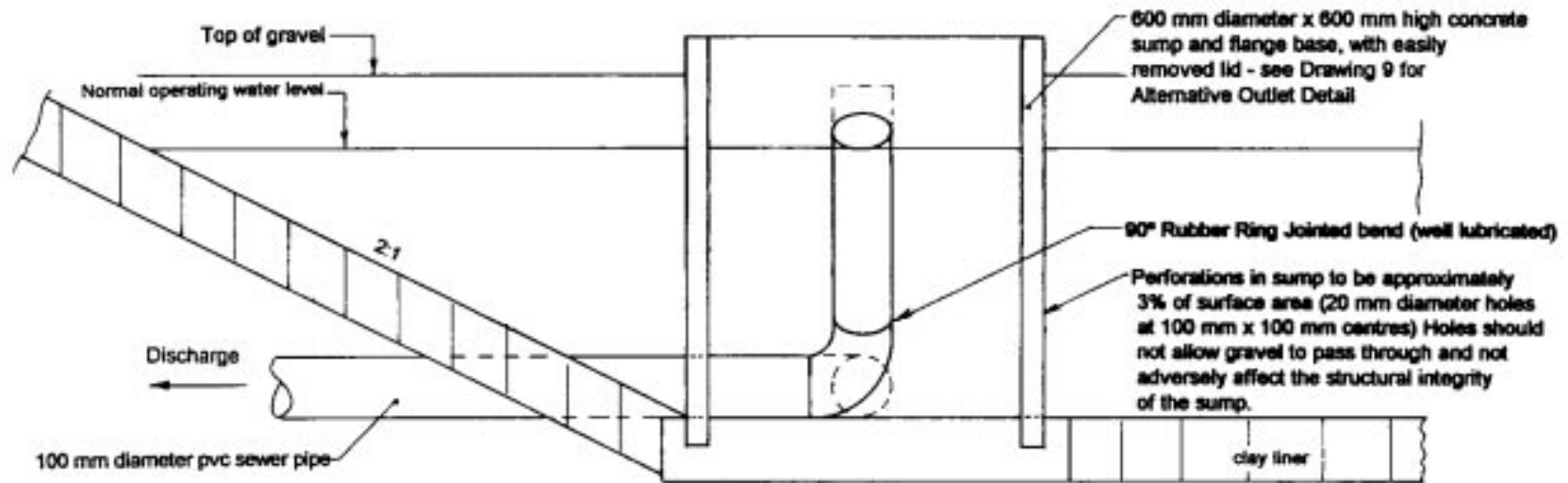
Unplanted splash pad, 65/40 mm clean hard gravel, no fines, 0.1 m above water level. Rotten rock or rock which crushes or weathers easily is not suitable



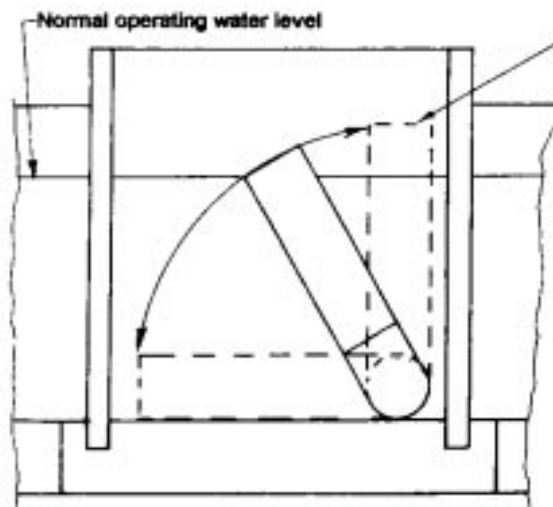
Drawing 7: Alternative inlet structure using timber supports



Drawing 8: Standard Outlet structure



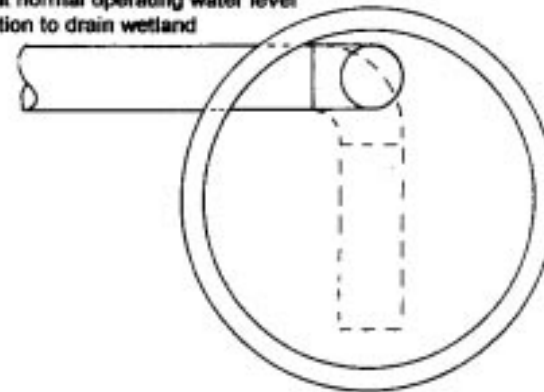
ELEVATION



ELEVATION

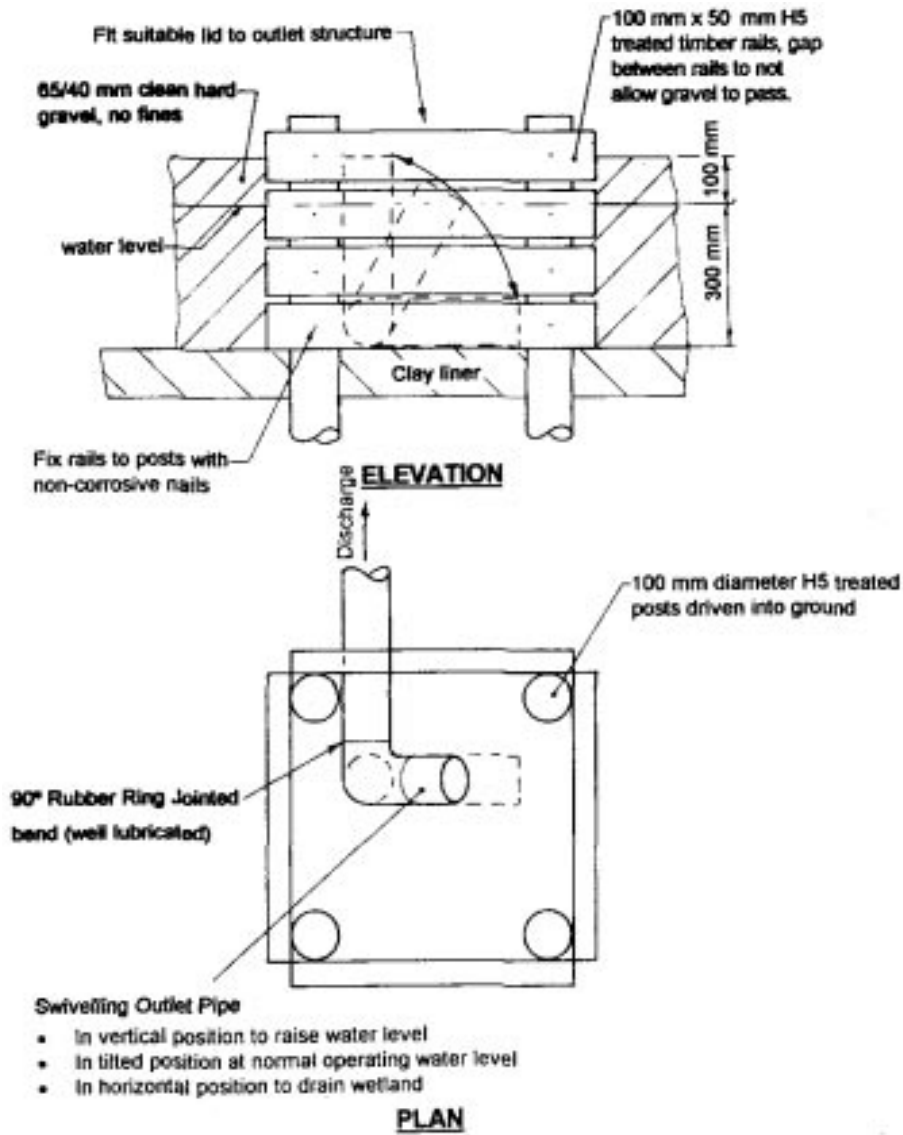
Swivelling Outlet Pipe

- In vertical position to raise water level
- In tilted position at normal operating water level
- In horizontal position to drain wetland

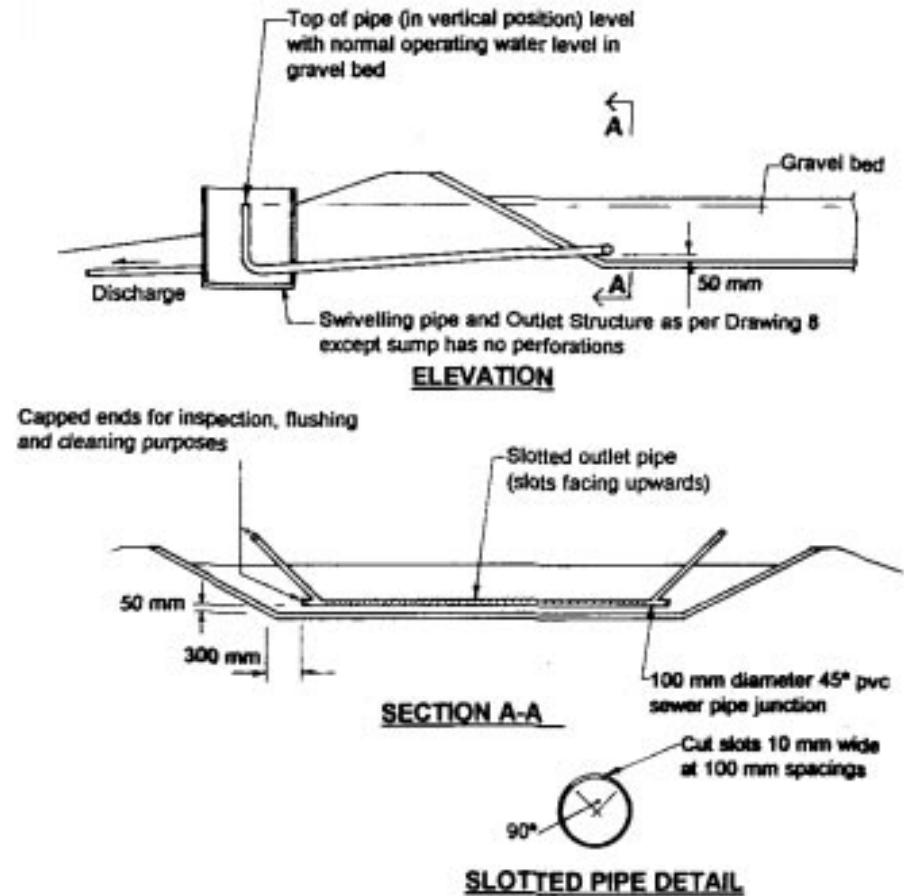


PLAN

Drawing 9: Alternative outlet structure using timber collection chamber.



