Queensland Government
Department of Natural Resources

Guidelines

Guidelines for Using Free Water Surface Constructed Wetlands to Treat Municipal Sewage

SINCLAIR KNIGHT MERZ

Guidelines for

Using Free Water Surface Constructed Wetlands to Treat Municipal Sewage

Prepared by Sinclair Knight Merz
For the Queensland Department of Natural Resources

September 2000

These guidelines were prepared as part of the *Artificial Wetlands for Water Pollution Control Research Program* initiated by the Department of Natural Resources to develop guidelines for planning, design and management of constructed wetlands for Queensland's climatic conditions. This has been a joint program between the Queensland State Government, Local Governments and Universities with additional funding from the Federal Government under the National Landcare Program. The *Artificial Wetlands Co-ordination and Advisory Committee* was formed to provide a steering role for the research program.

Artificial Wetlands Co-ordination and Advisory Committee Members

The following have been members of the *Advisory Committee* for varying periods between 1993 and 2000

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Mr Patrick Bourke	Brisbane City Council
Mr Ralph Dowling	Queensland Herbarium, Environmental Protection Agency
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GLOSSARY

Acid Sulfate Soils – are soils which contain pyritic materials, commonly iron sulfide. Sulfuric acid can be generated if these soils are disturbed and exposed to oxygen.

Adhesion – deposition of small particles onto a surface, eg sediments onto macrophyte leaves.

Adsorption – the adherence of a gas, liquid or dissolved chemical to the surface of a solid, eg sediment particle.

Aggregation – process whereby small particles cluster together due to particle attraction forces.

Aerobic – a state where free oxygen (0_2) is available.

Aesthetic – visual attractiveness or beauty of a site.

Algae – a group of single cell or multi-cell plants that typically grow in water.

Alleopathy – the natural interaction of plants with other organisms in their environment through the release of chemicals to their environment. The interactions may be both positive or negative, but the most common use of the term is for negative interactions.

Anaerobic – a state where neither free oxygen nor oxygen bound to other molecules are available.

Anoxic – a state where there is no free oxygen, but oxygen bound to other molecules is available.

Artificial Wetlands – see Constructed Wetland. This term is becoming less favoured as it implies the use of artificial or synthetic materials, which is generally not the case in wetland construction.

Aspect Ratio – the ratio of the wetland length to its width.

Asset Life – the period of time that a system will reliably perform its function.

Autotrophic – the production of organic carbon from inorganic chemicals. Photosynthesis is an example of an autrophic process.

Benthic – occurs on or in the bottom sediments of a wetland.

Biofilm – an organic layer, typically composing of algae, microfauna and bacteria, which adsorb small particles (colloids) and nutrients. Biofilms are an important treatment component within constructed wetlands.

Biomass – the living weight of plants or animals.

Biodiversity – see Diversity.

Blue-green Algae – see Cyanobacteria.

BOD – Biochemical Oxygen Demand is a measure of the oxygen consumed during bacterial breakdown of organic matter in water.

Brackish – water that contains a TDS concentration greater than 500 mg/L.

Climatic – data relating to the climate of a region.

Constructed Wetland – a wetland that has been purpose built to achieve a set of design objectives. Constructed wetlands apply the functions of natural wetlands and utilise soil, water and biota processes to achieve these objectives.

Continuously Stirred Tank Reactor – type of flow assumption used in wetland modelling whereby it is assumed that fluid particles are well mixed.

Cyanobacteria – primitive, photosynthetic bacteria occurring as single cells or in filaments.

Denitrification – process of reducing nitrate or nitrite to nitrogen gas, in the absence of freely available oxygen.

Desorption – the release back into solution of substances that have been previously adsorbed onto a surface.

Detention Time – the average period of time that effluent is detained within the wetland.

Detritus – dead plant material that is in the process of microbial decomposition.

Diatom – single cell algae with a silica skeleton.

Dinoflagellallate – single cell algae characterised by two flagella.

Diversity – the number and distribution of animal or plant species within a defined area.

Effluent – a liquid that flows out of a process or treatment system.