Drawing 10: Alternative outlet structure for gravel-beds greater than 10 m in width.



Final discharge options

Final discharge of effluents via simple overland-flow and seepage fields, vegetated drainage channels or natural wetlands is preferable to direct discharge to streams. Utilisation of simple systems such as these can supplement the treatment provided by ponds and constructed wetlands and provide further buffering of extremes of flow and water quality with minimal additional cost. Discharges from constructed wetlands generally have relatively low dissolved oxygen concentrations. Flow over simple rock cascades or water falls can help aerate the final discharge, reducing potential impacts in receiving waters.

The utilisation of indirect discharge options may also help to more fully address Maori cultural and spiritual values regarding waste disposal. Traditionally Maori have regarded natural surface waters as taonga (treasures), which require kaitiaki (careful stewardship). Direct discharge of wastes, in particular those of human origin, to surface waters is seen as an affront to the waters wairua (spirit), diminishing its mauri (life-force) and the mana (prestige) of those who use and live by it. Land application or some form of passage through soils has thus been the customary Maori method of purifying wastes. Maintenance of clean, unpolluted waterways through the adoption of improved treatment methods is also important for sustaining the productivity and quality of freshwater fish and invertebrates, including traditional maori foods, such as eels.

The simple indirect discharge methods outlined below are difficult to specify in exact terms and their performance difficult to accurately predict, given the diversity of site characteristics where they may be applied. They rely on the common-sense use of supplementary treatment opportunities available in the immediate environment surrounding a conventional waste treatment system. We have attempted to identify and give basic guidance for a range of options that could be widely applicable. All require adequate levels of pretreatment, generally at least 2-stage ponds followed by a basic Level 1 constructed wetland or equivalent.

1. Simple overland-flow and seepage fields.

Overland-flow is a well-tested technology for the treatment of domestic wastewaters. Wastewater is applied intermittently (~ 8 hours application followed by 16 hours rest) as a thin layer that flows slowly down low-gradient grassed slopes. Wastewater saturates the upper soil layers during application and percolates through the litter layer and grass stems. Suspended solids are removed by settling and filtration, and dissolved organic compounds and nutrients are adsorbed by the soil and associated microbial biofilms. Plants also take up a proportion of the wastewater nutrients into their biomass. During the rest phase, the soil drains allowing aerobic degradation of organic matter and nitrification of ammonia. In more permeable soils, a greater proportion of the wastewater will infiltrate into the soil in a manner similar to rapid or high-rate infiltration. To optimise treatment efficiency per unit area, conventional overland-flow systems generally require carefully graded slopes and regular cutting to maintain a high density grass sward. Simpler low-tech approaches such as the "wet meadow" treatment systems developed in the USA can however still achieve substantial treatment after suitable pretreatment. As their name suggests, these systems involve flow and seepage of wastewaters through shallow inundated areas of wet pasture, and require considerably less active management.

As proposed in the Dairying and the Environment Committee guidelines (DEC 1996, Section 3.6.5.5), the effluent should be dispersed, through a perforated pipe laid along the contour of a relatively smooth slope (2-10% gradient). We suggest that the flow pathway to the final receiving water should be at least 5 m and preferably 10 m or more. A dispersal pipe at least 20 metres in length with 20 mm holes drilled at 200 mm spacings would be required for an average 180-200 cow herd (i.e. ~1 m per 10 cows). Removable end-caps will allow periodic flushing of the dispersal pipe. The dispersal area should be fenced to avoid pugging of wet soils by livestock. Treatment will be optimised if flows are intermittent rather than continuous and if two or more different seepage areas are used sequentially (e.g. 1 year application followed by 1 year rest period) to

enhance breakdown of accumulated wastes and allow soil and vegetation recovery.

2. Discharge to vegetated drainage channels

Vegetated farm drainage channels have the potential to provide additional treatment of farm dairy wastewaters before they leave the farm boundaries and enter natural waters. Aquatic vegetation left to grow in the channel will assist treatment processes by trapping particulate matter and assimilating nutrients. The receiving drain should preferably be at least 300 m long and 1.5-2 m wide for an average dairy herd. Aquatic vegetation should be planted or allowed to colonise naturally. Species such as raupo (*Typha orientalis*) or, if already present in the area, reed sweetgrass (*Glyceria maxima*) would be ideal, but almost any vegetative cover will provide some benefit. Drain clearance (if required to maintain flow capacity) should be limited to short sections of the channel retaining at least 20% of the vegetation along the channel reach.

3. Discharge to natural wetlands

The use of natural wetlands for final discharge is potentially one of the more contentious options as it requires utilisation of natural systems that are known to already be under threat from agricultural development, drainage, livestock grazing and weed invasion. Obviously, pristine, low nutrient, high diversity natural bogs and wetlands with special conservation value should not be subject to wastewater disposal, as elevated nutrient and water levels could result in substantial changes in their plant and animal communities and reductions in their environmental quality. However, most wetlands and wetland remnants in agricultural landscapes are highly modified and relatively high in nutrient status. Such wetlands, especially those dominated by raupo (*Typha orientalis*), will generally be less sensitive to change and readily able to assimilate additions of appropriately treated wastewater. In some cases addition of extra water to these wetlands will provide a valuable supplementation of water levels depleted by drainage of surrounding farmland. Similar dispersal systems to those proposed above for overland-flow systems

should be utilised to disperse water evenly along the upper wetland margin. As a general rule of thumb, it is suggested that wastewater should not comprise more than 20% of the estimated inflow to the wetland, and/or the natural wetland should be at least 5 times larger than the Level 1 wetland that would be required to pretreat it. Before implementing this option it is important to check the policies of your local Regional Council with respect to use of natural wetlands. Further information and guidelines for assessing the impacts of wastewater discharges to natural wetlands are available from the Department of Conservation (DoC, 1988). Another approach is to restore or create additional wetland areas using the treated discharge from a suitable pond-wetland treatment system (see section on Landscaping).

costs

The costs for constructed wetlands will vary depending on the level of treatment required, site conditions and availability of materials. Itemised cost estimates are shown in Table 4 and these can be used as a guide to estimate the likely cost of your own constructed wetland.

Basis of Cost Estimate

- The costs given are rough-order construction cost estimates only, and do not include allowance for professional fees for design, site survey and any site investigations required. They do not include land costs, or ongoing costs of operation and maintenance, which should be considered when making comparisons with other treatment options.
- The rates specified are typical contract rates, assuming the work is carried out by an independent contractor who takes responsibility for the entire contract.
- The rates are as at January 1997, and these will need to be modified over time and adjusted for local conditions and availability of materials.
- The earthworks volumes (Item 3.1) assume that there is a cut to fill balance, so that the material which is excavated to form the wetland channel equals the amount required to construct the wetland embankments. This means that there is no need to import fill material to site. If fill does need to be imported to site the rates need to be adjusted accordingly.
- It is assumed that the clay liner used to seal the base and sides of the wetland channel can be obtained from material available on-site. If this is not the case, then rates need to be adjusted to allow for suitable clay material to be imported or synthetic liners (see Appendix for suppliers) to be used.

What Does Each Item Include?

1. **Site establishment** is a lump sum which includes the general expenses not incorporated into the other unit rates. It includes such things as insurances, bonds, safety requirements, providing any temporary access required, setting out the work, establishing the contractors resources and equipment on-site, locating any services at the site (water pipelines, power or telephone lines), site meetings and general contract administration undertaken by the contractor, removal of excess spoil, rubbish, debris and vegetation to a suitable dump site, and provision of as-built plans.
2. **Strip topsoil** allows for removal of the topsoil and vegetation and stockpiling in a separate area so that it can be reused later to provide a planting medium and to reinstate finished surfaces.
3. **Earthworks** includes the excavation and filling required to shape the wetland channels and the embankments (assumes cut to fill balance). The unit measure is cubic metres, and the quantities shown are in the solid measure before excavation, and so do not include an allowance for the bulking of the material after it is excavated.
4. **Clay liner** allows for 150 mm of compacted clay to line the base and the sides of the wetland channels. The unit rate assumes that the clay material is available on-site.
5. **Plant topsoil** allows for the placing of topsoil in the base of the wetland channel as a planting medium. It is assumed that the topsoil stripped from the site (refer Item 2) is used for this purpose and so the unit rate allows only for its placement and not its supply.
6. **Gravel.** 65/40 mm (or similar grade) gravel is required for the inlet and outlet zones of all wetlands and the main body of gravel-bed wetlands. For gravel-bed wetlands (Treatment levels 2 and 3) a 150 mm surface layer of finer 20/12 mm gravel is also required. Transport costs can be a significant component and so the on-site cost of the gravel will vary depending on the proximity of the quarry to the site. Unit rates therefore need to be adjusted accordingly.
7. **Inlet** structures include the **pipe work** (Item 7.1 and Drawing 6) and the optional **timber support** (Item 7.2 and Drawing 7). The unit measure is a lump sum so costs can be estimated based on the number of inlet structures required.
8. **Outlet** requirements include the **pipe work** (Item 8.1) and the standard **outlet structure** (Item 8.2 and Drawing 8). Costs can be estimated based on the number of outlets required (see 7 above).
9. **Topsoil and regrass** is shown in the cubic metre unit of measure and allows for spreading of topsoil on the outer embankments and surroundings using the balance of the topsoil that was removed in Item 2 above, and seeding with suitable grasses. The rate assumes that there is no need to import extra topsoil to site.
10. **Wetland plants** include the supply, delivery, planting and maintenance during the establishment phase of the selected wetland plants. Plant protection, and monitoring and maintenance of the effluent level and the wetland plants during the establishment phase is included, as described in the section on operation & maintenance.
11. **Fencing** allows for the supply and installation of a stock proof fence around the entire perimeter of the site. The suggested allowance can be readily adjusted using the metre rate for fencing.
12. **Drainage** includes the provision of surface runoff (stormwater) drains around the outside of the wetland embankments to ensure that surface runoff is diverted away from the constructed wetland. If more complex drainage is required, such as the interception of any seeps or

springs, or the provision of any subsurface drainage, then this is an additional cost.