Eh – a measure of redox potential, (oxidation-reduction potential) expressed in volts, using an electrochemical cell. See also Redox, Oxidation and Reduction.

Emergent Plants – are plants that are attached to the substrate and whose leaves and stems either float or protrude above the surface.

Ephemeral – systems which have water present only periodically.

Epiphytic Algae – are algae that are attached to the surfaces of other plants.

Equivalent Population – the total number of persons who would contribute the same quantity and/or quality of domestic sewage as the wastewater load being considered.

Euglenaphyte – type of single cell algae, usually with one flagella.

First Order Reaction – reactions where the rate of disappearance or production of a particular component is directly proportional to its available concentration.

Fixation – the conversion of nitrogen gas to ammonia by a select group of bacteria and cyanobacteria.

Flawra – Ej Strips – Wetland plants that have been established on a reinforced strip. Main application is wetland planting in deep or high velocity conditions.

Flow-forms – shaped channel form, usually in a cascading series, that promotes turbulent flow and hence provides aeration of effluent.

Free Water Surface Wetland – are wetlands designed to have the water surface above the wetland bed or substrate. Also referred to in the literature as Free Surface, Surface Flow or Open Water Surface Wetlands.

Generation Time – period of time for a bacteria population to double in number.

Helminths – intestinal worms, found in human faeces. Helminths of concern in constructed wetlands include round worms and tapeworms.

Herbaceous – soft non-woody plants that typically grow in damp or wet areas.

Heterotroph – organism which cannot photosynthesise and instead uses organic carbon as an energy source.

Hydraulic Conductivity – rate at which soil or substrate can transmit water.

Hydraulic Loading Rate – influent discharge into wetland per square meter of wetland surface.

Hydraulic Residence Time – see Detention Time.

Infiltration – the process of water moving into the surface of the soil or substrate.

Influent – a liquid that flows into a process or treatment system.

Kadlec and Knight Method – method to size constructed wetlands for wastewater treatment based on Kadlec and Knight (1996).

Larvae – or "wrigglers" correspond to an aquatic feeding stage of the mosquito life cycle prior to growing into pupae.

Log Removal – measure of treatment performance, especially used in disinfection as indicator bacteria may range several orders of magnitude. For example, if *Ecoli* counts are reduced from 10^6 to 10^3, this is equivalent to a three log reduction.

Macrophyte – plants that are macroscopic, ie able to be seen with the naked eye. Often used to describe large aquatic plants.

Maturation Lagoon – a pond used to treat secondary effluent. These ponds generally receive low effluent loads, are aerobic and have long retention times.

Mineralisation – the decomposition of organic matter into its inorganic constituents.

Monoculture – a system that is dominated by one plant species.
Nappe Aeration – The nappe is the spilling flow pattern over a sharp wested weir. An air pocket forms beneath the nappe which needs to be aerated, usually by a vent pipe, to provide a reliable flow measurement.

Nitrification – biological process by which bacteria convert ammonia to nitrate nitrogen.

Oxidation – the addition of oxygen to a substance, or the removal of hydrogen from it. Generally any reaction in which an atom losses an electron (see Reduction). For example, oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) occurs under aerobic conditions.

Oxidation Pond – or Stabilisation Pond is a general term for various pond systems used in wastewater treatment. These ponds could be aerobic, anaerobic or include both aerobic and anaerobic conditions (also known as Facultative Ponds).

pH – a measure of the hydrogen ion concentration in a solution, indicating the presence of acidic, neutral or alkaline conditions.

Photosynthesis – the biological synthesis of organic matter from inorganic matter in the presence of sunlight and chlorophyll. See also Autotrophic and Heterotroph.

Plug Flow – type of flow assumption used in wetland modelling whereby it is assumed that fluid particles are discharged from a wetland in the same order as they entered it, ie no mixing occurs.

Polishing – general term for final treatment of wastewater effluent prior to discharge.

Potable Reuse – treated effluent used for drinking water.

Precipitation – chemical reaction causing substance in a solution to be deposited as a solid.

Pupae – or "tumblers" correspond to an aquatic non-feeding stage of the mosquito life cycle prior to emerging as adults.

Reclaimed Wastewater – wastewater that has been treated to a level appropriate to its intended reuse.

Redox – the potential of sediments to oxidise or reduce chemical substances. A redox potential Eh >300 mV indicates aerobic conditions (dissolved oxygen is available); and Eh <-100 mV indicates anaerobic conditions (no dissolved oxygen is available).

Reduction – the removal of oxygen from or addition of hydrogen to a substance. Generally any reaction in which an atom accepts an electron (see Oxidation). Reduction of ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}) is a typical reaction in anaerobic sediments.

Reed Method – method to size constructed wetlands for wastewater treatment based on Reed, Crites and Middlebrooks (1995).

Refractory – substance very resistant to decomposition or degradation.

Reuse – the beneficial use of treated wastewater.

Rehabilitation – drainage, removal of plants as required, desludging and replanting of the wetland to retain ongoing treatment performance.

Retention Time – see Detention Time.

Rhizome – any fleshy stem that grows horizontally in the ground and enables the plant to reproduce itself. It is not a root, but grows roots on its lower side and shoots from its upper side.

Rhizosphere – the chemical sphere of influence of plant roots in soils.

Riffle - long, uneven channel that promotes turbulent flow and hence aeration of effluent.

Riparian – associated with the banks of rivers, streams and other water bodies.

Short Circuiting – occurs when a discharge to a wetland follows a preferential flow path to the outlet, without fully mixing across the wetland.

Substrate – an engineering term for the material that forms the wetland bed and provides the base for wetland planting. In treatment processes, the material that forms the base of further transformation, eg nitrate is the substrate for denitrification.

Substratum – a scientific term for material that forms the wetland bed, underneath the accumulated litter and detritus. See also Substrate.

Sub-Surface Flow Wetland – are wetlands designed such that the flow moves through a soil or gravel matrix, which is planted with macrophytes.

Surface Flow Wetland – see Free Water Surface Wetland.

Submerged Plant – are plants that maybe attached to the wetland substrate or free floating, but whose leaves and stems are permanently submerged.

Viro-cell – wetland plants established in special tubes prior to planting out.

Viro-tube – similar to a viro-cell, except tube is deeper.

Volatilisation – conversion of a chemical substance from a liquid or solid to a gas.

Water Balance – water volume changes in a wetland in response to variations in wastewater discharges, rainfall, seepage, evapotranspiration and other hydrological factors.

ABBREVIATIONS

AS	-	Australian Standard
BNR	-	Biological Nutrient Removal
BOD	-	Biochemical Oxygen Demand
C	-	Carbon
C:N:P	-	Carbon, Nitrogen and Phosphorus ratio
CAMBA	-	China – Australia Migratory Bird Agreement
CFU	-	Coliform Forming Unit
CH_4	-	Methane
CO_2	-	Carbon Dioxide
COD	-	Chemical Oxygen Demand
CSTR	-	Continuously Stirred Tank Reactor
CP	-	Coarse Particulates
DLWC	-	New South Wales Department of Land and Water Conservation
DM	-	Dissolved Matter
DNR	-	Queensland Department of Natural Resources
DNRA	-	Dissimilatory Nitrate Reduction to Ammonium
DON	-	Dissolved Organic Nitrogen
DOP	-	Dissolved Organic Phosphorus
Ecoli	-	Escherichia coli bacteria
EP	-	Equivalent Population
EPA	-	Queensland Environmental Protection Agency
EPBC	-	Environmental Protection and Biodiversity Conservation Act 1999
EPP	-	Environmental Protection Policy
Fe^{2+}	-	Ferrous Iron
Fe^{3+}	-	Ferric Iron
FP	-	Fine Particulates
FRP	-	Filterable Reactive Phosphorus
FWS	-	Free Water Surface
H_2	-	Hydrogen gas
H_2O	-	Water
IDAS	-	Integrated Development Assessment System
IPA	-	Integrated Planning Act 1997
JAMBA	-	Japan – Australia Migratory Bird Agreement
LP	-	Large Pathogens
mg/L	-	milligrams per litre
N	-	Nitrogen
N_2	-	Nitrogen gas
NADB	-	North American Wetland Treatment System Database
NH_3	-	Ammonia gas
NH_4	-	Ammonium
NO_2	-	Nitrite
NO_3	-	Nitrate
O&M	-	Operation and Maintenance
O_2	-	Oxygen gas
P	-	Phosphorus
P1	-	noxious plant category referring to plants whose introduction into Queensland is prohibited
P2	-	noxious plant category referring to plants that are to be destroyed throughout Queensland or the relevant parts thereof
P3	-	noxious plant category referring to plants whose numbers and/or distribution are to be reduced through Queensland or the relevant parts thereof
P4	-	noxious plant category referring to plants that are to be prevented from spreading from the place in which they occur in Queensland or the relevant parts thereof
P5	-	noxious plant category that should be controlled only on land under the control of a Government Department or Local Government
PM	-	Particulate Matter
PO_4	-	Orthophosphate
PON	-	Particulate Organic Nitrogen
POP	-	Particulate Organic Phosphorus
RAMSAR	-	Ramsar Convention on Wetlands of International Importance, 1971