How to Use the Cost Estimates

The cost estimate sheets can be used to make a preliminary assessment of the likely costs for your system. After determining the treatment level (1, 2 or 3) you require and the wetland area you need for your herd size (Tables 2 & 3), the following Table 4 of quantities and rates, can be modified to estimate rough order costs. Cost rates should be adjusted using information on:

- the need to import extra fill material, topsoil and/or suitable lining material, or use a synthetic liner,
- the local availability and costs of gravel and transport to the site
- site specific conditions (e.g.: the site may already be partially fenced).

Table 4: Cost estimates for the three constructed wetland treatment options.

Item	Description	Unit*	Treatment Level 1 (415m ² surface flow wetland)			Treatment Level 2 (500m ² surface flow and 215m ² gravel-bed wetland)			Treatment Level 3 (305m ² surface flow and 175m ² gravel-bed wetland)	
			Quantity	Rate	Amount	Quantity	Rate	Amount	Quantity	Rate
1	Establishment	LS	1	\$2,500	\$2,500	1	\$2,500	\$2,500	1	\$2,500
2	Strip Topsoil	LS	1	\$320	\$320	1	\$660	\$660	1	\$408
3	Earthworks									
3.1	Cut To Fill	m ³	175	\$8	\$1,400	350	\$8	\$2,800	275	\$8
4	Clay Liner	m ³	60	\$15	\$900	128	\$15	\$1,920	93	\$15
5	Plant Topsoil	m ³	43	\$12	\$516	53	\$12	\$636	30	\$12
6	Gravel									
6.1	Coarse 65/40	m ³	12	\$45	\$540	73	\$45	\$3,285	60	\$45
6.2	Fine 20/12	m ³				30	\$50	\$1,500	24	\$50
7	Inlet									
7.1	Pipework	EA	1	\$450	\$450	2	\$450	\$900	2	\$450
7.2	Timber Support	EA	1	\$270	\$270	2	\$270	\$540	2	\$270
8	Outlet									
8.1	Pipework	EA	1	\$340	\$340	2	\$340	\$680	2	\$340
8.2	Outlet Structure	EA	1	\$200	\$200	2	\$200	\$400†	2	\$200
9	Topsoil & Regrass	m ³	30	\$20	\$600	55	\$20	\$1,100	30	\$20
10	Wetland Plants (4/m ²)	m ²	415	\$4	\$1,660	714	\$4	\$2,856	480	\$4
11	Fencing	m	150	\$10	\$1,500	250	\$10	\$2,500	220	\$10
12	Drainage	LS	1	\$360	\$360	1	\$660	\$660	1	\$525
13	Mechanical aerator ^{††}	EA							1	\$4,500
14	Provision of power to site ^{†††}	LS							1	\$2,500
					\$11,556				\$22,937	
Contingency (20%)					\$2,311				\$4,587	
GRAND TOTAL (excl. GST)					\$13,867				\$27,524	

* LS = Lump sum; EA = each; m² = square metres, m³ = cubic metres.

** Requires mechanically aerated pond pretreatment system or similar.

***Plus annual power charges, estimated at \$1,050-1,580-, based on continuous year-round operation of 1-1.5 kW aerator @ 12c /kW hr.

† For gravel-bed wetlands >10 m an increased outlet cost of \$640 must be allowed (see design drawing 10 for alternative outlet detail)

†† Assumes 1-1.5 kW/hr aspirator or brush aerator required for a 200 cow herd. ††† Assumes 150 m distance from suitable power source.

wetland plantings

The proper functioning of constructed wetland is dependant on the establishment and maintenance of a dense cover of emergent wetland plants. Plants perform a diversity of roles including:

- promoting the settling of suspended solids,
- providing surfaces for the development of biofilms,
- shading the water surface to reduce algal growth,
- releasing oxygen into their root-zone,
- taking-up and cycling nutrients,
- improving wildlife and aesthetic values.

Wetland plant establishment can be relatively rapid and simple if it is carried out correctly. However, problems can multiply and operation be significantly delayed where plant establishment is compromised by planting too late in the season, provision of insufficient or excessive water levels, use of inappropriate soils or gravels, plant damage by livestock or pukeko, or suppression by weeds. 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

Table 5 lists the key species recommended for constructed wetlands treating farm dairy wastewaters. These species which can form 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 5). These supplementary plantings help to stabilise the embankment slopes, reduce weed ingress, and enhance plant and habitat diversity. Plant species chosen need to :

1. Tolerate environmental conditions in the wetland, including local climate, water depths and wastewater strength.
2. Establish and spread readily to form a dense stable vegetation cover with high pollutant removal capacity and resistance to weed invasion.

3. Not pose a significant weed risk elsewhere in the surrounding catchment or region.

Further guidance on landscaping areas surrounding constructed wetlands is given in the later section on landscaping for wildlife and aesthetic enhancement. For further information on New Zealand wetland plants see Johnson & Brooke (1989).

Planting

Wetland species can be either obtained as small plants established from seed (e.g. 1 year-old root-trainer grade) or as bare-root rhizome cuttings with shoots trimmed to 200-300 mm. Both generally establish well if in good condition and planted in the right conditions. Plants can be sourced from nursery cultures or, in the case of bare-rooted cuttings, from wild populations on private land. In this latter case, care should be taken to safeguard the viability of natural populations. Plants are generally best obtained from established and reputable suppliers (see Appendix) and, where possible, 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 8).

Wetland planting is best carried out in spring or early summer– generally before Christmas and the earlier the better. Growing seasons are generally longer in northern and coastal areas of the country allowing more leeway. Any weed growth should be controlled before planting (see later section). The planting surface should be level (± 20 mm) to allow suitable water depths to be maintained during establishment. Topsoils used in the wetland should be of reasonable agricultural quality without excessive clay, peat or sand content, and should be evenly spread (150 mm depth) and lightly compacted. The surficial 150 mm of planted gravel-bed zones should be of appropriate particle size (12/20 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 1 or 2 days of receipt). The wetland plant propagules should be carefully maintained up until the time of planting, following the suppliers 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 be carried out at a density of at least 4 plants per square metre (i.e. at 0.5 m centres). It is best carried out by a team of planters (3 or more) working together in a line. Each planter can carry a bucket of plants which they periodically replenish or plants can be laid out in advance by one person, taking care they don't become desiccated. A small area of the wetland (say 3 by 3 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 commonest 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 less 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 within ± 20 mm of the gravel surface during plant establishment. If there are reliable wastewater flows of effluent from the upstream ponds then this should be used, adjusting the outlet water level as appropriate. Where

insufficient effluent is available at the time of planting, supplementation from the farm water supply or by siphoning or pumping from the ponds or nearby watercourses may be required. If water supply is a problem, flooding every 2 or 3 days may be used to maintain the water level as near to the sediment surface as possible.

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 normal operational water levels should be maintained at 10-30 mm below the gravel surface. 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 via surface-waters.

Weed management

If left unmanaged, weeds can compete with and suppress establishment of the desirable wetland and embankment species planted. 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*) grass that can form floating mats across the wetlands, and control of embankment weeds more generally, is best achieved by dense plantings around the wetland margins using hardy species such as flax and non-invasive native varieties of toetoe. This also has the advantage of stabilising the wetland embankments and providing cover for wildlife.

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 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. 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 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 twice yearly weed control thereafter.

Table 5: Key constructed wetland plants

Tall-growing, hardy species suitable for main constructed wetland plantings

Plant species	Common name	Geographic range in NZ	General growth characteristics ¹	Depth range ² (m)	Comments
<i>Baumea articulata</i>	jointed twig-rush	Nthld. S to Manawatu R.	1.8-2 m tall. Green year-round. Dark green, “leafless”, cylindrical shoots with “joints”. Red-brown pendulous seed heads borne on separate fertile shoots.	0-0.3	Relatively slow to establish. Best planted in association with <i>S. tabernaemontani</i> as nurse-crop at ratio of 3:2 <i>Baumea</i> . Generally takes two growth seasons for plants to develop fully.
* <i>Glyceria maxima</i>	reed sweetgrass (formally widely known in NZ as <i>Poa aquatica</i>)	common in all except E of N Is.; scattered in S Is. locally common in S Otago and Sthld.	0.5-1.5 m tall. 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 intertwined mats over shallow openwater.	0-0.4	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 in new spring and autumn growth can cause poisoning of unaccustomed livestock (Sharman, 1967, 1968; Barton et al. 1983). Tends to overgrow and outcompete other species.
<i>Eleocharis sphacelata</i>	kuta, tall spike-rush or spike-sedge	throughout, most common in the Nthld. and uncommon in Cant.	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.	0-0.4	Moderately quick to establish. Not suitable for use in gravel-beds, but excellent for surface-flow wetlands. Traditionally used by Maori for weaving.
† <i>Schoenoplectus tabernaemontani</i> (= <i>Schoenoplectus validus</i>)	kapungawha, soft-stem bulrush or lake clubrush	Nthld. S to Wld. and Cant.	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.	0-0.3	Quick to establish in spring and early summer. Probably the most common wetland plant used in NZ constructed wetlands. Best used in combination with other species that do not die back strongly in winter.
* <i>Schoenoplectus californicus</i>	giant bulrush or giant clubrush	Waikato Heads, Kaipara, and scattered constructed wetlands in Nthld. , Auck. & Waik.	1-2 m tall. Shoots remain green year-round. Very similar growth form to <i>S. validus</i> , but shoots are triangular in cross-section near their base, and taller.	0-0.4	Only recently identified in NZ. Forms taller, deeper-growing, more robust growths than <i>S. validus</i> , with much reduced winter die-back. Overall weed risk believed to be low, but advisable not to spread into new catchments (refer to notes on present geographic distribution)

Table 5 continued: Key constructed wetland plants

Plant species	Common name	Geographic range in NZ	General growth characteristics ¹	Depth range ² (m)	Comments
<i>Typha orientalis</i>	raupo, bulrush equivalent to: cumbungi (Aust.), reed mace (UK) & cattail (US)	throughout	1.5-3 m tall. Tall, dull blue-green, erect leaves arising in clumps from stout spongy rhizomes. Thick, cylindrical brown seed heads borne on tall shoots. Shoots die back strongly in winter.	0-0.3	Generally the dominant emergent wetland plant in fertile lowland NZ swamps. Although closely related species are used widely in constructed wetlands overseas, this plant is generally 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 high nutrient conditions, 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 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 description and illustration.