SP	-	Small Pathogens
spp	-	Species
SS	-	Suspended Solids
SSF	-	Sub Surface Flow
TDS	-	Total Dissolved Solids
UV	-	Ultra Violet

SYMBOLS

a	=	wetland roughness factor
A	=	wetland surface area
C_i	=	influent pollutant concentration at wetland inlet
C_o	=	effluent pollutant concentration at wetland outlet
C*	=	background pollutant concentration in wetland
d	=	water depth in wetland
d_i	=	water depth at wetland inlet
d_o	=	water depth at wetland outlet
$\frac{dv}{dt}$	=	change in water volume per unit of time
ET	=	evapotranspiration
HLR	=	hydraulic loading rate
I	=	infiltration
K_p	=	first order phosphorus reaction rate constant
k	=	first order areal rate constant
K_R	=	rate constant at 20^{o}C reference temperature
K_T	=	reaction rate constant corresponding to water temperature in wetland
L	=	wetland length
M_1	=	loading parameter
n	=	Manning's roughness coefficient
nc	=	number of wetland cells in series
n_v	=	void ratio or porosity, corresponding to the space available in wetland for water to flow through
P	=	precipitation
Q_{av}	=	average discharge through wetland
Q_{bf}	=	median baseflow through wetland
Q_i	=	influent wastewater flow into wetland
Q_m	=	minimum discharge capacity
Q_o	=	effluent wastewater flow out of wetland
R	=	runoff into wetland
S	=	hydraulic gradient or wetland bed slope
S_1	=	slope parameter
t	=	detention time
T_d	=	time to drain surcharge volume
T_W	=	wetland temperature
V_d	=	surcharge volume
Θ_R	=	temperature coefficient for rate constant

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These guidelines are the culmination of the Artificial Wetlands for Water Pollution Control Research Program, a joint research project between the Department of Natural Resources and ten local governments funded under the former National Landcare Program. Howard Gibson and John Simpson from DNR and Margaret Greenway of Griffith University were responsible for the establishment of the program. Anne Woolley and Pat McCourt from DNR finalised the project, collated data and provided extensive supporting documentation, a literature review and direction to the consultants.

Constructive review comments of the Guideline drafts were provided by Anne Woolley and Pat McCourt (DNR) and by Margaret Greenway (Griffith University) who gave freely of her time. Review comments of the final draft were also provided by members of the Artificial Wetlands Co-ordination and Advisory Committee.

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Authors of the various sections of the Guidelines include John Simpson (Wetlands, Water and Waste), Ralph Dowling (Queensland Herbarium), Mike Muller (Brisbane City Council Mosquito and Pest Services), Peter Breen (CRC Freshwater Ecology), Ross Anderson (Ross Anderson and Associates), Peter Gross, Ian Brodie, John Llewellyn, Michelle Silvester and Tim Wrigley (all from Sinclair Knight Merz).

Chapter 1 Introduction

1.1 Overview

This publication follows on from interim guidelines first released by the Department of Natural Resources in August 1994 and revised in 1995. It provides information about the planning, design, construction and operation of constructed wetlands used for the treatment of municipal sewage. Wetland processes, monitoring and costs are also covered by these guidelines.

The content of these guidelines is based on research conducted as part of the Artificial Wetlands for Water Pollution Control Research Program in Queensland.

The guidelines focus on Free Water Surface (FWS) Wetlands. These systems have the water surface above the wetland bed or substrate. Alternative systems, including Sub Surface Flow (SSF) Wetlands, are briefly discussed. In SSF wetlands, the wastewater flows through a porous media such as gravel or coarse sand. The basic configuration of FWS and SSF constructed wetlands is shown in **Figure 1.1**.

The Guidelines do not cover wetlands designed for treatment of stormwater, minewater drainage or industrial wastewater.

The term `constructed wetland' has been used in the Guidelines in preference to alternative terms including `artificial wetland'.

1.2 The Guidelines at a Glance

Section 1 – Introduction

Outline: provides an overview of the contents of the Guidelines.

Key Points: The Guidelines cover Free Water Surface (FWS) wetlands used to treat municipal sewage. Queensland has been divided into six climatic zones to discuss the range of wetland design and management aspects that are expected across the State.

The climatic zones are Equatorial-Tropical, Desert, Grassland, Sub-Tropical (Dry Season), Sub-Tropical (No Dry Season) and Temperate.

Section 2 – Use of Wetlands for Wastewater Treatment

Outline: describes an inventory of existing wetlands in Australia and outcomes of Queensland pilot wetland trials.

Key Points:

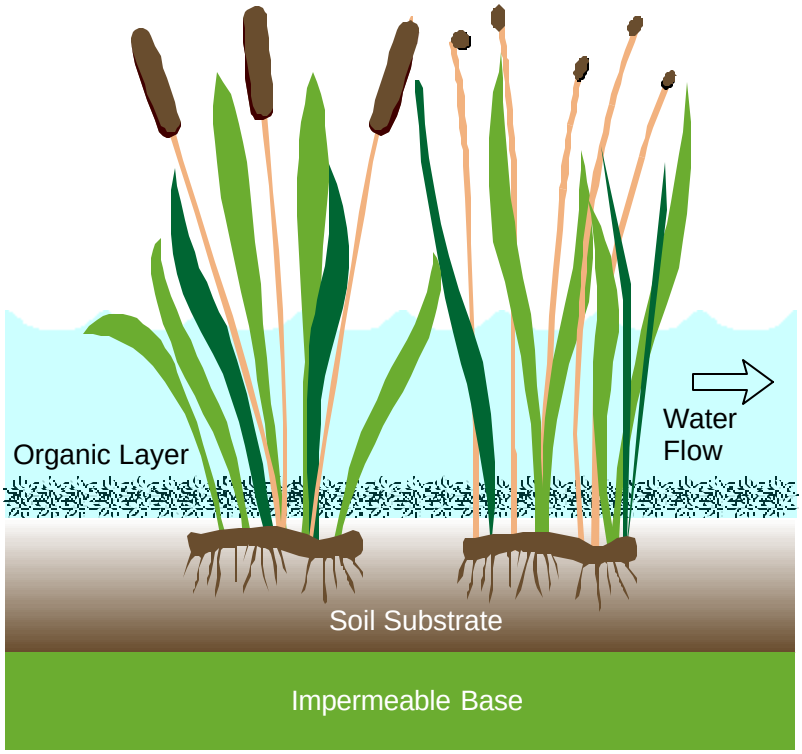
- About 40 constructed wetlands have been installed for wastewater treatment in Australia. Most are FWS systems and irrigation reuse is practised at 30% of wetland sites.
- As part of the Artificial Wetlands for Water Pollution Control Research Program, nine FWS pilot wetlands were designed and built by DNR in conjunction with local governments to treat secondary effluent. The wetlands were constructed at Mossman, Edmonton near Cairns, Ingham, Logan, Townsville, Mackay, Blackall, Emu Park and Goondiwindi.
- Appendix A contains a report summarising the outcomes of this pilot wetland program.
- The ability of FWS wetlands to treat municipal sewage to high standards should not be overstated. The pilot studies demonstrate that wetlands have an application, but they are unable to produce an effluent similar to that achieved by advanced treatment technology.