2. Suggested final operational depth range for constructed wetlands treating dairy farm wastewaters. Deeper depths may be possible for more highly treated or lower strength wastewaters.

* Introduced species

† Revised name for species formerly referred to in New Zealand (in order of precedence) as *Schoenoplectus validus*, *Scirpus validus*, and *S. lacustris*

Table 6: 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 name	Geographic range in NZ	General growth characteristics ¹	Depth range ² (m)	Comments
<i>Bolboschoenus fluviatilis</i> & <i>B. medianus</i>	purua grass, kukuraho, ririwaka, river bulrush, marsh clubrush	Nthld. S to Wld. and Cant.	1-1.8 m tall. Leafy sedges with stems, triangular in cross-section, emerging from woody bulbous tubers. Seed heads borne in leafy terminal umbel. Dies back over winter.	0+-0.15	Particularly common in coastal areas. Fast-growing in spring and early summer. Useful species to provide diversity along shallow wetland margins.
<i>Carex secta</i>	purei, makura, niggerhead	throughout	1-1.5 m tall. Drooping harsh tussocks forming trunk-like base when mature. Green year-round.	0+-0.05	Classic plant of NZ wetland and stream margins. Suitable for constructed wetland margins and embankments.
<i>Carex</i> spp.; especially <i>C. geminata</i> complex & <i>C. lessoniana</i>	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.
<i>Cordaterra richardii</i> , <i>C. fluvida</i> , <i>C. toetoe</i>	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 stabilization and screening. Ensure more invasive introduced pampas species are avoided.
<i>Cordyline australis</i>	ti kouka, cabbage tree	throughout	Tall-growing soft-stemmed tree bearing tufts of fibrous leaves.	0++	Classic NZ wetland tree suitable for areas surrounding constructed wetlands. Ensure plantings do not weaken embankments.
* <i>Cyperus involucratus</i>	umbrella sedge	common garden plant throughout	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++-0.1	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.
<i>Cyperus ustulatus</i>	toetoe upokotangata, giant umbrella sedge	Nthld. S to Cant. & Fiordld., mainly coastal and lowland.	0.5-1 m tall. Harsh pale-green leaves in clumps, with emergent seed-bearing leafy umbells.	0+-0.05	Tolerates dry periods. Suitable for wetland margins and embankments.
<i>Eleocharis acuta</i>	sharp spike-rush or -sedge	throughout	0.1- 0.5 m tall. Short-growing leafless shoots similar to <i>E. sphacelata</i> .	0-0.1	Suitable for localised plantings in shallow wetland margins, in association with <i>E. sphacelata</i> . Likely to be shaded out by taller, denser-growing species such as raupo. Often colonises wet areas naturally.

Table 6 continued: Supplementary wetland species

Plant species	Common name	Geographic range in NZ	General growth characteristics ¹	Depth range ² (m)	Comments
<i>Juncus</i> spp.; especially <i>J. pallidus</i> , <i>J. gregiflorus</i> , * <i>J. effusus</i> , * <i>J. procerus</i> ,	leafless rushes	throughout	Generally range in height from around 0.4 to 1.5 m, but <i>J. pallidus</i> & <i>J. procerus</i> will grow to 2 m or more. Form clumps of green cylindrical stems with seedheads emerging from just below the tip.	0+-0.1	Rush species commonly found in wet pastures and swampy areas. Suitable for stabilising wetland margins and embankments. <i>J. gregiflorus</i> will generally only tolerate periodic immersion. All species, once established, will tolerate periods of dryness.
<i>Lemna</i> & * <i>Spirodela</i> sp.	karearea, duckweed	generally throughout	Minute floating platelets (leaves) with fine rootlets extending down into the water.	free-floating	Useful supplementary species to provide surface cover in bare or sparsely vegetated patches in surface-flow wetlands. Reduces algal growth by shading the water surface. Valuable wildlife food plant, which often colonises naturally.
* <i>Phalaris arundinacea</i>	reed canary grass	widely scattered and only locally common	1-2 m tall. Blue-green, robust, rhizomatous grass with dense, narrow, erect seed heads (panicle).	0+-0.1	Productive perennial grass, suitable for wetland margins and embankments. Often grazed by livestock, but there have been some reports of poisoning in sheep. (McBarron, 1976; Johnson & Brooke, 1989). Potential weed - advisable not to spread into new catchments.
<i>Phormium tenax</i>	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++-0.05	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 bouyant flower stalks. Also an important nectar source and cover plant for wildlife.

1. Consult Johnson & Brooke (1989) for detailed description and illustration.
 2. Suggested final operational depth range for constructed wetlands treating dairy farm wastewaters. Deeper depths may be possible for more highly treated or lower strength wastewaters. 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 7: Weed species to avoid

Ensure plants brought onto the site are not contaminated with propagules of these species. Invasive weeds that pose unacceptable weed risks in New Zealand and should not be planted or allowed to spread.

Plant species	Common name	Geographic range in NZ	Growth form ¹	Comments
* <i>Alternanthera philoxoides</i>	alligator weed	Nthld. S to N Waikato, abundant in localised areas	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. High risk plant pest banned from sale, propagation and distribution.
* <i>Myriophyllum aquaticum</i>	parrot's feather	Nth Is. and N Sth Is.	sprawling emergent	Perennial herb with whorls of feather-like leaves emerging from the water. Can completely choke waterways, excluding other species. High risk plant pest banned from sale, propagation and distribution.
** <i>Eichhornia crassipes</i>	water hyacinth	N half of Nth Is., 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 plant subject to a National Pest Management Strategy under the Biosecurity Act 1993. Often used in waste treatment systems in tropical areas of the world where it is widespread in the wild.
* <i>Iris pseudacorus</i>	yellow flag iris	Locally common in areas of central and S Nth Is., and Cant. to Sthld.	emergent	Tall yellow-flowered iris. High risk plant pest banned from sale, propagation and distribution.
* <i>Lythrum salicaria</i>	purple loosestrife	Horowhenua and Cant. to Sthld.	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 areas where present, and is a serious weed in North America. Presently banned from sale, propagation and distribution in the Manawatu-Wanganui Region, but restrictions likely to be extended.
* <i>Phragmites australis</i>	common reed	Hawkes Bay and Murchison	tall emergent	Tall bamboo-like reed with feathery flowers. High risk plant pest banned from sale, propagation and distribution. Widely used in constructed wetlands in many other parts of the world where it occurs naturally.
** <i>Salvinia molesta</i>	salvinia	N half of Nth Is., generally very limited distribution in wild	free-floating	A water fern capable of forming thick floating mats that can choke waterways. A notifiable plant subject to a National Pest Management Strategy under the Biosecurity Act 1993.
* <i>Hydrodictyon reticulatum</i>	water net	N half of Nth Is., abundant in localised areas	net-forming algae	Can form dense filamentous nets that choke waterways. Can be spread by water fowl and amongst plant material from infected areas.
* <i>Zizania latifolia</i>	Manchurian wild rice	Nth Is., abundant in localised areas, particularly Nthld	tall emergent	Forms very tall growths (> 3m) capable of invading pasture, drainage channels, and natural wetlands and lake margins. High risk plant pest banned from sale, propagation and distribution.

1. Consult Johnson & Brooke (1989) for detailed description and illustration.

* Introduced species

** Classified as National Surveillance Plant Pests under the Biosecurity Act 1993, as at October 1, 1996.

Table 8: Common weeds and their control

Common weeds of wet soils that often require control, particularly during plant establishment, to avoid suppression of main wetland species. Significant expansion of any weed species at the expense of the main tall-growing species should be controlled. Many common pasture weeds and grasses 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 *Glyceria maxima*, with the potential to dominate the vegetation may also require control. Strategic hand weeding or spot spraying, before invading species become well established, will often be the most effective means of control.

Species ¹	Common Name	Areas commonly found.	Suggested chemical control ^{2,3}
* <i>Apium nodiflorum</i>	water celery	Nth. Is.	Roundup G2, Glyphosate, Activated amitrole [†]
* <i>Glyceria fluitans</i>	floating sweetgrass	throughout	Roundup G2, Glyphosate, or selective grass herbicides such as Fusilade [†] & Gallant [†]
* <i>Holcus lanatus</i>	Yorkshire fog	throughout	Roundup G2, Glyphosate, or selective grass herbicides such as Fusilade [†] & Gallant [†]
<i>Isolepis prolifer</i>	sprawling clubrush	Scattered Nth. Is.	Roundup G2, Glyphosate
* <i>Juncus articulatus</i>	jointed rush	throughout	Roundup G2, Glyphosate
* <i>Ludwigia palustris</i> & <i>L. peploides</i>	water purslane & water primrose	Nth. Is. & Marl.	Roundup G2, Glyphosate
* <i>Lycopus europaeus</i>	gypsywort	Waik., BOP	Roundup G2, Glyphosate
* <i>Polygonum</i> spp.	willow weeds and water pepper	throughout	Roundup G2, Glyphosate
* <i>Rumex</i> spp. particularly <i>R. conglomeratus</i>	docks	throughout	Roundup G2, Glyphosate
* <i>Paspalum disticum</i>	mercer grass	Nth. Is., scattered in Nelson & Cant.	Roundup G2, Glyphosate, or selective grass herbicides such as Fusilade [†] & Gallant [†]
* <i>Salix</i> spp., particularly <i>S. cinerea</i>	willows	throughout	Roundup G2, Glyphosate, Escort [†]

1. Consult Johnson & Brooke (1989) for detailed description and illustration.
 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 deoxygenation and release of toxic substances into the water as weeds rot, detrimentally affecting 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 and herbicides not specifically registered for use in waterways should only be sprayed under drained conditions, with outflows to waterways avoided for suitable withholding periods.
 3. Mention of specific tradenames of herbicides, is given for guidance only and does not indicate specific endorsement over equivalent products marketed under different tradenames.
- * Introduced species
† Herbicides not specifically registered for use in waterways.

Pukeko management

Pukeko can cause serious problems in new plantings, if large populations are present in the area. They tend to pull out new plants before their root systems can gain good anchorage, either grazing on young new shoots or insects and worms associated with their roots. They can almost completely "un-plant" a wetland in a few days if bird numbers are high and left unchecked. Although there is no totally fool-proof way of excluding them completely, they can usually be adequately controlled for sufficient time to enable plant establishment, after which plantings are generally less affected. If there is a large resident population of pukeko 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 advise.

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, Wetland Services, 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 to be considered include:

1. Temporarily tethering a dog on a long lead near the wetland. Provision of adequate housing, exercise, and supplies of food and water are required to ensure the health and welfare of the dog.

2. 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 problem if the wetland is sited near to residences or sensitive livestock.

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

Livestock management

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 areas.

landscaping

Loss and modification of natural wetlands through agricultural development, has had a major impact on aquatic wildlife, particularly waterfowl. Ponds and dams constructed on farms for wastewater treatment, stock watering and irrigation have provided some compensation for this loss and now constitute a significant proportion of the potential habitat available for water birds in agricultural landscapes. Attention to the siting and landscaping of these artificial ponds and wetlands can greatly increase the diversity of species that can utilise them and enhance their visual appearance. Increasing the habitat quality of farm pond and wetland treatment systems can also provide additional opportunities for recreational hunting.

Features that enhance wildlife values

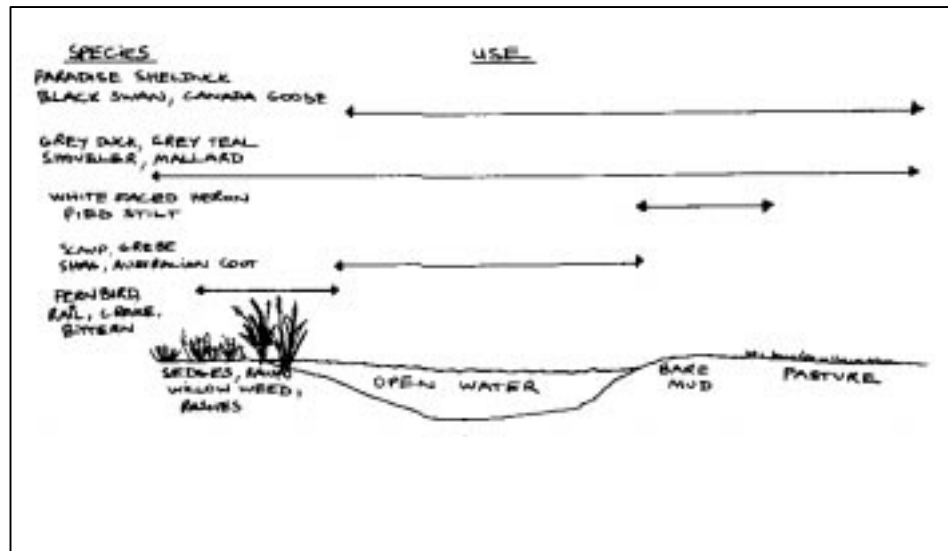
Pond-wetland complexes that provide a range of feeding, nesting, brood rearing, loafing and resting sites will provide habitat for a greater diversity of waterbird species (Fig 3). Features that will attract a wider range of waterbirds include provision of:

1. *a variety of feeding areas* – differences in feeding methods and morphological adaptations (eg. bill shape, neck and leg length) enable each species to exploit different ecological niches. A mosaic of open-water, interspersed with short and tall vegetated zones generally provides the greatest diversity of habitats. Shallow gently sloping edges of ponds and wetlands, which are generally the most productive, can be lengthened by creating irregular margins and embayments. As well as providing more feeding areas, such increased spatial heterogeneity can increase the density of effective breeding territories available to water fowl.
2. *vegetative cover* – many species favour sites where overhead and ground cover provide security and shelter. Ground nesting waterfowl require cover to conceal their nests and to enable broods, fledglings and moulting adults to evade aerial and ground predators. Aquatic and terrestrial vegetation also provides an important source of food, both

directly in the form of shoots, leaves, berries and seeds, and indirectly as habitat for invertebrates and other small animals.

3. *loafing areas* – birds have a very fast metabolic rate compared to most mammals and require significant periods to rest, care for their plumage, rear young and interact socially. Clear areas of water edge which can be accessed by swimming and walking from the water are generally favoured. Maintaining around 20% of pond margins as shallow gradient open grass areas is recommended. Controlled light grazing by sheep may be used to help maintain these areas.

4. *reduced predation* – the greatest threat to wetland birds (next to habitat loss and for gamebirds recreational hunting) is predation. Wild cats, mustelids and possums are the most lethal, but rats will also impact on smaller wetland bird species and kill nestlings and young ducklings. Approaches to reduce the threat posed by predators include direct control by trapping and poisoning, and provision of secure nesting sites such as nesting boxes and floating platforms.



5. *linkage to wider networks of natural wetland and riverine habitat* – siting of pond-wetland systems near natural wetlands and riparian corridors enables waterbirds to utilise a range of different wetland areas

See Buxton (1992) for further information on wildlife enhancement of wetlands.

Table 9: Waterbirds likely to benefit from landscaping enhancement of farm ponds, constructed wetlands and associated areas.

Species	Origin	Status
Dabbling ducks		
grey duck	native	game bird
mallard duck	introduced	game bird
grey teal	native	protected
NZ shoveller	endemic	game bird
Grazers		
paradise shelduck	endemic	game bird
Waders		
white-faced heron	native	protected
pieb stilt	native	protected
Rails and crakes		
pukeko	native	game bird
spotless crake	native	protected

Aesthetic enhancement

Developing farm landscapes in an environmentally sound and aesthetically pleasing way can increase farm land values. Also, as the success of New Zealand's dairy industry and its ability to attract premium prices depends on the credibility of its "clean-green" image, enhancing the scenic and

environmental quality of farms is one of the ways that the industry can raise public perceptions of its activities and products.

Sensitive siting and landscaping of pond and wetland treatment systems can soften their visual impact, changing them from a strictly utilitarian facility (or eyesore) into an unobtrusive part or environmental feature of the landscape. Landscaping should ideally aim to link and integrate pond and wetland treatment areas into the surrounding landscape. In particular, attention should be paid to creating harmony with the landforms and vegetation in the surrounding area, and its interplay with human modifications such as buildings, raceways, drainage channels and shelter belts. A series of landscaping concepts representing different levels of "naturalness" and integration with other wetland areas illustrated in Figures 4-6.

It is generally advised that the edges of anaerobic and facultative ponds treating higher strength wastewaters should be maintained free of marginal aquatic and overhanging vegetation to avoid potential insect proliferation, reduce maintenance associated with weed growth and scum build-up across the pond surface. However, providing machinery access required for pond maintenance is retained, the upper and outer edges of pond embankments are amenable to careful planting, which can substantially enhance their aesthetic and wildlife values, and enhance their functioning. By lowering wind velocities, sheltering vegetation around anaerobic ponds can reduce convective heat loss and reaeration—important factors limiting treatment efficiency. The proper functioning of facultative or aerobic ponds is dependant on sunlight to support the growth of algae (oxygen producers) and inactivate pathogens. Therefore vegetation growing on the northern side of these ponds should be low growing (<2 m) to avoid shading of the pond surface (see MAF, 1985 for detailed recommendations). There are conflicting views as to whether wind mixing of facultative ponds is beneficial (by promoting reaeration and mixing) or detrimental (by resuspending particulate material and reducing the stability of thermal stratification) to treatment performance. The relative

merit of using plantings to either promote or restrict wind access to the surface of facultative ponds is therefore unclear.

Pond and wetland shapes can be softened to fit into the surrounding landform, within the practical limitations required for their proper functioning. Pond length to width ratios of around 2:1 are suggested for anaerobic ponds, while the shape of facultative or aerobic ponds is more adaptable with length to width ratios of above 2:1 recommended (DEC 1996). Particular care should be taken in pond design to minimise the potential for effluent short-circuiting by maximising the distance between the inlet and outlet point, and to minimise dead zones or poorly flushed backwaters that reduce the treatment efficiency of the available pond area. Later treatment stages such as constructed wetlands and associated natural or created pond, wetland and scrub areas are amenable to greater flexibility in form and design and can be constructed and landscaped to provide a higher quality and diversity of wildlife habitat (see guideline sections on construction and planting).

Suggested general planting associations for areas around pond and wetland treatment systems are listed in Table 10, covering typical lowland, upland and coastal areas in the central North Island. Plantings can be purely native or include exotic species that are non-invasive and non-toxic to livestock. The lists given are indicative only and advice should be sought on the most appropriate species combinations for particular locations and sites. Observations of natural plant associations in wetlands and riparian zones can be a useful guide to what sort of plantings to use. Deciduous trees should not be planted where substantial quantities of their leaves will fall into ponds or wetlands. Fruit and nut-bearing trees such as oaks and some native species can be a further enticement to ducks and other wildfowl (including pheasants), and along with nectar producing species can attract a wider variety of bird species (eg. tui and kereru or wood pigeon).