Section 3 – Wetland Processes

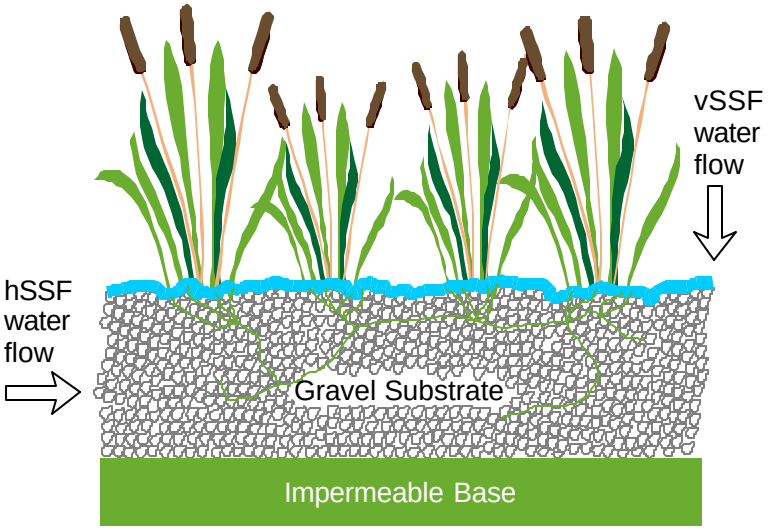
Outline: describes key physical, chemical and biological processes in wetlands and the main mechanisms of pollutant removal.

Key Points:

- Detention Time or the period of time that wastewater is retained in the wetland, is critical to the various treatment processes that occur. A water balance analysis is generally required to estimate the detention time in a constructed wetland.
- Treatment processes in constructed wetlands are complex. Descriptions of the mechanisms and pathways for the removal of suspended solids, BOD, nitrogen, phosphorus and pathogens are given in Sections 3.3 to 3.7. This detail is provided to give a basic understanding of key processes and how they can be optimised by appropriate wetland design.
- The presence of anaerobic and/or aerobic conditions, macrophytes, biofilms and wetting and drying cycles are important elements that significantly influence a wide range of treatment processes.



Free Water Surface Wetland



Note: Flow direction may be horizontal (hSSF) or vertical (vSSF)

Sub Surface Flow Wetland

Figure 1.1 – Major Types of Constructed Wetlands

Section 4 – Wetland Planning

Outline: describes making a decision to use wetlands, site aspects, legislative requirements and opportunities for effluent reuse.

Key Points:

- The selection of a constructed wetland site needs to consider a range of factors including land availability, town planning zones, treatment objectives, site access, prevailing winds, surface and groundwater hydrology, topography, soils, buffer areas and flood protection.
- Development approvals for constructed wetlands may include planning approvals under the Integrated Planning Act 1997, environment approvals under the Environmental Protection Act 1994 and various natural resource and heritage approvals (eg, under Fisheries Act 1994).
- The approvals that need to be applied for will vary from project to project, depending on the specific circumstances of the proposed constructed wetland.
- Treated effluent from constructed wetlands have been reused in various ways including for irrigation, to create ponded waterbodies in resort areas and to scrub flue gases from sugar mills.
- Emerging applications of constructed wetlands include lemna (duckweed) production for fish and stock food, treatment of recycled water for the aquaculture industry and producing zooplankton and crustaceans for fish food.
- Constructed wetlands are natural systems subject to variability in treatment performance. If consistently low effluent concentrations are needed, the use of a constructed wetland is not a reliable option.

Section 5 – Design Principles

Outline: describes good design practice for wetland sizing, geometry, zones and plant selection. Design aspects of edges, inlets and outlets. Outlines alternative designs including Sub Surface Wetlands Design for uses other than treatment, such as wildlife habitat, visual amenity and public education.