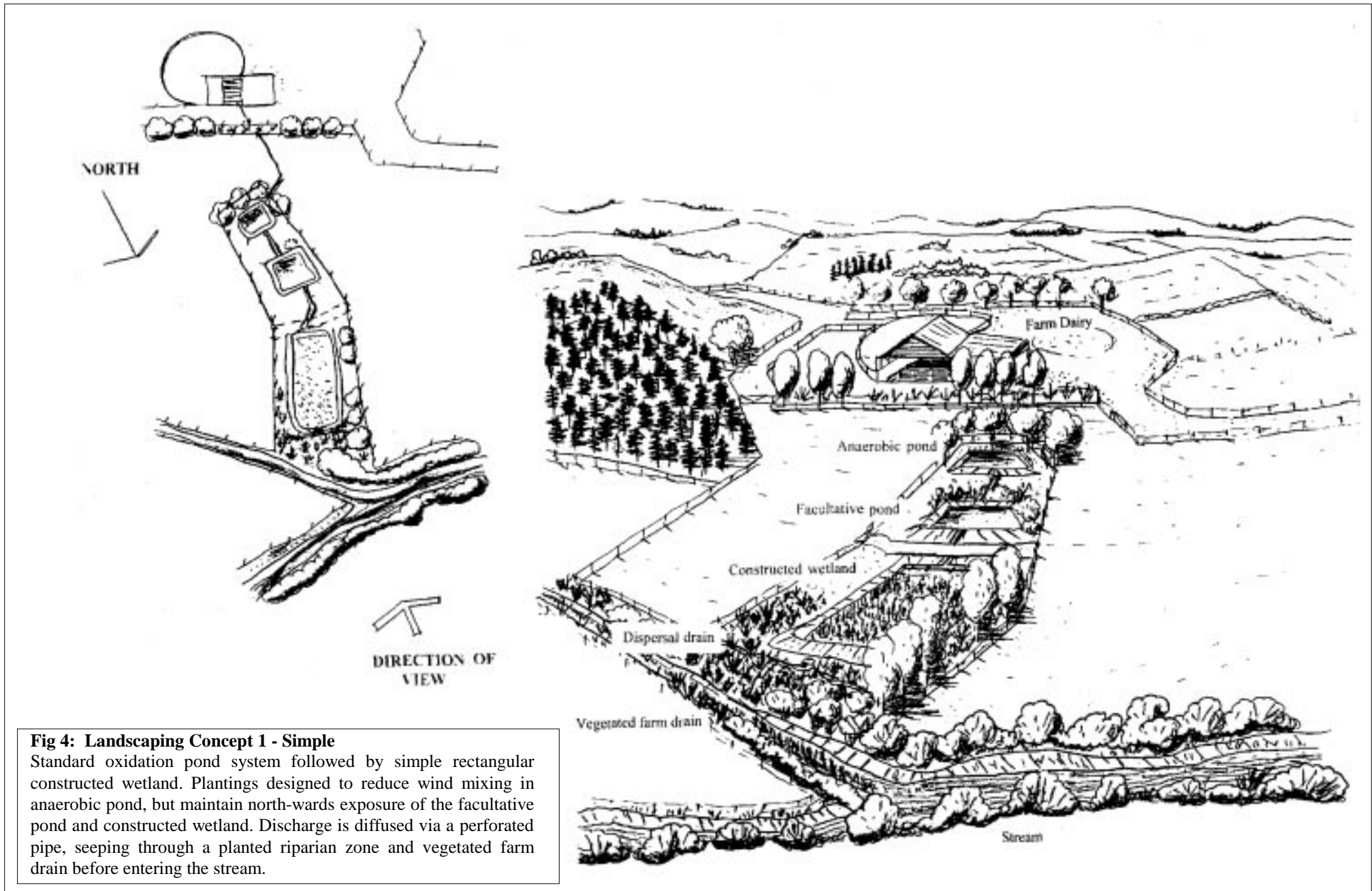


Fig 4: Landscaping Concept 1 - Simple

Standard oxidation pond system followed by simple rectangular constructed wetland. Plantings designed to reduce wind mixing in anaerobic pond, but maintain north-wards exposure of the facultative pond and constructed wetland. Discharge is diffused via a perforated pipe, seeping through a planted riparian zone and vegetated farm drain before entering the stream.

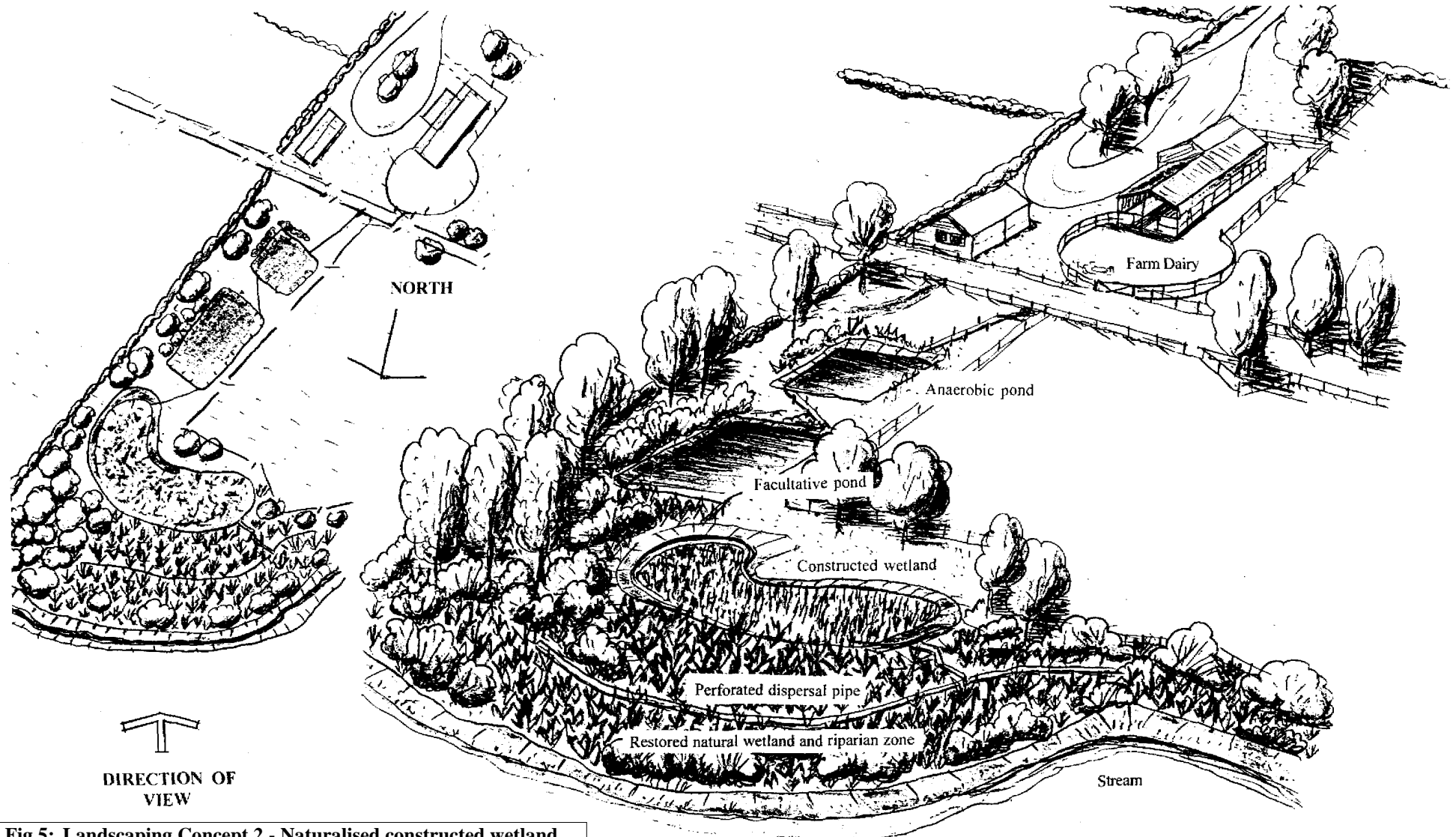


Fig 5: Landscaping Concept 2 - Naturalised constructed wetland
 Similar to concept 1 except wetland shape and plantings further naturalised. A restored natural wetland is used to filter the final discharge before it enters the stream.

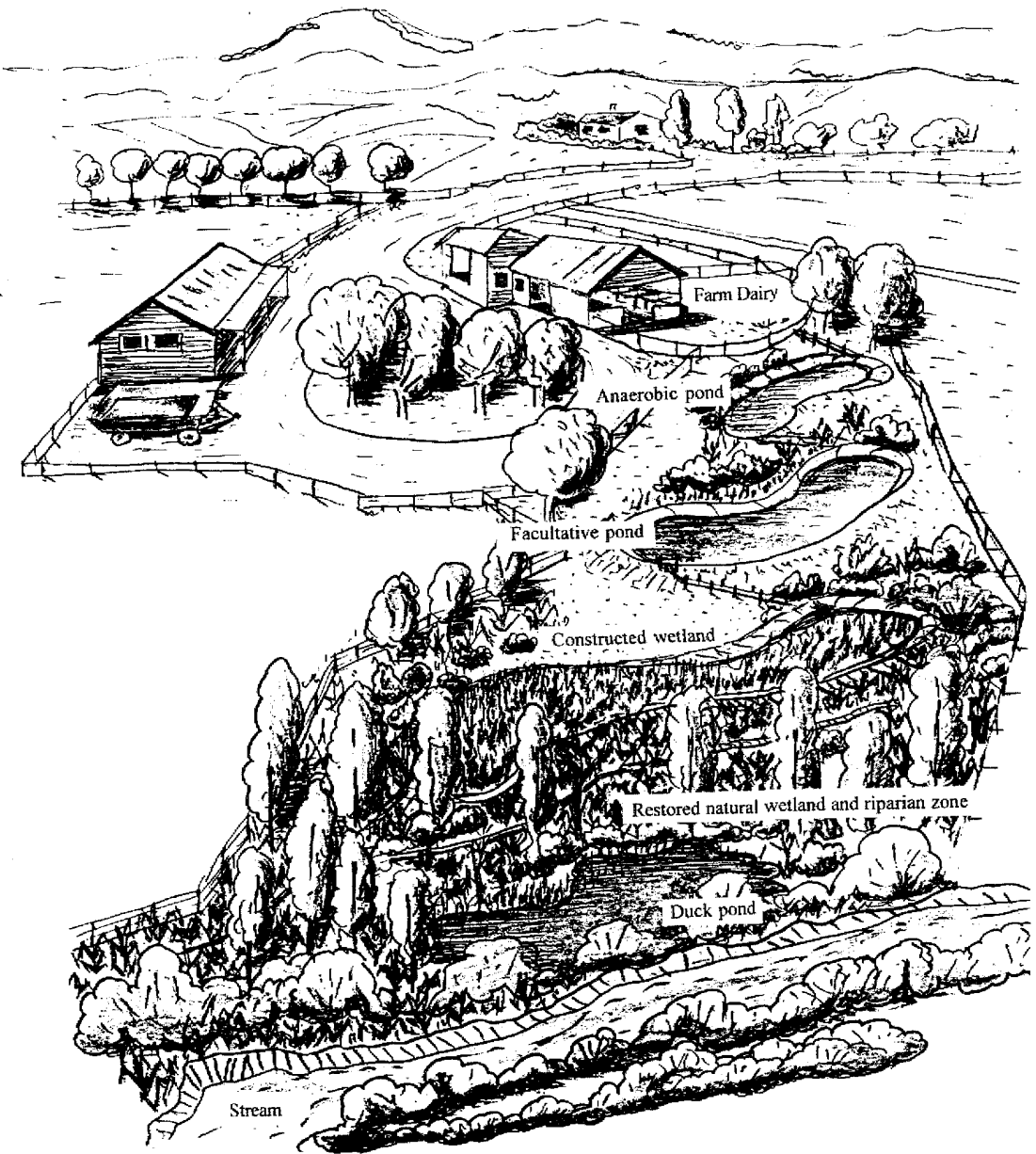
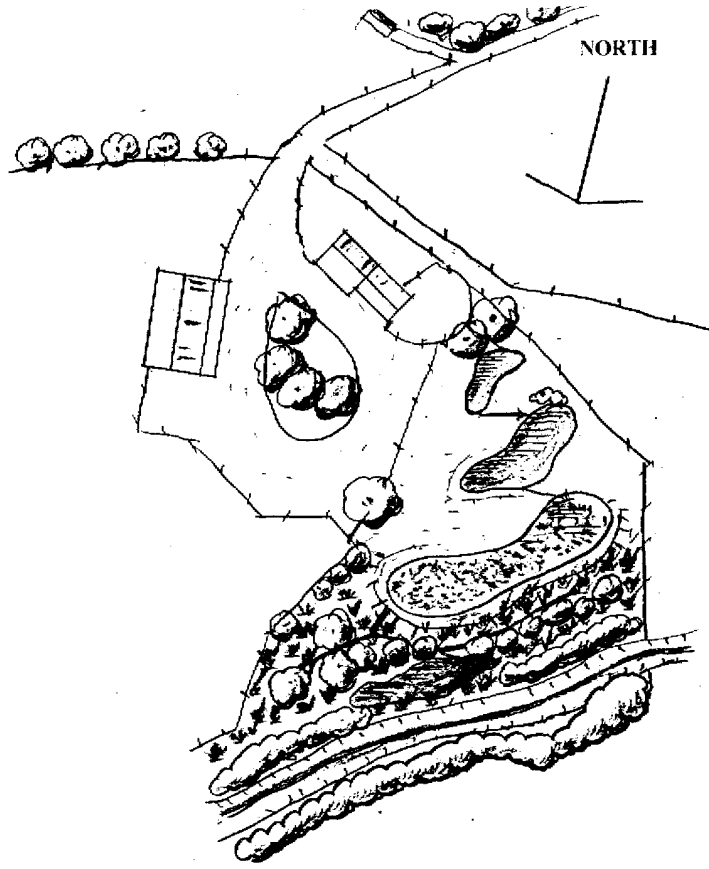


Fig 6: Landscaping Concept 3 - Integrated, naturalised treatment system.

Waste stabilisation ponds and constructed wetlands have been integrated with natural wetland areas. The final discharge is filtered through an extensive wetland and pond area providing a diversity of aquatic habitats for wildlife.

Table 10: Typical plant associations for landscaping around pond and wetland treatment systems in the central North Island.

COASTAL AREAS		UPLAND AREAS		LOWLAND AREAS	
NATIVES	EXOTICS	NATIVES	EXOTICS	NATIVES	EXOTICS
Ake ake <i>Dodonaea viscosa</i>	Flame Tree <i>Erythrina</i> spp.	Five Finger <i>Pseudopanax arboreus</i>	Camellias <i>Camellia</i> spp.	Cabbage Tree <i>Cordyline australis</i>	Camellias <i>Camellia</i> spp.
Coastal mahoe <i>Melicytus novae-zelandiae</i>	<i>Grevillea</i> spp.	Hinau <i>Elaeocarpus dentatus</i>	Cedars <i>Cedrus</i> spp.	Flax <i>Phormium tenax</i>	Cedars <i>Cedrus</i> spp.
Houpara <i>Pseudopanax lessonii</i>	Gum trees <i>Eucalyptus</i> spp. <i>Leucadendron</i> spp.	Kamahi <i>Weinmannia racemosa</i>	Chamaecyparis spp. eg. <i>C. lawsoniana</i> , <i>C. obtusa</i> , <i>C. pisifera</i>	Kahikatea <i>Dacrycarpus dacrydioides</i>	Chamaecyparis spp. eg. <i>C. lawsoniana</i> , <i>C. †obtusa</i> , <i>C. pisifera</i>
Kanuka <i>Kunzea ericoides</i>	Macrocarpa & other cypresses <i>Cupressus macrocarpa</i> , <i>C. sempervirens</i> , <i>C. glabra</i> , <i>C. lusitanica</i>	Kanono <i>Coprosma arborea</i>	Claret Ash <i>Fraxinus</i> ‘Raywoodii’	Kanono <i>Coprosma arborea</i>	Claret Ash <i>Fraxinus</i> ‘Raywoodii’
Karaka <i>Corynocarpus laevigatus</i>		Kanuka <i>Kunzea ericoides</i>	English Beech <i>Fagus europaeus</i>	Kapuka <i>Griselinia littoralis</i>	English Beech <i>Fagus europaeus</i>
Karo <i>Pittosporum crassifolium</i>	Norfolk Is. hibiscus <i>Lagunaria pattersonii</i>	Kohuhu <i>Pittosporum tenuifolium</i>	Firethorns <i>Pyracantha</i> spp.	Kauri <i>Agathis australis</i>	Firethorn <i>Pyracantha</i> spp.
Kawakawa <i>Macropiper excelsa</i>	Paulownia <i>Paulownia tomentosa</i>	Koromiko <i>Hebe</i> spp.	Ginkgo <i>Ginkgo biloba</i> .	Koromiko <i>Hebe</i> spp.	Ginkgo <i>Ginkgo biloba</i>
Korokio <i>Corokia buddleioides</i>	<i>Protea</i> spp.	Kowhai <i>Sophora microphylla</i>	Gum trees <i>Eucalyptus</i> spp.	Kowhai <i>Sophora a microphyll</i>	Gum trees <i>Eucalyptus</i> spp.
Koromiko <i>Hebe speciosa</i> , other <i>Hebe</i> spp.	Rosemary <i>Rosmarinus officinalis</i>	Manuka <i>Leptospermum scoparium</i>	Honey locust <i>Gleditsia triacanthos</i>	Lacebark <i>Hoheria populnea</i>	Honey locust <i>Gleditsia triacanthos</i>
Kowhai <i>Sophora microphylla</i>	Salt cedars <i>Tamarix</i> spp.	Mapou <i>Myrsine australis</i>	Idesia <i>Idesia polycarpa</i>	Mahoe <i>Melicytus ramiflorus</i>	Idesia <i>Idesia polycarpa</i>
Kumarahou <i>Pomaderris kumeraho</i> , <i>P. hamiltonii</i>	She-oaks <i>Casuarina</i> spp.	Mingimingi <i>Leucopogon fasciculatus</i>	Japanese Maples <i>Acer</i> spp. eg. <i>A. palmatum</i>	Manuka <i>Leptospermum scoparium</i>	Japanese Maples <i>Acer</i> spp. eg. <i>A. palmatum</i>
Manuka <i>Leptospermum scoparium</i>	Tasmanian blackwood <i>Acacia melanoxylon</i>	Miro <i>Prumnopitys ferruginea</i>	Larch <i>Larix decidua</i> , <i>L. kaempferi</i>	Mapou <i>Myrsine australis</i>	Larch <i>Larix decidua</i> , <i>L. kaempferi</i>
	Weeping pine <i>Pinus patula</i>	Mountain Flax <i>Phormium cookianum</i>	Liquidamber <i>Liquidamber styraciflua</i>		

Table 10 continued: Typical plant associations for landscaping around pond and wetland treatment systems in the central North Island.