Key Points:

- The most recognised techniques used in international practice to size FWS wetlands are the Reed Method and the Kadlec and Knight Method.
- BOD loading into constructed wetlands should be less than 75 kg BOD/ha/day.
- Various `rules of thumb' are available to estimate indicative wetland sizes in Queensland.
- An extensive aquatic plant list is provided that can be used to select wetland plants within the various climatic zones of Queensland.
- Engineering design of constructed wetlands must account for the characteristics of the selected plants.
- A diversity of plants should be used in constructed wetlands, in preference to a monoculture.
- Constructed wetlands can also be used as wildlife habitats, provide an attractive visual feature and for public education and passive recreation. Some of these uses may conflict with wastewater treatment objectives.

Section 6 – Construction Principles

Outline: covers key construction issues such as site preparation, substrate suitability, civil works and construction sequence. Describes plant establishment.

Key Points:

- Clay liners (or alternative measures) should be placed and well compacted to minimise effluent infiltration into the groundwater.
- The wetland substrate should be loosely compacted to aid plant establishment. Application of fertilisers to the substrate should be avoided.
- During plant establishment, the water level should be always below the height of the emergent plants. This is typically less than 150 mm depth.
- Planting densities vary from 1 to 10 plants per m^2. Planting layout patterns for emergent species include band planting (across the wetland) and parallel to the wetland edge.

Section 7 – Operation Principles

Outline: covers water level management, plant harvesting and control of weeds, mosquitos and other pests, algae, odours and accumulation of toxicants.

Key Points:

- The ability to alter water depth is critical for all constructed wetlands.
- Design should allow for water depths to vary from zero to the maximum depth tolerated by the emergent macrophytes, typically not greater than 0.6 m.

- The main benefit of harvesting plants, particularly emergent species, would appear to invigorate growth and reduce dense, rank growth.
- Some nutrient removal from the wetland would occur if plants are harvested. Nutrient storage in macrophyte plant tissue typically represents less than about 20% of the nutrient mass detained in the wetland, but this is highly dependent on the type of plant, its stage of growth and the time of year that harvesting occurs. In some cases, nutrients stored in plant biomass may account for up to about 60% of the nutrients within the wetland.
- The disadvantages of plant harvesting include high costs, some reduction in habitat values and re-suspension of sediment and nutrients.
- Water depths greater than 30 to 40 cm, sparse vegetation along the wetland margins, wave action in open water, predators including fish and insects and draining the wetland are factors that control mosquito populations.
- Bti and S-Methoprene are products for mosquito control which are environmentally sound.
- Algae growth, especially in open water zones, can lead to high suspended solids and low DO concentrations in the wetland effluent.
- Algae control measures include installing a rock matrix at the wetland outlet to act as a filter.
- An Operation and Maintenance Plan should be prepared for each constructed wetland.

Section 8 – Wetland Monitoring

Outline: covers techniques to monitor the treatment performance and physical condition of wetlands.

Key Points:

- Wetland monitoring can be undertaken to satisfy a range of purposes.
- Compliance monitoring is usually a requirement of approval authorities and generally measures effluent quality.
- Performance monitoring is often done to quantify the mass of pollutants removed by the wetland. This type of monitoring typically focuses on quantifying the pollutant loads in and out of the wetland.
- Operational control and maintenance monitoring is designed to help manage the performance of the wetland. It may cover all wetland features including inflows, outflows, substrate conditions (eg detritus buildup) and wetland flora and fauna.

Section 9 – Wetland Costs

Outline: provides information on expected asset life and capital and annual operating costs.

Key Points:

- A well maintained constructed wetland is expected to have an asset life in the order of 30 to 50 years.
- Wetland rehabilitation to retain ongoing treatment performance is expected to be required approximately every 10 years.
- Indicative capital costs for wetlands vary from \$1.60 to \$12.00 per m^2, depending on size, design and site conditions.
- Indicative annual operating costs for wetlands vary from \$0.25 to \$2.70 per m^2, depending on size and extent of work. Additional allowance should be made for harvesting, replanting and desludging activities.

1.3 Queensland Climatic Zones

As Queensland is geographically a large area, there is a diverse range of climatic zones occurring within the State. For the purpose of the Guidelines, the following zones have been used, based on Bureau of Meteorology climatic zone mapping. The extent of each zone is shown in **Figure 1.2: Queensland Climatic Zones**.