COASTAL AREAS		UPLAND AREAS		LOWLAND AREAS	
NATIVES	EXOTICS	NATIVES	EXOTICS	NATIVES	EXOTICS
Mangeao <i>Litsea calicaris</i>		Pigeonwood <i>Hedycarya arborea</i>	Magnolias <i>Magnolia</i> spp.	Mingimingi <i>Leucopogon fasciculatus</i>	Liquidamber <i>Liquidamber styraciflua</i>
Manuka <i>Leptospermum scoparium</i>		Putaputaweta <i>Carpodetus serratus</i>	Oaks <i>Quercus</i> spp	Pate <i>Schefflera digitata</i>	Magnolias <i>Magnolia</i> spp.
Mountain Flax <i>Phormium cookianum</i>		Rimu <i>Dacrydium cupressinum</i>	Poplars <i>Populus</i> spp. e.g. <i>P. x canadensis</i>	Pukatea <i>Laurelia novae-zelandiae</i>	Oaks <i>Quercus</i> spp.
Ngaio <i>Myoporum laetum</i>		Tarata <i>Pittosporum eugenioides</i>	Rhododendrons <i>Rhododendron</i> spp	Ribbonwood <i>Plagianthus regius</i>	Poplars <i>Populus</i> spp. eg. <i>P. x canadensis</i>
Nikau <i>Rhopalostylis sapida</i>		Tawa <i>Beilschmiedia tawa</i>	Rowan Tree <i>Sorbus aucuparia</i>	Tarata <i>Pittosporum eugenioides</i>	Rhododendrons <i>Rhododendron</i> spp.
Northern rata <i>Metrosideros robusta</i>		Toi <i>Cordyline indivisa</i>	Silk Tree <i>Albizzia julibrissin</i>	Tawa <i>Beilschmiedia tawa</i>	Rowan Tree <i>Sorbus aucuparia</i>
		Toro <i>Myrsine salicina</i>	Silver Birch <i>Betula pendula</i>	Totara <i>Podocarpus totara</i>	Silk Tree <i>Albizzia julibrissin</i>
		Tree Fuschia <i>Fuchsia excorticata</i>	Spruces <i>Picea</i> spp		Silver Birch <i>Betula pendula</i>
			Tree Lucerne <i>Chamaecytisus palmensis</i>		Spruces <i>Picea</i> spp.
			Tulip tree <i>Lirodendron tulipifera</i>		Tree Lucerne <i>Chamaecytisus palmensis</i>
			Walnuts <i>Juglans regia, J. nigra</i>		Tulip tree <i>Lirodendron tulipifera</i>
					Walnuts <i>Juglans regia, J. nigra</i>

operation & maintenance

Constructed wetlands require regular maintenance to ensure that they operate correctly. The saying, *prevention is better than cure* certainly holds true for constructed wetlands. Identification of potential problems at an early stage keeps maintenance requirements to a minimum.

The main areas of maintenance relate to care for the pretreatment system, plants, inlet and outlet structures, embankments and fencing. As for other farm dairy treatment systems (DEC, 1996) it makes good sense to keep records of operation and maintenance activities, and to monitor the effectiveness of the waste management system.

Constructed wetlands, although well proven for domestic waste treatment, are still an emerging technology for agricultural waste treatment. Most constructed wetland systems treating farm dairy wastes have been in operation for five years or less. The operational lifetime of constructed wetlands is dependent on the rate at which organic matter accumulates in them. Much of the suspended solids discharged by dairy ponds is comprised of grass fibres and detritus, which is relatively slow to break down. Gradual accumulations can readily be accommodated in surface-flow wetlands by raising the operational water level. Gravel-bed wetlands are potentially more prone to clogging (Tanner & Sukias 1995) and are only recommended for use after surface-flow wetlands or other treatment stages that reduce suspended solids levels.

The wetlands systems proposed in this guideline have an expected operational lifetime of ~20 years, providing appropriate pretreatment is used and maintenance is carried out regularly. After this time additional maintenance such as desludging of influent zones may be required to extend their operational life.

Pretreatment

Adequate pretreatment of wastewaters is necessary to ensure effective and sustainable treatment in constructed wetlands. The pond or other pretreatment system used should be routinely checked to ensure it is

functioning properly. It is particularly important to guard against excessive sludge carry-over from the ponds (guidelines for pond desludging are given in DEC, 1996). 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 removed and the wetland replanted.

The effluent quality and flow from the ponds and the structural integrity of the pond should be visually checked on a regular basis. Pipe blockages or embankment leakages in pre-treatment ponds can reduce or halt flows into the wetland, affecting treatment performance; and wetland health and survival. Increased wastewater loadings due to herd additions, and the use of wintering or loafing pads or extended holding times in yards linked to the treatment system will require provision of additional pretreatment capacity.

Plants

Plant establishment and care immediately after planting has been covered previously. 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 any 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. Handweeding, application of appropriate herbicides (see Table 7) and short periods of elevated water level are potential control options. Also keep an eye out for plants which are dead or showing signs of stress. Some plants become dormant or die-off over cold winter periods, but if plants look stressed or unhealthy at other times, then the cause needs to be established and rectified. Insufficient water is a likely cause during dry periods, when cows are not being milked, or after desludging and partial draining of anaerobic ponds. Supplementary water may need to be supplied, for

example by siphoning or pumping from the ponds or alternative water sources.

In addition to routine inspections and maintenance, an annual gardening session in early spring is highly recommended. In addition to weed control, this should include removal of any patches of permanently dead plants or weeds and replanting of bare patches using 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 tee, and carefully adjusting these by tilting them up or down 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 pipe and flushing and cleaning it 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 by rotating the outlet stand pipe to maintain normal operating depths of 300 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 5.

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

Summary of maintenance requirements

During wetland establishment

WEEKLY ACTION LIST

- | | |
|-------------|---|
| Plants | <ul style="list-style-type: none">• 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 | <ul style="list-style-type: none">• visual inspection for adequate inflow and identification of blockages and damage• check inlet tees for uniform flow and adjust as required |
| Outlet | <ul style="list-style-type: none">• visual inspection for blockages and damage• clear any plants or blockages around the outlet• adjust water level as required by rotating outlet pipe |
| Embankments | <ul style="list-style-type: none">• visual inspection for weeds, erosion and damage by rabbits or other pests |

MONTHLY ACTION LIST

- | | |
|--------------|--|
| Pretreatment | <ul style="list-style-type: none">• visual inspection of upstream waste stabilisation system for structural integrity, and quantity and quality of effluent |
| Plants | <ul style="list-style-type: none">• control weeds in wetland by handweeding, herbicide application, and/or temporary water level increases.• replace any significant areas of unsuccessful plantings. |
| Embankments | <ul style="list-style-type: none">• control weeds on inner embankments by handweeding or herbicide application• where appropriate, mow or graze (sheep only) grass on embankments and wetland surrounds |

Once wetland established

FORTNIGHTLY ACTION LIST

- | | |
|-------------|--|
| Plants | <ul style="list-style-type: none">• visual inspection for any weed, plant health or pest problems. Take remedial action as necessary |
| Inlet | <ul style="list-style-type: none">• visual inspection for adequate and uniform inflow and identification of blockages and damage• maintain and adjust as required |
| Outlet | <ul style="list-style-type: none">• visual inspection for blockages and damage, and visual check of water level and outflow quality and quantity |
| Embankments | <ul style="list-style-type: none">• visual inspection for weeds, erosion and damage |
| Fencing | <ul style="list-style-type: none">• check that fence and gate is stockproof |

TWO-MONTHLY ACTION LIST

- | | |
|--------------|---|
| Pretreatment | <ul style="list-style-type: none">• visual inspection of upstream waste stabilisation system for structural integrity, and quantity and quality of effluent |
| Plants | <ul style="list-style-type: none">• control weeds in wetland by handweeding, herbicide application, and/or temporary water level increase |
| Embankments | <ul style="list-style-type: none">• where required control weeds on inner embankments by handweeding or herbicide application• where appropriate, mow or graze (sheep only) grass on outer embankments and wetland surrounds |
| Outlet | <ul style="list-style-type: none">• check functioning of discharge system and apparent health of receiving water |

YEARLY ACTION LIST

- | | |
|--------------|---|
| Pretreatment | <ul style="list-style-type: none">• check sludge levels in anaerobic ponds and desludge as necessary to maintain treatment performance and avoid sludge carry-over into wetland |
| Plants | <ul style="list-style-type: none">• remove dead plants and replant if necessary (some plants may be dormant or die-back over the winter months) |
| Inlet | <ul style="list-style-type: none">• remove end caps from inlet pipe and flush out and clean thoroughly to remove slimes and blockages |
| Outlet | <ul style="list-style-type: none">• clean and remove plants around outlet pipe to provide access and guard against blockages. |

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appendix

Wetland plant suppliers*

- KARIOI NURSERY
PO Box 26
Raglan
Ph 07-8567638
- ORATIA NATIVE PLANT NURSERY
625 West Coast Rd
Oratia
Auckland 7
Ph 09-8186467
- TAUPO NATIVE PLANT NURSERY
Terra Firma Ltd
PO Box 437
Taupo
Ph 07-3785450
- WETFEET PLANTS
92 MacFarlane St
Hamilton
Ph 07-8566591
- WETLAND SERVICES
RD2 Maungatoroto
Northland
09-4312900

Wetland and pond liners*

■ ALLCO AGENCIES LTD
PO Box 101903, NSMS
North Shore City
Ph 09-4430095
(bentonite)

■ BISLEYS ENVIRONMENTAL LINING LTD
PO Box 923
Hamilton
Ph 07-843 8008
(synthetic sheeting and bentonite)

■ HIGH DENSITY PLASTICS LTD
PO Box 787
Taupo
Ph 07-378 6808
(synthetic sheeting)

■ OVERGARD SYSTEMS LTD
PO Box 9216
Auckland
Ph 09-6342732
(synthetic sheeting)

■ PERMATHENE PLASTICS LTD
PO Box 71015
Auckland
Ph 09-8285179A
(synthetic sheeting)

■ RJ REID (NZ) LTD
PO Box 100116
North Shore City
Ph 09-4443802
(synthetic sheeting)

* Suppliers as listed in the 1996 NZ Water and Wastes Association Annual Yearbook and Trade Directory or otherwise known to authors

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