- Equatorial – Tropical – includes equatorial savanna, tropical savanna and tropical rainforest regions.
- Sub Tropical (Dry Season) – includes sub-tropical regions that experience distinctly dry or moderately dry winters.
- Sub Tropical (No Dry Season) – includes sub-tropical regions that have no distinct dry season.
- Temperate – includes temperate regions that have no distinct dry season or moderately dry winters.
- Grassland – includes grassland regions that are hot and persistently dry or experience winter drought.
- Desert – includes desert regions that are hot and persistently dry or experience winter drought.

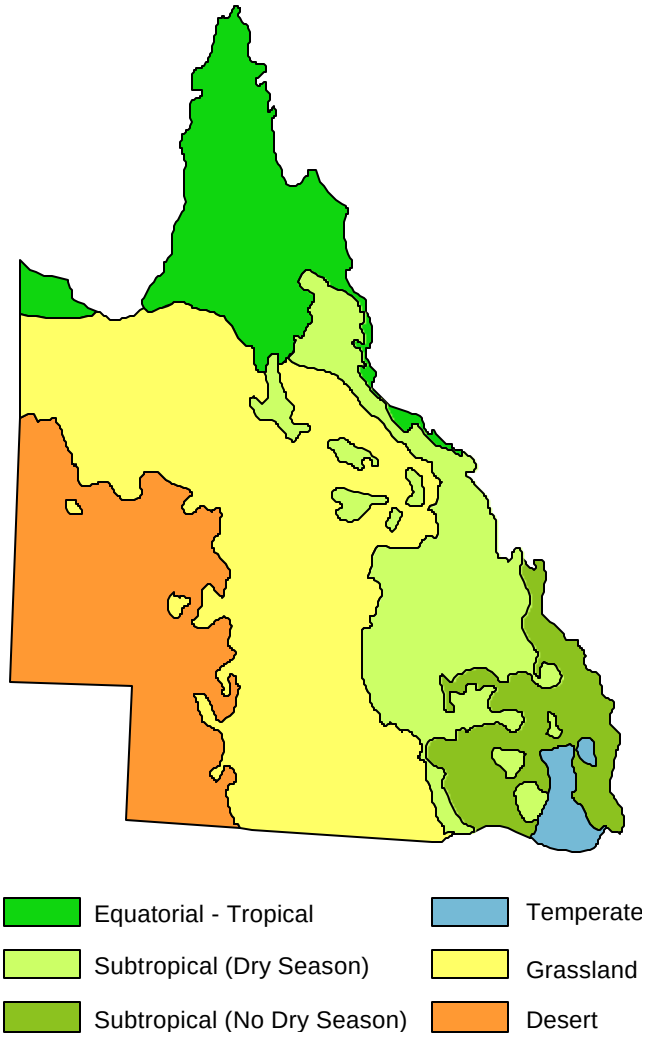


Figure 1.2 – Queensland Climatic Zones

The characteristics of each Climate Zone will influence wetland design and operation, as summarised in **Table 1.1: Queensland Climatic Zone - Implications for Constructed Wetlands**.

Table 1.1: Queensland Climatic Zone - Implications for Constructed Wetlands

Aspect of Design or Operation	Implication of Climatic Zones
Water balance and detention time	Rainfall and evaporation may have significant effects on the water balance in a wetland and hence detention time. For example, prolonged hot, dry periods may increase detention time due to evaporative water loss. Refer to Section 3.1 Hydrology for details.
Wetland size	The rate of some wetland treatment processes depends on temperature as described in Section 5.1 Wetland Size.
Plant Selection	Climate affects various plant selection issues including the range of aquatic plant species available for wetlands and the length of growing season. These effects are discussed in Section 5.4 Plant Selection.
Water level control	Good control of water depth is critical for constructed wetlands. In Tropical and Sub Tropical areas, drawdown of water level prior to the onset of wet weather would assist in preventing overtopping. Refer to Section 7.1 Water Level Control.
Weed control	In North Queensland Tropical and Sub Tropical areas in particular, wetlands can rapidly become infested and overgrown with nuisance weeds. Refer to Section 7.2 Weed Control and Plant Harvesting.